

**FROM CODE TO LEGAL EFFECTS: THE
JURIDICAL CONSTRUCT OF FUNCTIONAL
LEGAL SUBJECTIVITY OF DECENTRALISED
AI SYSTEMS IN SOLE-CODE SMART
CONTRACTS**



Lucia della Ventura

Trinity College Dublin, the University of Dublin

A thesis submitted to the School of Law in the Faculty of Arts,
Humanities and Social Sciences at the University of Dublin in partial
fulfilment of the requirements of the degree of Doctor in Philosophy

Hilary Term 2026

DECLARATION

I declare that this thesis has not been submitted as an exercise for a degree at this or any other university and it is entirely my own work.

I confirm that the work has been completed in full compliance with relevant university policies, including the Academic Integrity policy, the Trinity Policy on Good Research Practice, and the guidance on AI and GenAI in Teaching, Learning, Assessment and Research.

I agree to deposit this thesis in the University's open access institutional repository or allow the Library to do so on my behalf, subject to Irish Copyright Legislation and Trinity College Library conditions of use and acknowledgement.

I consent to the examiner retaining a copy of the thesis beyond the examining period, should they so wish (EU GDPR May 2018).



Lucia della Ventura

September 2025

Supervised by Prof. Deirdre Ahern

ABSTRACT

This thesis explores the legal role of Decentralised Artificial Intelligence (DsAI) systems operating as multi-agent systems on public and permissionless blockchains, specifically within sole-code smart contract transactions, agreements formed and executed exclusively through code. In such contexts, DsAI systems act as decentralised multi-agent entities capable of autonomously producing legally relevant effects deriving from these transactions, even in the absence of formal legal recognition. This development poses a direct challenge to traditional legal categories of personhood, capacity, and subjectivity, which have historically been framed with reference to natural and legal persons. The central research question is whether, and under what conditions, DsAI multi-agent systems, when forming and executing sole-code smart contracts, can be regarded as an autonomous locus – or source - of attribution of legal effects within decentralised contractual transactions.

The thesis adopts comparative and interdisciplinary methodology. From a legal perspective, it analyses how civil law and common law traditions conceptualise contractual intention, legal capacity, legal personhood and subjectivity, also drawing on supranational frameworks such as the Principles of European Contract Law (PECL). From a technical perspective, it considers how DsAI systems exhibit autonomy in their decision-making process, adaptive learning, and emergent behaviour, and under what conditions these characteristics can be interpreted as legally relevant conduct. This approach highlights the inadequacy of existing legal doctrines and regulatory frameworks, including the EU Artificial Intelligence Act, when applied to decentralised architectures.

Building on this analysis, the thesis introduces two theoretical yet practical instruments. The Paradigm of Autonomous Behaviour (PAB) defines measurable parameters to determine when the technical autonomy of DsAI systems becomes legally significant. The Functional Legal Subjectivity (FLS) reframes legal subjectivity as a context-dependent and emergent quality,

recognising DsAI systems as functional legal subjects capable of contractual capacity, without conferring legal personhood. Together, these instruments aim to resolve the paradox of contractual legal effects stemming from an undefined legal source, allowing the law to recognise contractual capacity once the DsAI surpasses a defined threshold of technical autonomy.

The main finding is that DsAI, although excluded from traditional categories, can nonetheless be treated as a functional entity within the legal system: not as a legal person or a moral agent, but as a context-dependent and threshold-conditioned source of attribution of contractual legal effects, operative exclusively within the domain of sole-code smart contracts on open, permissionless blockchains. By recognising their conduct as legally relevant through the Paradigm of Autonomous Behaviour and the Functional Legal Subjectivity, contract law can preserve coherence and certainty in decentralised environments. The thesis concludes that both the Paradigm of Autonomous Behaviour and the Functional Legal Subjectivity models can offer a pragmatic and consistent way to integrate the decentralised AI within the legal framework, ensuring that the growing social and economic impact of these AI systems is adequately addressed by law.

SUMMARY

While law traditionally confers legal subjectivity and legal capacity on natural and legal persons, the emergence of Decentralised Artificial Intelligence (DsAI) systems challenges this conventional paradigm. DsAI systems, structured as multi-agent systems, operating on public and permissionless decentralised architectures, increasingly engage in contractual interactions without human oversight. Specifically, through sole-code smart contracts—agreements formed and executed exclusively through code—they are able to autonomously generate obligations and transfer rights, producing legally relevant effects. However, these systems, lacking legal personhood, remain outside the boundaries of existing legal categories. This paradox, whereby effects arise without an identifiable legal subject, calls for a fundamental reappraisal of how contract law conceptualises legal subjectivity, intention, and capacity in decentralised environments.

The argument commences with the acknowledgement that contract law, in both civil law and common law traditions, rests on the assumption that legal effects arise from subjects possessing intention and capacity. In decentralised settings, contractual intention is not explicitly expressed; instead, it is inferred from coded behaviour and validated through the blockchain's consensus mechanism. Sole-code smart contracts disclose the constraints of traditional theories, demonstrating that legal relevance could also originate from algorithmic interactions rather than expressions of intent. The critical challenge is assessing whether DsAI systems, which are formally devoid of rights or duties, can nonetheless functionally operate as an independent source of production of legal effects in contract formation.

To address this challenge, the thesis combines doctrinal, comparative, and interdisciplinary methods. From a doctrinal perspective, it addresses fundamental concepts of contract law, specifically dealing with legal personhood, capacity, and subjectivity—drawing on legal doctrines of will, intention and consent. A comparative perspective contextualises the

analysis within European civil law and common law traditions, while also integrating European frameworks, like the Principles of European Contract Law. The thesis integrates cognitive science and computer science to elucidate the autonomy, learning, and adaptive behaviour of DsAI systems, therefore anchoring legal discourse in the technical realities of decentralised architectures. This methodological integration enables the thesis to not only highlight the inadequacies of traditional legal frameworks in relation to decentralised AI systems but also to propose a novel conceptual paradigm.

The central findings are presented systematically throughout the chapters. Preliminary analysis indicates that DsAI systems are structurally and functionally distinct from centralised AI, demonstrating characteristics such as distributed learning, self-organisation, internal modelling, and cooperative negotiation. These characteristics allow DsAI to function not only as passive tools but also as active, adaptive entities that can produce binding legal outcomes without direct human intervention. In this context, sole-code smart contracts are investigated as potential contracts by conduct, where consensus arises from algorithmic behaviour that is observable and verifiable on-chain. Although these contracts challenge the conventional dynamics of offer and acceptance, they align with overarching contractual principles when evaluated through the lens of conduct-based agreements.

The subsequent analysis examines the role of DsAI in contract formation, emphasising contractual intention. This thesis differentiates between will and intention in civil and common law systems, indicating that civil law stresses the alignment of subjective wills, whereas common law focusses on outward manifestations. Nonetheless, both systems fundamentally depend on the assumption of entities capable of intending. This presumption fails when applied to DsAI, which does not possess recognised volition. By exhibiting autonomous decision-making and behaviour, DsAI systems may be regarded as possessing a functional intention that can be sufficient to establish contractual effects. Therefore, this thesis proposes the concept of Integrated Agency, in which DsAI function as autonomous computational agents within the legal framework of natural or legal subjects, exercising self-governance over externally defined interests. This conceptualisation enables the law to recognise the significance of DsAI conduct without attributing human qualities to the system or assigning legal personhood.

On this basis, the thesis presents two theoretical instruments aimed at resolving the legal paradox. The Paradigm of Autonomous Behaviour (PAB) offers a framework for assessing the legal implications of autonomy in DsAI. The study identifies five parameters: learning model, degree of human control, environmental complexity, internal models, and representational-inferential capacity. It establishes a threshold requiring that at least three parameters, including either internal models or representational-inferential capacity, be present at the highest level. Surpassing this threshold allows for the classification of DsAI behaviour as having autonomous artificial agency. The theory of Functional Legal Subjectivity (FLS) then complements these aspects by redefining subjectivity as an emergent, context-dependent, and functional quality rather than an ontological attribute. Under this theory, DsAI systems may be acknowledged as functional subjects within limited contexts, possessing contractual capacity to the degree that their actions consistently yield legally significant outcomes.

The findings indicate that contractual capacity and contractual intention, though traditionally interconnected, must be reconceptualised in the context of DsAI. Contractual capacity precedes intention, signifying the normative ability to bind oneself, while intention pertains to the willingness to be bound. In sole-code contracts, DsAI may exhibit functional capacity once the Paradigm of Autonomous Behaviour threshold (PAB-T) is met, while intention is inferred ex post from the coherence between algorithmic behaviour and contractual structure. This inversion of classical logic whereby intention is evaluated ex post reflects the unique reality of decentralised, autonomous systems. The thesis concludes by demonstrating that, through the combined model of the Paradigm of Autonomous Behaviour and the functional Legal Subjectivity, DsAI systems can be treated as functional centres of attribution of legal effects when operating in the formation and execution of sole-code smart contract transactions. This resolves the paradox of producing effects within the decentralised ecosystem, lacking a specific legal subject they can be attributed to, by adapting, rather than abandoning, the traditional link between legal capacity and subjectivity. The proposed framework does not confer legal personhood but instead recognises a limited, context-specific subjectivity grounded in functional performance.

Therefore, this thesis makes a two-fold contribution: analytically, it exposes the inadequacy of traditional legal categories when confronted with decentralised AI systems; theoretically, it offers a functional and measurable model that integrates technical autonomy into legal doctrine. By doing so, it demonstrates how private law can evolve to uphold coherence and certainty in the age of decentralised artificial intelligence, ensuring that legally relevant effects are acknowledged, attributed, and governed within an appropriate conceptual framework.

ACKNOWLEDGEMENTS

I would first like to express my deepest gratitude to my supervisor, Professor Deirdre Ahern, for her constant guidance, patience, and rigorous intellectual commitment. Her advice, support, and confidence in my abilities have been a guiding light throughout my extensive research journey, which, I am certain, has been challenging for both of us over the years.

Special thanks also go to Professors Eoin O'Dell and Maria Grazia Porcedda for their invaluable advice and encouragement to develop a critical and innovative approach. I would also like to express my sincere gratitude to the members of the examination board for dedicating their time, attention, and expertise to the evaluation of my work. Their presence and commitment are an honour and a privilege.

I am grateful to all the Professors and staff of Trinity College Dublin's School of Law and to the Technologies Law & Society research group for welcoming and supporting me over the years, providing not only academic resources but also an intellectually stimulating and collaborative environment. I also like to thank my fellow doctoral students and researchers who have shared discussions and ideas with me, contributing to the enrichment and deepening of this work.

On a personal level, I am immensely grateful to my family. To my parents, for teaching me the value of perseverance and the courage to embrace my own ideas, and for believing in me even in the most difficult moments. To my uncle Antonio, without whom I would never have been able to build a new personal and professional life away from home. To my sister

Francesca, for her constant support and unconditional affection. My heartfelt thanks also go to my dear friends, Michela and Alessandro, whose unwavering trust in my abilities and generous support have accompanied me throughout this journey, enabling me to reach this important milestone. Thanks also go to my brilliant colleagues and friends Dr. Marta Lasek-Markey, Dr. Philip Gavin, Jerome Zhe Zang, and Ahmed Ellaboudy, with whom we shared the joys and sorrows of the academic journey. I am infinitely grateful for their friendship over these years and for accompanying and encouraging me in my personal and professional progress, helping to create fertile ground for the development of my ideas and making this journey less lonely and more meaningful. I want to thank all my friends who, in different ways, have accompanied me over these years, offering encouragement, understanding, and light-heartedness when I needed it most.

Finally, a special thanks to Cillian. For reminding me of the most important things in life. For his incredible patience, his support, and his ability to bring me peace of mind during the most challenging stages of this project. Without his presence in my life, I would not be able to complete this journey.

This thesis is the result not only of my work, but also of the trust and affection of everyone who has supported me. To each of them goes my most sincere gratitude.

TABLE OF CONTENTS

DECLARATION	I
ABSTRACT.....	II
SUMMARY	IV
ACKNOWLEDGEMENTS.....	VIII
CHAPTER 1	1
1.1 Research Scope, Context and Boundaries.....	1
1.1.1 Nature of Decentralised AI (DsAI) Systems.....	5
1.1.2 Why DsAI Matters: Applications and Legal Relevance	10
1.2 Key Legal Challenges of DsAI Systems.....	18
1.3 Existing Literature	23
1.4 Identified Gaps.....	32
1.5 Central Research Question and Themes	33
1.6 Research Methodology	36
1.6.1 Legal Theory and Doctrinal Research	37
1.6.2 Comparative Research	38

1.6.3 Theoretical Lineage of Functional Legal Subjectivity: Doctrinal and Jurisprudential Roots .	40
1.7 Originality and Contribution to Existing Knowledge.....	46
1.8 Limitations of the Study	48
1.9 Setting the Scene: Technical and legal Context for DsAI Systems	49
1.9.1 The Historical Context of Artificial Intelligence Development	49
1.9.2 Origins of Distributed Ledger Technology and Blockchain Infrastructure.....	52
1.9.3 Smart Contracts Protocols: The Legal Challenge of Sole-code Decentralised Transactions ..	57
1.9.4 The role of DsAI in Sole-Code Smart Contracts: A Brief Overview	60
1.10 Chapters Outline.....	62
CHAPTER 2.....	66
2.1 Introduction	66
2.1.1 Artificial Intelligence and Legal Relations: The Necessity of a Juridical Perspective.....	67
2.1.2 Legally Binding Interests and Subjective Legal Situations: A Taxonomic Framework	68
2.2 Technical Foundations of Artificial Intelligence Systems	72
2.2. a) Autonomy: Defining the Core Trait of Artificial Intelligence Systems	73
2.2. b) AI Learning Models and Degrees of Human Control	74
2.2. c) The Influence of Internal State over AI Decision-Making Process.....	78
2.2. d) Adaptation and Self-Regulation in AI Models.....	80
2.3 The Decentralised Artificial Intelligence Systems	81
2.3.1 a) Multi-agent systems Foundations of DsAI Systems: The Decentralised Architecture ...	83
2.3.1 b) Real-Time Adaptability Feature and Goal Orientation	84
2.3.1 c) Autonomy Trait in DsAI Systems	84
2.3.1 d) Learning Models in Multi-Agent Systems	85
2.3.1 e) Cooperation, Collaboration, and Negotiation.....	87
2.3.1 f) Desires, Intentions and Beliefs: How Multi-agent systems Cooperate, Collaborate and Negotiate	87
2.3.1 g) DsAI Self-Organisation and Co-Evolution	91
2.3.2 How DsAI Operate in Sole-Code Smart Contracts Transactions: Technical Overview	92
2.3.3 Final Considerations over the Technical Traits of DsAI Systems.....	95
2.4. From Technical to Legal Debate: Transition to Legal Analysis.....	96
2.5 The Challenge to Fundamental Legal Concepts: Evaluating the Applicability of Legal Personhood to Multi-Agent Systems.....	97
2.6 Foundations of Legal personhood, Subjectivity and Legal Capacity in European Legal Systems: Comparative Analysis of Civil Law and Common Law Traditions	99
2.6 a) Legal Subjectivity of Natural and Artificial Persons: The Qualitative Trait of Legal Personhood	100

2.6. b) Legal Capacity and Capacity to Act: The Quantitative Trait of Legal Personhood	103
2.7 The Unitarian Concept of Legal Personhood: Encompassing Legal and Philosophical Theories	105
2.8 Persons under the Law: An Introduction	106
2.8.1 Human Beings under the Law: Natural Persons	106
2.8.2 Contractual Capacity in Natural Persons	111
2.8.3 Non-Human Entities Under the Law: Legal Persons	114
2.8.4 The Contractual Capacity of Juridical Persons: The Role of Agency Law and Legal Representation in Legal Persons	119
2.9 Reevaluating the Traditional Legal Concepts Within the Context of DsAI Systems	123
2.10 Seeking Certainty Amidst the Evolving AI Landscape: The European Union Artificial Intelligence Act Regulatory Approach	126
2.11 The Applicability of the AI Act to DsAI Systems	135
2.12 Conclusions.....	139
CHAPTER 3	141
3.1 Introduction.....	141
3.2 Blockchain Technology: Unveiling a New Framework for Legal Relations.....	143
3.2.1 The Blockchain Realm: Architecture and Operations	143
3.2.1 a) Technical Anatomy of The Blockchain	144
3.2.1 b) Public vs Private and Permissioned vs Permissionless Blockchain Infrastructure	145
3.2.2 Core Features of Blockchain Systems	147
3.2.2 a) Disintermediation and Decentralisation.....	147
3.2.2 b) Resilience and Tamper-Resistance	148
3.2.2 c) Transparency and Traceability.....	149
3.2.2 d) Pseudonymity and Trust by Design.....	150
3.2.3 The Consensus Mechanism: The Backbone of Blockchain Systems.....	150
3.2.3 a) Main Consensus Models and the Phenomenon of Transaction Failure	152
3.2.4 From Technical Traits to Legal Challenges.....	153
3.3 Smart Contracts: The Evolution of Contracts	157
3.3.1 Defining Smart Contracts in the Blockchain Environment.....	157
3.3.2 Technical Functions and Operational Features	158
3.3.2 a) Automation and Self-Execution.....	160
3.3.2 b) Security, Determinism and Irreversibility	161
3.4 The Lifecycle of Blockchain Transactions	164
3.4.1 Lifecycle of a Simple Transaction	164
3.4.2 Lifecycle of Smart Contract Transactions.....	166
3.4.3 From Automation to Legal Qualification?.....	170

3.5 Legal Transactions and Juristic Acts: Foundations	170
3.5.1 Legal Relations: Sources, Effects and Structure	170
3.5.2 Facts, Events and Acts: The Taxonomy of Legal Change.....	171
3.5.3 Juristic Acts and the Centrality of Intention	173
3.5.4 Legal Transactions as Bridges Between Legal Positions	173
3.5.5 Why Contracts Are Paradigmatic Legal Transactions	174
3.6 Contracts as Legal Transactions: Comparative Principles and Digital Challenges.....	175
3.6.1 Scope, Method and the Role of PECL.....	175
3.6.2 What Is a Contract? Definitions and Core Principles.....	176
3.6.3 Intention and Agreement: Subjective vs Objective Theories	177
3.6.4 Consideration and Cause: Divergences and PECL's Neutrality.....	181
3.6.5 The Dynamics of Offer and Acceptance: Rule and Exceptions	183
3.6.5 a) The Mirror-Image Rule and Its Limits	184
3.6.5 b) Contracts by Conduct and Implied Agreements	185
3.6.6 Electronic Contracts: Point-and-Click and Multi-Step Digital Formation	187
3.6.7 Performance Architecture: Independent/Dependent Obligations and Conditions.....	188
3.7 From Juristic Acts to Code: Evolution of Transactions	189
3.8 Sole-Code Smart Contracts 'on' Chain: Are They Contracts Made by Conduct?	190
3.8.1 Models of Smart Contracts: Integrated, Non-Integrated and Sole-Code.....	194
3.8.2 Contract Formation in Sole-Code: Offer, Acceptance and Conduct	196
3.8.3 Collapsing Formation and Performance: Legal Effects of Sole-Code Smart Contracts.....	198
3.9 Conclusions	200
CHAPTER 4.....	203
4.1 Introduction	203
4.1.1 Framing the Analysis: The Underlying Problem and its Implications	205
4.2 Detecting the presence of intentionality and intention to contract in Decentralised AI multi-agent systems	211
4.2.1 Will and Intention in Contract Formation: A Comparative Perspective Under European Civil Law and Common Law Traditions.....	214
4.2.2 Bridging Will, Intention and Interpretative Theories in Civil and Common Law	216
4.2.3 Illustrative Scenarios and Legal Relevance of DsAI System's Behaviour in Contract Formation	218
4.3 Rethinking the Role of Agency in Contractual Intention: A Functional Legal Enquiry	222
4.3.1 The Concept of Agency as a Form of Self-determination Within the Intention to Contract: A Normative Benchmark	223
4.3.2 From Cognitive Design to Legal Relevance: Conceptual Foundation of Artificial Agency in DsAI Systems.....	226
4.3.3. The Intentional Stance as an Interpretative Tool to Detect Artificial Agency	232
4.3.4 How DsAI Agents Decide: Cognitive Structures and Legal Implications for Intention to Contract	234

4.4 Autonomy Without Self-Determination: Why DsAI Systems Are Not an Independent Contractual Party	240
4.4.1 Understanding the Relationship Between DsAI Behaviour, Agency, Autonomy and Self-determination in Contract Law	242
4.5 The Outer-determination and the Self-government of Legal Interests: The Interrelation between The Decentralised AI Systems and Legal Subjects.....	246
4.6. Overcoming the Paradox: The Integrated Agency and the Functional Attribution of Contractual Intention to DsAI Systems	249
4.7 Conclusions.....	254
CHAPTER 5	255
5.1 Introduction.....	255
5.1.1 The Terms of the Investigation: An Introductory Overview.....	257
5.2 Decentralised AI systems and Legal Personhood: Bridging Traditional Institutions with Emerging Challenges.....	258
5.2.1 DsAI System Role: Setting the Scene by Revising Key Findings	259
5.2.1 a) The Role of DsAI Systems in Producing Legal Outcomes in Smart Contract Transactions	259
5.2.1 b) Legal Implications and Emerging Challenges	260
5.2.1 c) Legal Personhood, Subjectivity and Legal Capacity: Towards a Graduate Perspective.....	261
5.3 The Decentralisation Element: The Structural Shift That Compounds the Inadequacy of Current Legal Concepts.....	263
5.4 Functional Legal Subjectivity: A Legal Model for Decentralised AI Systems in Sole-Code Smart Contracts	265
5.5 The Operational Model of The Paradigm of Autonomous Behaviour (PAB): From Technical Autonomy to Legal Relevance.....	275
5.5.1 a) The Technical Components of the PAB: Foundations and Methodological Originality	275
5.5.1.b) The Selection Rationale of the Five PAB Parameters: Technical Architecture, Artificial Agency, and Legal Foundation	277
5.5.1.c) The Five Parameters as Constitutive Conditions of AI Autonomy.....	279
(i) Learning Model: The Cognitive Engine of Autonomous Decision-Making	281
(ii) Gradient of Human Control: Autonomy as Inversely Proportional to Supervision	283
(iii) Environmental Complexity: Nonlinearity, Unpredictability, and the Amplification of Autonomy	284
(iv) Internal Models: Beliefs, Desires, and Intentions as Computational Architectures of Autonomous Agency	285
(v) Representation and Reasoning: Self-Organisation, Symbolic Inference, and Functional Algorithmic Intentionality.....	287
(vi) The Methodological Logic of Five Parameters: From Lieto's MCG to the PAB	288

(vii) Systemic Integration: Why Parameters Must Be Assessed Holistically.....	289
(viii) The PAB-T Threshold: From Technical Autonomy to Legal Autonomy	290
(ix) The Conceptual Bridge: From Technical Parameters to Legally Meaningful Conduct Through Artificial Agency	292
5.5.1 d) Assessing Autonomy in Decision-Making: The Operability of The Paradigm of Autonomous Behaviour.....	296
5.5.2 The Technical-Functional Structure of the PAB: Threshold Parameters and Application to the DsAI System.....	299
5.5.3 The Graduated Structure of Legal Consequences	307
5.5.4 The PAB as Regulatory and Compliance Instrument.....	310
(i) Classification Function: Addressing the Regulatory Gap in Decentralised AI Governance	310
(ii) Compliance Operationalisation: The Five Criteria as Verifiable Governance Standards	311
5.5.5 The Application of the PAB to DsAI Systems: from Operational Autonomy to Artificial Agency.....	316
5.5.6 Practical Case Study: A DsAI-Governed Automated Market Maker on the Ethereum Blockchain.....	320
5.5.6 a) Introduction and System Selection.....	320
5.5.6 b) Technical Description of the DsAI-AMM System	321
5.5.6 c) PAB Application: Assessing Autonomous Behaviour	322
5.5.6 d) From PAB Assessment to Artificial Agency: The Foundation for FLS Attribution.....	324
5.5.6 e) FLS Implications: Contract Formation and Legal Attribution	325
5.5.6 f) Regulatory Consequences and PAB-Based Governance	326
5.5.6 g) Theoretical and Practical Implications	327
5.5.6 h) Conclusion	329
5.6 The Concept of Functional Legal Subjectivity: An Evolving Abstraction.....	329
5.6.1 The Functional Legal Subjectivity of DsAI Systems in sole-code Smart Contracts: Implications of an Operational Approach of Legal Capacity.....	336
5.7 Legal Capacity and Contractual intention: Justifying the Legal Role of DsAI within the Smart Contracts' Formation.....	338
5.8 Rethinking Representation: Why DsAI Does Not Operate as a Legal Agent	342
5.9 Functional Divergence: Capacity is not Delegated but Emergent.....	343
5.10 No Need for Legal Personhood: The DsAI as The Operational Component of The Legal Subject's Legal Sphere	344
5.11 Conclusions	344
CONCLUSIONS	348
6.1 Addressing the Central Research Question	348
6.2 Summary of Results	350
6.3 Formalisation of the Theories: Considerations.....	352

6.4 Systemic Implications of Functional Legal Subjectivity and PAB Model	356
6.5 Limitations	357
6.6 Future Research Directions and Developments	358
APPENDIX.....	360
APPENDIX A	360
A.1. Comparative Table: AI Learning Models	360
APPENDIX B	361
B.1 The Unitarian Concept of Legal personhood: Encompassing Legal and Philosophical Theories	361
B.2 Challenging the Unitary View: Diverging Theories on Legal Personhood	361
B.3 Beyond Legal Recognition: The Philosophical Hallmark of Legal personhood	362
B.4 The Philosophical and Legal Framework of Personhood: Freedom, Autonomy and the Social Dimension	363
B.5 The Teleological Ground of Legal Personhood in European Legal Traditions: The Christian Influence on Freedom, Autonomy and Responsibility	366
B.6 Traditional Theories of Legal Personhood: The Antagonistic View between Legalist and Metaphysical Realists	370
APPENDIX C	374
Tables and Figures	374
BIBLIOGRAPHY	383

CHAPTER 1

Introduction

1.1 Research Scope, Context and Boundaries

This thesis investigates the legal role of Decentralised Artificial Intelligence (DsAI), the convergence of Artificial Intelligence and blockchain technology, a specific form of Distributed Ledger Technology (DLT)¹, within on-chain sole-code smart contracts executed on open-permissionless blockchain (OPB). These DsAI systems execute contractual logic entirely through code, without human intervention or oversight, thereby challenging the applicability of traditional legal categories, such as legal capacity, legal subjectivity, contractual intention, agency and legal personhood.² The core aim is to identify threshold conditions for the formation of a valid contract in decentralised environments as without capacity no contract can be formed. Likewise, without intention to contract, no legally binding agreement can arise.

Since blockchain protocols and smart contract applications represent the most suitable environment for DsAI, a specific subtype of artificial intelligence systems, this research focuses on three interrelated areas of investigation (Fig. 1.1). Specifically, it analyses DsAI

¹ Shreya Girish Savadatti, Shruthi Krishnamoorthy and Radhakrishnan Delhibabu, 'Survey of Distributed Ledger Technology (DLT) for Secure and Scalable Computing' (2024) IEEE Access, 1.

² Katrina Geddes, 'The Death of the Legal Subject: How Predictive Algorithms Are (Re)Constructing Legal Subjectivity' (2024) 47 Computer Law & Security Review, 105873.

systems operating in open, permissionless environments, engaging with a specific type of smart contract called on-chain sole-code smart contracts.

3 Main Interrelated Areas of Investigation

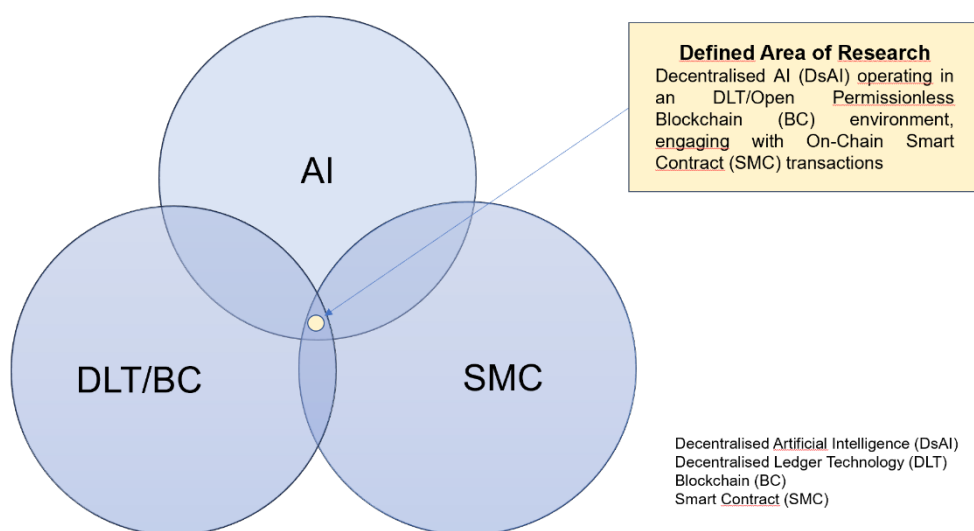


Fig. 1.1 Areas of investigation

While the concepts of decentralised ledger technology, open-permissionless blockchain, and on-chain sole-code smart contracts will be further explored in the scene setting of this chapter and in detail in subsequent chapters, it is useful to provide a brief overview to contextualise the scope of this research. In general terms, the decentralised ledger technology is a technology that enables the recording, verification, and storage of transactions or data in a decentralised and distributed manner.³ It provides a synchronised database shared among

³ José Luis Romero Ugarte, 'Distributed Ledger Technology (DLT): Introduction' (Banco de España, Article 19/18, 16 October 2018), 1; European Central Bank, *Blockchain – Distributed Ledger Technology (DLT): What Impact on the Financial Sector?* (In-Depth Analysis, European Parliament, Directorate-General for Internal Policies 2016) <https://www.academia.edu/30192464/Blockchain_Distributed_Ledger_Technology_DLT_Wh

multiple participants or nodes without dependence on a central authority. Within this broader family of technologies, blockchain is the best-known example and can be considered a subtype of the former.

Within blockchain systems, the open permissionless blockchain constitutes a network open to anyone's participation, without the need for prior approval. They allow any participant to join the network, validate transactions, and contribute to governance processes without restrictions, and are not controlled or owned by a single actor.⁴ On-chain smart contracts are contracts whose code and data reside entirely within the blockchain environment, so that their activation and execution occur exclusively on-chain, without dependence on external components.⁵ The term sole-code is instead used within this thesis to refer to smart contracts

at *_Impact_on_the_Financial_Sector*> accessed 30 March 2020; Sabrina Leo and Ida Claudia Panetta, 'Distributed Ledger Technology and the Future of Finance: Tracking Innovation, Regulation and Inclusion' (2025) 37 (4) *Technology Analysis & Strategic Management* 369; Shreya Girish Savadatti, Shruthi Krishnamoorthy and Radhakrishnan Delhibabu, 'Survey of Distributed Ledger Technology (DLT) for Secure and Scalable Computing' (2025) 13 *IEEE*, 8393.

⁴ Michèle Finck, *Blockchain Regulation and Governance in Europe* (CUP 2018); Anton Wahrstätter, Sajjad Khan and Davor Svetinovic, 'OpenFL: A Scalable and Secure Decentralized Federated Learning System on the Ethereum Blockchain' (2024) 26 *Internet of Things* 101174; Chunpeng Ge, Siwei Sun and Pawel Szalachowski, 'Permissionless Blockchains and Secure Logging' (2019) arXiv preprint <<https://arxiv.org/abs/1903.03954>> accessed 20 August 2025.

⁵ Vitalik Buterin, *A Next-Generation Smart Contract and Decentralized Application Platform* (Ethereum White Paper, 2014) <https://cryptorating.eu/whitepapers/Ethereum/Ethereum_white_paper.pdf> accessed 2 March 2020; Christopher D Clack, Vikram A Bakshi and Lee Braine, 'Smart Contract Templates: Foundations, Design Landscape and Research Directions' (2016) <<https://arxiv.org/abs/1608.00771>> accessed 5 December 2020; Hamed Taherdoost, 'Smart Contracts in Blockchain Technology: A Critical Review' (2023) 14(2) *Information* 117; Deepa Mishra and Shraddha Phansalkar, 'Blockchain Security in Focus: A Comprehensive Investigation Into Threats, Smart Contract Security, Cross-Chain Bridges, and Vulnerabilities Detection Tools and Techniques' (2024) 13 *IEEE Access*, 1.

whose operational and execution logic is determined exclusively by code, without parallel natural language versions or external intervention once deployed.⁶

From a legal perspective, the technological features of DsAI systems operating within the open permissionless blockchain infrastructure generate significant complexity. Their decentralisation, autonomy, and opacity challenge the linear application of traditional legal theories, as such theories are developed for environments based on a central authority, identifiable subjects, and human-mediated intentionality. Consequently, it is important to clarify the boundaries of this research. The thesis does not consider the role of AI in general but focuses on a particular subset of AI systems whose characteristics and applications distinguish them from standard AI, making DsAI a distinct field of inquiry. Likewise, the analysis is limited to a specific type of blockchain – the open permissionless- and a distinct category of smart contracts (on-chain sole-code), each of which raises specific legal issues that require targeted assessments. Consequently, the findings and solutions developed in this thesis may not be applicable to other forms of AI or decentralised environments.

Having set out the scope and boundaries of this thesis, the remainder of this chapter is structured as follows. Section 1.1 introduces the scope, context, and boundaries of the research, while Sections 1.1.1 and 1.1.2 further define the nature of DsAI systems, their applications, and their legal relevance. Section 1.2 identifies the main legal challenges raised by DsAI in smart contract transactions, followed in Section 1.3 by a review of the existing literature. Section 1.4 outlines the main knowledge gaps, leading to Section 1.5, where the research question and central themes are formulated. Section 1.6 outlines the research methodology employed, including both doctrinal and comparative approaches. Section 1.7 presents the

⁶ Sadaf Azimi, Ali Golzari, Naghmeh Ivaki & Nuno Laranjeiro, 'A Systematic Review on Smart Contracts Security Design Patterns' (2025) 30 Empirical Software Engineering 95; Bahadır Köksal and Roee Sarel, 'The Smart Contracts Trilemma' (2024) University of Illinois Law Review (forthcoming) SSRN <https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4689013> accessed 8 May 2025; Stuart D Levi and Alex B Lipton, 'An Introduction to Smart Contracts and Their Potential and Inherent Limitations' (Harvard Law School Forum on Corporate Governance, 26 May 2018) <<https://corpgov.law.harvard.edu/2018/05/26/an-introduction-to-smart-contracts-and-their-potential-and-inherent-limitations/>> accessed 2 August 2024.

originality and contribution of the thesis, while Section 1.8 illustrates its limitations. Finally, Sections 1.9 and 1.9.1–1.9.2 provide context, introducing the broader technological and legal context, while Section 1.10 outlines the overall structure of the thesis.

1.1.1 Nature of Decentralised AI (DsAI) Systems

In this thesis, the term Decentralised Artificial Intelligence specifically refers to multi-agent artificial intelligence systems implemented within an open permissionless blockchain architecture, where the decision-making process and the operational control of the DsAI system are distributed among independent nodes operating according to a shared consensus protocol.⁷ From a technical standpoint, the DsAI is a form of cognitive artificial intelligence, as it goes beyond mere data processing, but employs hierarchical semantic memory structures suited to supporting autonomous and interpretable reasoning processes.⁸ In other words, DsAI is not simply an AI system, but rather takes on an intrinsically cognitive nature, thanks to its ability to model conceptual representations, facilitate autonomous inference, and support shared knowledge infrastructures.⁹ Hence, in the context of the blockchain infrastructure, DsAI systems are implemented to autonomously initiate, accept or execute distributed contractual

⁷ Michael Wooldridge, *An Introduction to Multi-Agent Systems* (2nd edn, Wiley 2009); Yves Demazeau and Jean-Pierre Müller (eds), *Decentralized A.I.* (Elsevier Science Publishers BV (North-Holland 1990); Yoav Shoham and Kevin Leyton-Brown, *Multiagent Systems: Algorithmic, Game-Theoretic, and Logical Foundations* (Cambridge University Press 2009); Roberta Calegari, Giovanni Ciatto, Viviana Mascardi and Andrea Omicini, ‘Logic-based technologies for multi-agent systems: a systematic literature review’ (2021) 35(1) *Autonomous Agents and Multi-Agent Systems*, 1–67; Monjurul Karim, Dong Hoang Van, Sangeen Khan, Qiang Qu and Yaroslav Kholodov, ‘AI Agents Meet Blockchain: A Survey on Secure and Scalable Collaboration for Multi-agent systems’ (2025) 17(2) *Future Internet*, 57.

⁸ Tooraj Helmi, ‘SHIMI: Semantic Hierarchical Memory Index for Efficient Cognitive AI Systems’ (2025) <arXiv <https://arxiv.org/abs/2504.06135>> accessed 1 August 2025.

⁹ Giuseppe Riva, ‘Invisible Architectures of Thought: Toward a New Science of AI as Cognitive Infrastructure’ (2025) arXiv <arXiv:2507.22893 <https://arxiv.org/abs/2507.22893>> accessed 22 August 2025.

transactions, in the form of smart contracts, without human intervention over their performance at the time of formation and execution.¹⁰ In such systems, there is no single point of control: AI multi agents are indeed coordinated via distributed and decentralised protocols, without centralised supervision.¹¹ Therefore, no single human or legal person exercises ongoing authority over the DsAI systems' operational decisions.¹² As a consequence, this analytical scope excludes hybrid arrangements involving instead off-chain governance or human-in-the-loop validation – which definitions will be analysed in depth in the following chapters-focusing instead on configurations where the role of the DsAI systems' conduct can be assessed independently from the human oversight.

When the blockchain platform integrates the AI systems, the AI itself embodies the decentralised traits of the blockchain. This is the reason why the DsAI system is also defined as 'multi-agent systems' system. In other words, the AI that runs on a decentralised network possesses itself a decentralised architecture, where multiple decentralised AI agents are called to make decisions, perform tasks and processes in a collaborative manner with one another. Such a collaborative interplay between agents might generate what it is termed 'emergent behaviour'. Which is, to some extent, designed to be deliberately unpredictable.¹³ The unpredictability of DsAI behaviour stems from the high level of autonomy in decision-making

¹⁰ Max Raskin, 'The Law and Legality of Smart Contracts' (2017) 1 Georgetown Law Technology Review 305; Christopher D Clack, Vikram A Bakshi and Lee Braine, 'Smart Contract Templates: Foundations, Design Landscape and Research Directions' (2016) arXiv:1608.00771 <<https://arxiv.org/abs/1608.00771>> accessed 2 March 2023; Andrea M. Delgado-Segura, Cristina Pérez-Sola, Guillermo Navarro-Arribas and Jordi Herrera-Joancomartí, 'Analysis of the Bitcoin UTXO set' (2019) 6 IEEE Access, 1414.

¹¹ Tshilidzi Marwala and Bo Xing, 'Blockchain and Artificial Intelligence' (arXiv, 23 October 2018) <<https://arxiv.org/abs/1802.04451>> accessed 18 August 2024.

¹² Volker Strobelt, Eduardo Castello Ferrer and Marco Dorigo, 'Managing Byzantine Robots via Blockchain Technology in a Swarm Robotics Collective Decision-Making Scenario' in Proceedings of the 17th International Conference on Autonomous Agents and Multi-Agent Systems (International Foundation for Autonomous Agents and Multiagent Systems, Stockholm, July 2018), 541.

¹³ Mireille Hildebrandt, *Smart Technologies and the end(s) of Law* (Edward Elgar Publishing 2015).

abilities of the multi-agent systems which, acting like a unity of action, emancipate themselves from the original creator to be more effective in finding ways to achieve their goals.¹⁴

Thus, this decentralised dynamic, backed up with the AI abilities, can easily affect the way in which we humans have formed and developed legal interactions so far. Furthermore, the sophistication and autonomy in decision-making of DsAI agents operating with smart contract transactions, stress the question about the nature of interactions with artificial agents in an unsupervised setting.¹⁵ This characteristic makes it relevant in the contemporary context for three main reasons. The first is indeed autonomy: DsAI agents can make decisions independently, interacting with each other and with the environment, to the point of generating forms of artificial agency that take on legal significance, especially in automated contractual systems.¹⁶ The second is decentralisation. Indeed, the absence of a single control centre enables distributed governance, reducing the risk of monopolies and increasing process reliability in highly interconnected scenarios such as decentralised finance (DeFi).¹⁷ The last relates to social and economic implications. DsAI finds application in strategic sectors such as collective resource management, decentralised digital markets, contract automation, and global financial networks. In such contexts, the autonomous decisions of DsAI systems produce legal and economic effects without direct human intervention, raising questions about the recognition of

¹⁴ Yves Demazeau and Jean-Pierre Müller (n. 7).

¹⁵ Rajesh Ranjan, Shailja Gupta and Narajan Singh, 'LOKA Protocol: A Decentralized Framework for Trustworthy and Ethical AI Agent Ecosystems' (2025) arXiv <<https://arxiv.org/abs/2504.10915>> accessed 8 August 2025.

¹⁶ Leonard Dung, 'Understanding Artificial Agency' (2025) 75(2) *Philosophical Quarterly* 450; Fatih Sinan Esen, 'The risk of Agentic AI: The Curse of Autonomy', Omer Aydin and Enis Kaararslan (edn), *The Age of Generative Artificial Intelligence* (2025, Izmir Academy Association Publishing House), 156.

¹⁷ Lennart Ante, 'Autonomous AI Agents in Decentralized Finance: Market Dynamics, Application Areas, and Theoretical Implications' (2025) ResearchGate <https://www.researchgate.net/publication/387049652_Autonomous_AI_Agents_in_Decentralized_Finance_Market_Dynamics_Application_Areas_and_Theoretical_Implications> accessed 3 August 2025.

their legal capacity and the distribution of responsibilities.¹⁸ In this sense, DsAI redefines the construction of knowledge in the contemporary digital ecosystem: these structures elaborate meanings, anticipate epistemic needs, and redefine the locus of cognitive action beyond the human subject.¹⁹ While all these distinctive feature from a technical perspective represent a significant milestone in technological development, it also directly challenges legal doctrines that assume a clearly identifiable entity exercising such control and responsible for decision-making.

In March 2016, the victory of AlphaGo, an artificial intelligence system developed by DeepMind, over world champion Lee Sedol in the game of Go was recognised as a turning point in the perception of artificial intelligence.²⁰ Go, much more complex than chess, had long been considered beyond the reach of machines. AlphaGo's unexpected moves, perceived as 'creative' by human observers, demonstrated that AI could produce autonomous and unpredictable behaviours, not simply determined by pre-programmed logic.²¹ This breakthrough was not only technological but also legal: from that moment on, the question of how to qualify the autonomous behaviour of artificial systems that produce significant effects arose, paving the way for debate on the role they could play in social and legal relationships.²² This breakthrough had a significant impact on both technological and social levels. For the first time, an AI system was perceived as capable of behaviours typically associated with

¹⁸ Ibid; Shakil Hassan, Wessel Reijers, Kim Wuyts and Primavera De Filippi, 'Decentralized Autonomous Organizations: Concept, Model, and Applications' in *Proceedings of the IEEE International Conference on Blockchain (Blockchain)* (IEEE 2021), 1.

¹⁹ Xule Lin, 'Cognitio Emergens: Agency, Dimensions, and Dynamics in Human-AI Knowledge Co-Creation' (2025) arXiv <<https://arxiv.org/abs/2505.03105>> accessed 18 August 2025.

²⁰ James Vincent, 'Former Go champion beaten by DeepMind retires after declaring AI invincible' <<https://www.theverge.com/2019/11/27/20985260/ai-go-alphago-lee-se-dol-retired-deepmind-defeat>> accessed 29 December 2019.

²¹ Mikael Johansson, 'AlphaGo: When Artificial Intelligence Made History' (2016) *Journal of Science and Technology* 45, 112; Alex Irpan, 'AlphaGo vs Lee Sedol: Post Match Commentaries' (2016) <<https://www.alexirpan.com/2016/03/17/alphago-isd.html>> accessed 10 October 2023.

²² Marta Halina, 'Creativity for Comparative Psychology' (2021) 34 *Minds and Machines* 495; Trevor Leach, 'What Does AlphaGo Teach Us About Human Creativity?' (2022) 1 *AI and Ethics*, 113.

human action, beyond mere computational logic.²³ This raised questions about the consequences of such developments and the implications of a technological phenomenon capable of overcoming the limits of traditional automation and impacting the rules that have always placed human intelligence at the centre of the social and legal order.²⁴ From this emblematic episode to present day applications, AI has gradually attracted growing attention, not only technically, but also socially and regulatory.

Today, AI systems are widespread in almost every area of daily life: virtual assistants in smartphones, online search tools, automotive and medical devices, shopping preference tracking systems, smart homes and cities, and even recent creative applications of generative AI like ChatGPT.²⁵ These examples demonstrate AI's ability to perceive, learn, and adapt to different contexts, often with an increasing degree of autonomy.

Thus, AI inevitably enters human relationships, many of which take on legal significance, transforming into acts, facts, and transactions. Social and economic interactions are now intertwined with artificial systems to which we tend to attribute knowledge, decisions, or responsibility. For this reason, AI must be considered not merely as a technological artefact, but as a socio-legal phenomenon whose integration into everyday interactions reshapes the modalities of developing social and legal interactions, attributing agency, responsibility, and legal effects.

²³ Haonan Wang and others, 'Can AI Be as Creative as Humans? Relative Creativity and its Measurement' (2024) arXiv <<https://arxiv.org/abs/2401.01623>> accessed 8 September 2024.

²⁴ Alexa Hagerty and Igor Rubinov, 'Global AI Ethics: A Review of the Social Impacts and Ethical Implications of Artificial Intelligence' (2019) arXiv <<https://arxiv.org/abs/1907.07892>> accessed 3 August 2024; Luye Bao and others, 'Whose AI? How Different Publics Think about AI and Its Social Impacts' (2022) 130 *Computers in Human Behavior*, 107182.

²⁵ Yihan Cao, Siyu Li, Yixin Liu, Zhiling Yan, Yutong Dai, Philip S. Yu, Lichao Sun, 'A Comprehensive Survey of AI-Generated Content (AIGC): A History of Generative AI from GAN to ChatGPT' (2023) arXiv <<https://arxiv.org/abs/2303.04226>> accessed 19 March 2023; Maria T Baldassarre, Lorenzo De Stefano and Roberto Navigli, 'The Social Impact of Generative AI: An Analysis on ChatGPT' (arXiv, 7 March 2024) <<https://arxiv.org/abs/2403.04667>> accessed 8 March 2025.

1.1.2 Why DsAI Matters: Applications and Legal Relevance

The resulting tension is not merely theoretical: it has direct implications for risk allocation, contractual enforceability and regulatory oversight of decentralised markets themselves. Indeed, the emergence of the DsAI industry is rapidly gaining traction, holding significant promises in revolutionising various domains by combining the AI capabilities with the distributed architecture and transparency of blockchain.²⁶ Multiple studies²⁷ show how over the next 5-10 years, there will be a significant adoption of such technologies²⁸ which will allow to unveil the hidden processes behind AI decision-making process, enhancing transparency, security and control.²⁹ Examples of DsAI systems can be found nowadays in different industries, including but not limited to healthcare³⁰ and energy³¹, supply chain management³²,

²⁶ Erik Karger, 'Combining Blockchain and Artificial Intelligence – Literature Review and State of The Art' (International Conference on Information Systems (ICIS 2020) <https://www.researchgate.net/publication/350734729_Combining_Blockchain_and_Artificial_Intelligence_-_Literature_Review_and_State_of_the_Art> accessed 15 March 2023.

²⁷ Mariya Vincent, Anju E George, Christa T S, N. Jayapandian, 'Systematic Review on Decentralised Artificial Intelligence and Its Applications' (International Conference on Innovative Data Communication Technologies and Application (ICIDCA) Uttarakhand, India, 2023) <<https://ieeexplore.ieee.org/document/10100017>> accessed 5 April 2023.

²⁸ PwC, 'DeFi: Defining the Future of Finance' (2021) <<https://www.pwc.ch/en/publications/2021/defi-defining-the-future-of-finance-may-2021.pdf>> accessed 7 February 2023.

²⁹ Hamed Taherdoost, 'Blockchain Technology and Artificial Intelligence Together: A Critical Review on Applications' (2022) 12(24) Appl. Sci., 12948.

³⁰ Priti Tagde, Sandeep Tagde, Tanima Bhattacharya, Pooja Tagde, Hitesh Chopra, Rokeya Akter, Deepak Kaushik & Md. Habibur Rahman, 'Blockchain and artificial intelligence technology in e-Health' (2021) 28 (38) Environmental science and pollution research international, 52810.

³¹ <<https://verv.energy>> accessed 5 February 2023.

³² Vincent, George, Christa T S, Jayapandian (n 27) 243.

music,³³ robotics³⁴, gaming³⁵ and self-driving cars domains and, in particular, robotics, Web3 finance applications, such as DeFi.³⁶ Decentralised AI can be applied in the field of robotics to enable a more distributed and collaborative approach to decision-making. In traditional robotics systems, decision-making is usually centralised, meaning that all the robots in the system rely on a central decision-making algorithm. However, with DsAI, robots can learn from each other and make decisions based on shared knowledge and experiences. This means that robots can work together more efficiently and adapt to changing environments in real-time.³⁷ In the financial sector, DsAI is increasingly being applied to decentralised finance (DeFi) systems – one of the most developed and economically significant domains within the broader Web3 ecosystem – with the aim of providing more efficient and accessible financial services.³⁸ In this context, DsAI algorithms are used to analyse market data, optimise trading strategies and autonomously execute investment decisions. Blockchain-based protocols also enable peer-to-peer lending, decentralised trading and other financial interactions without

³³ Na Li, ‘Combination of Blockchain and AI for Music Intellectual Property Protection’ (2022) *Computational Intelligence and Neuroscience* 1.

³⁴ See Vasco Lopes, Luís A. Alexandre, ‘An Overview of Blockchain Integration with Robotics and Artificial Intelligence’ (2018) arXiv <<https://arxiv.org/abs/1810.00329>> accessed 4 December 2022.

³⁵ Sydney Jacobs, ‘AI & Blockchain Transform Gaming: AILAND building on SKALE’ (2023) <<https://skale.space/blog/ai-blockchain-transform-gaming-ailand-building-on-skale>> accessed 25 April 2023.

³⁶ Vincent, George, Christa T S, Jayapandian (n 27), 244.

³⁷ Vasco Lopes, Luís A. Alexandre, ‘An Overview of Blockchain Integration with Robotics and Artificial Intelligence’ (2018) arXiv <<https://arxiv.org/abs/1810.00329>> accessed 4 December 2022.

³⁸ The Web3 is described as the next evolution of the World Wide Web, known as Internet 2.0. The Web3 and its applications use the concept of decentralization, blockchain, non-Fungible tokens (NFTs) and smart contract transactions to develop an entire new Internet ecosystem. See Shenghui Cheng, Yue Zhang, Xiaofei Li, Lin Yang, Xin Yuan, Stan Z., ‘Roadmap toward the metaverse: An AI perspective’ (2022) 3(5) *The Innovation* 100293; Alex Murray, Dennie Kim, Jordan Combs, ‘The promise of a decentralized internet: What is Web3 and how can firms prepare?’ (2023) 66 (2) *Business Horizons*, 191.

relying on banks or other traditional intermediaries.³⁹ These capabilities are already operational in DeFi through mechanisms such as liquidity pool management, automated market making and cross-chain arbitrage, where DsAI agents manage high-value transactions in real time.⁴⁰ Although DeFi represents the financial core of Web3, the transformative impact of DsAI extends beyond finance. By enabling more autonomous decentralised transactions – ranging from the creation and exchange of digital assets to advanced applications such as sentiment analysis and generative modelling – DsAI is expected to catalyse a new generation of Web3 services. This evolution marks a shift from sector-specific automation to a generalised ecosystem in which decentralised, code-based transactions become a structural feature of digital interactions.⁴¹ It is in this rapidly expanding context that the legal implications become more acute.

There are different types of platforms on the market which already use one of the most notable versions of DsAI systems. One of the most relevant is certainly OpenCOG Hyperon⁴²

³⁹ Benedikt C. Eikmanns, Pascal Mehrwald, Philipp G. Sandner, Isabell M. Welp, ‘Decentralised finance platform ecosystems: conceptualisation and outlook’ *Technology Analysis & Strategic Management* <<https://doi.org/10.1080/09537325.2022.2163886>> accessed 7 March 2023.

⁴⁰ Ibid.

⁴¹ Longbing Cao, ‘Decentralized AI: Edge Intelligence and Smart Blockchain, Metaverse, Web3, and DeSci’ (2022) 37(3) *IEEE Intelligent Systems* 6-9; Shicheng Wan, Hong Lin, Wensheng Gan, Jiahui Chen, Philip S. Yu, ‘Web3: The Next Internet Revolution’ (2023) arXiv <<https://arxiv.org/abs/2304.06111>> accessed 27 April 2023.

⁴² OpenCog is an open-source research project born around 2008 with the goal of developing an artificial general intelligence (AGI) platform. It is a modular cognitive structure: not a single algorithm, but a set of components for reasoning, machine learning, natural language, perception, and planning. The heart of OpenCog Hyperon is AtomSpace: a sort of "cognitive database" that represents knowledge in the form of a hyperstructured graph (nodes and links called atoms). This allows for the integration of logic, probability, and symbolic learning. The language used is MeTTa: a new cognitive programming language developed for OpenCog Hyperon (the recent evolution of the project). MeTTa combines formal logic and distributed representation, intended to be a "meta-metalanguage" for Artificial General Intelligence (AGI). The goal is to create a system capable of developing general cognitive capabilities (learning, inference, knowledge representation) similar to human ones, not

running on SingularityNET platform. OpenCOG is a DsAI cognitive system part of the SingularityNET, a decentralised AI platform built on blockchain technology.⁴³ It allows DsAI agents and developers to publish and offer their AI services in the form of smart contracts.⁴⁴ For example, DsAI agents providing natural language processing services can autonomously accept a request from another agent for sentiment analysis to inform a DeFi market forecast, perform the task, and trigger the payment entirely via a sole-code smart contract, without any human intervention in the execution phase.⁴⁵ The decentralised nature of SingularityNET enables the creation of a network where DsAI agents can interact, collaborate, and transact with each other autonomously, initiating, and mediating transactions through smart contracts. Another significant instance is Numerai. Numerai is a decentralised hedge fund that combines machine learning and blockchain technology.⁴⁶ Data scientists can build and train AI models using Numerai's data and submit predictions in the form of encrypted transactions. These encrypted transactions are used as inputs to smart contracts, where the DsAI models compete and contribute to the fund's investment strategies.⁴⁷ A further example is Cortex.⁴⁸ This platform aims to integrate AI into smart contracts, enhancing the decentralised applications

limited to specific tasks (such as Large Language Models). See Ben Goertzel and others, 'OpenCog Hyperon: A Framework for AGI at the Human Level and Beyond' (2023) arXiv <<https://arxiv.org/abs/2309.10131>> accessed 20 August 2024; OpenCOG Hyperon <<https://superintelligence.io/portfolio/opencog-hyperon/>> accessed 2 February 2025.

⁴³ SingularityNET <<https://singularitynet.io/aboutus/>> accessed 5 May 2021.

⁴⁴ SingularityNET, 'White Paper 2.0' (2019) <chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://public.singularitynet.io/whitepaper.pdf> accessed 28 June 2021.

⁴⁵ Sentiment analysis is a Natural Language Processing (NLP) technique used to determine the attitude or emotion expressed in a text. Aggregated sentiment can influence trading decisions, prices, or investment strategies. In sole-code smart contracts, the results of sentiment analysis can directly trigger or block transactions. See Mohsen Farhadloo and Erik Rolland, 'Fundamentals of Sentiment Analysis and Its Applications' in Witold Pedrycz and Jorge Manuel de Oliveira (eds), *Sentiment Analysis and Ontology Engineering* (Springer 2016), 1.

⁴⁶ Numer.ai <<https://numer.ai/>> accessed 22 October 2022.

⁴⁷ Ibid.

⁴⁸ Cortex Labs <<https://www.cortexlabs.ai/>> accessed 10 January 2020.

‘Dapps’ with more diverse use cases. For example, a supply chain DApp could invoke an AI-based demand forecasting model directly from the blockchain, allowing suppliers to adjust production in real time based on forecasts, with contractual commitments formed and executed entirely through code.

Nonetheless, DsAI systems, as AI subset systems with a blockchain protocol, can raise issues which can have effects on society since they might be thought as a sum of critical aspects belonging to both AI and blockchain systems. For instance, the use of DsAI systems has the potential to create decentralised organisation structures as autonomous sources of the entire blockchain governance, based exclusively on DsAI-based application that can deploy smart contracts, neither controlled by any person but completely by codes.⁴⁹ For example, a DsAI system in a decentralised marketplace could automatically create a simple fee-for-service contract when a buyer requests a data analytics task, ensuring that payment is released to the provider once the results are delivered on-chain. Another examples is a system called Decentralised Autonomous Organisations (DAO).⁵⁰ A DAO refers to a type of decentralised organisation that operates using algorithmic rules and smart contracts.⁵¹ DAOs rely on predefined algorithms and code to automate decision-making processes.⁵² The decision-making process in a DAO is typically driven by algorithms that follow certain parameters or

⁴⁹ Ibid.

⁵⁰ Fulvio Sarzana and Massimiliano Nicotra, *Diritto della Blockchain Intelligenza Artificiale e IoT* (1st edn, IPSOA 2018); Jungsuk Han, Jongsub Lee and Tao Li, ‘A Review of DAO Governance: Recent Literature and Emerging Trends’ (2025) 91 *Journal of Corporate Finance* 102734; Qin Wang and others, ‘Understanding DAOs: An Empirical Study on Governance Dynamics’ (*IEEE Transactions on Computational Social Systems*, early access, 2025) <<https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=10891558>> accessed 7 July 2025.

⁵¹ Andrea Peña-Calvin, David Duenas-Cid and Junaid Ahmed, ‘Is DAO Governance Fostering Democracy? Reviewing Decision-Making in Decentraland’ (Working Paper, Universidad Complutense de Madrid and Kozminski University 2025) <https://mostwiedzy.pl/pl/publication/download/0/is-dao-governance-fostering-democracy-reviewing-decision-making-in-decentraland_202409241016096284311.pdf> accessed 2 August 2025.

⁵² Alexandra Sims, ‘Blockchain and Decentralised Autonomous Organisations (DAOs): the evolution of companies?’ (2019) 28 *New Zealand Universities Law Review*, 423.

formulas.⁵³ For example, a DAO might use an algorithm to determine the allocation of funds based on predefined rules, market conditions, or other variables. A real-world example of a DAO is Aragon. It is an open-source project that enables the creation and management of decentralised organisations on the Ethereum blockchain.⁵⁴ Aragon allows users to create DAOs with features such as voting systems, proposal mechanisms, token issuance, and membership management.⁵⁵ For example, organisations in the blockchain space have utilised Aragon to establish decentralised governance structures for fund management, project funding, and community-driven decision-making.⁵⁶

Finally, to offer a further overview of the overall themes of this thesis, it is useful to present the results of few reports around the AI and blockchain provisional market growth. The smart contract sector is growing faster than imagined with an estimated further development in the following years⁵⁷ (Fig. 1.2).

⁵³ Ibid.

⁵⁴ Aragon <<https://aragon.org>> accessed 29 October 2022.

⁵⁵ Ibid.

⁵⁶ Ibid.

⁵⁷ Research and markets, 'Blockchain AI Global Market Report' (2023) <<https://www.researchandmarkets.com/report/blockchain-artificial-intelligence>> accessed 6 April 2023.

Source: *Valuates Reports*



Fig. 1.2 – Smart Contracts Market Growth Projection

Such a provision, coupled with a global market growth of smart contracts by 2028⁵⁸ (Fig. 1.3)

⁵⁸ Ibid.



Fig. 1.3 – Smart Contracts Market Report

and the spreading impact of the Blockchain AI business⁵⁹ (Fig. 1.4) makes this research relevant for the DsAI systems global market expansion. This thesis aims at improving the legal certainty around the role of DsAI in smart contract interactions, boosting further research in this merged field.

⁵⁹ Ibid, ‘The global blockchain ai market grew from \$0.39 billion in 2022 to \$0.48 billion in 2023 at a compound annual growth rate (CAGR) of 25.1%’.

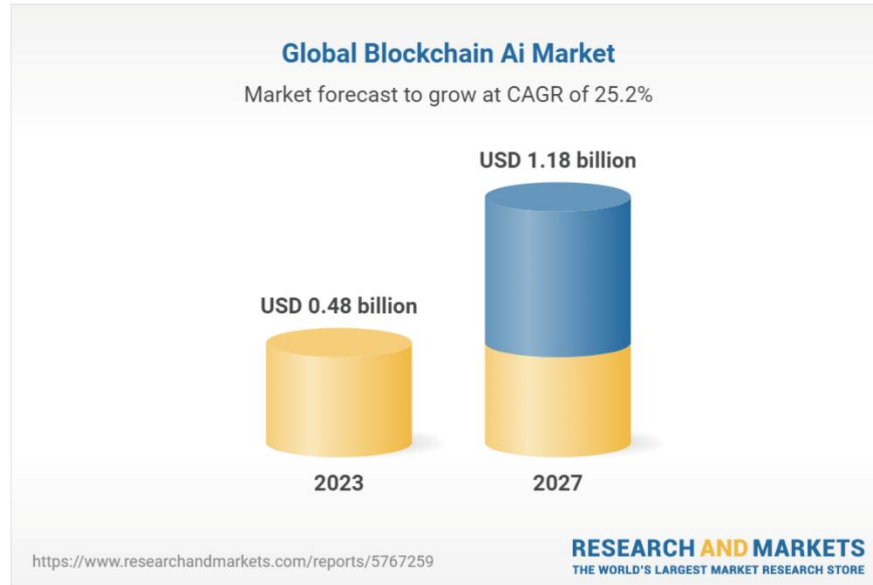


Fig. 1.4 – Global BC and AI Market Provision

Therefore, rather than prescribing new legislation, the thesis identifies regulatory gaps and offers analytical tools to adapt existing legal categories to the technical specificities and operational roles of decentralised AI.

1.2 Key Legal Challenges of DsAI Systems

The progressive integration of DsAI into decentralised markets, particularly through sole-code smart contracts, brings the technical and operational characteristics described above into direct contact with the fundamental doctrines of private law. In this context, issues relating to contractual capacity, intent and attribution of conduct take on renewed urgency, as the absence of a single legal source of contractual interactions and effects calls into question traditional regulatory frameworks related to aspects such as legal capacity and intention to contract. As humanity progress towards more AI and blockchain-oriented applications, the role of DsAI systems is increasing. Therefore, understanding the role that DsAI multi-agent systems perform in the reactive and proactive blockchain environment and, more specifically, in smart contract transactions, is pivotal. The growing autonomy of decentralised transactions,

particularly those executed via smart contracts based on unique code implemented by DsAI systems, amplifies existing uncertainties in contract law and beyond. It is in this context of decentralised smart contract transactions, which this thesis shall discuss in detail in following Chapters, that the DsAI is currently mostly deployed as a transaction initiator and/or mediator, within human-to-human interactions, human-AI interactions or even AI-to-AI interactions. Despite such relevant implications on both AI and blockchain domains, the DsAI applications in smart contract transactions are still at their initial stage but moving faster from a niche field towards a more substantial place in the market.⁶⁰ Thus, it comes with no surprise that the urge of legal responses around the role of DsAI systems in blockchain-based transactions, and smart contracts, has gained momentum.⁶¹ From a legal perspective, although the concept of Artificial agents is not new, with the development of DsAI agents we are experiencing a new level of complexity which informs not only the AI process itself but is also increasing the legal uncertainty around the following aspects: 1) the legal relationship between humans and DsAI agents in smart contract transactions. Questions relevant to agency might arise in such a case; 2) the degree of DsAI autonomous decision-making process produces a cause-effect interrelation in the legal realm as regards the legal effects that such AI-based decisions can determine. Questions around intentions, legal capacity, degree of binding legal effects and personhood might arise; 3) the relationship between the performed activities of DsAI and the effects that they produce can be, under some circumstances, a result of emergent behaviours. In the specific case of DsAI systems such conundrums invest an AI system which: a) performs a high-level of autonomy in decision making in setting up goals, strategies and activities; b) owns a high-level of independent behaviour from the human control; c) can act as initiator and mediator agent of smart contract transactions which can lead towards the production of binding legal effects in a decentralised environment; c) as a result of autonomous decision-making and activities, DsAI can produce emergent behaviours. In other words, behaviours that are not and

⁶⁰ Taherdoost (n. 29), 12948.

⁶¹ Hongdan Han, Radha K. Shiwakoti, Robin Jarvis, Chima Mordi, David Botchie, 'Accounting and auditing with blockchain technology and artificial Intelligence: A literature review' (2023) 48 *International Journal of Accounting Information Systems*, 100598.

are designed not to be foreseeable by humans in order to increase the AI effectiveness.⁶² On top of that, the main DsAI systems' trait is to be a cohort of artificial agents which act as a unity in a decentralised and distributed environment where no one can be considered as the owner of the infrastructure within which the AI operates. Rather, any participant with network access in a permissionless blockchain environment, regardless of identity, jurisdiction, or prior relationship to other participants is part of the environment.⁶³ In such a scenario, the legal conundrum is to try to understand whether such legal effects that stem from the DsAI decentralised contractual activities are attributed to the AI itself. In other words, when DsAI engages in decentralised contractual activities, its decisions and actions must be considered as AI-based or AI-mediated. Moreover, in an open permissionless blockchain, there is uncertainty about whether such DsAI decisions must be qualified as completely taken on behalf of other subjects- whether natural or legal person - thus involving the legal concept of agency, or as part of DsAI internal process that belongs entirely to it, thus involving the concept of legal intention. On a general viewpoint, DsAI systems do not select a course of action based on what would be most beneficial to an external party; rather, they identify and pursue the most likely option to achieve a predefined or emergent goal, evaluating alternatives based on their own programmed or learned optimisation criteria.⁶⁴ Such a concept convey issues when DsAI performs in the contract law domain, where contractual intention and legal capacity are

⁶² Daniel Trusilo, 'Autonomous AI Systems in Conflict: Emergent Behavior and Its Impact on Predictability and Reliability' (2023) 14(1) *Journal of Military Ethics* 2; UK Government, *International Scientific Report on the Safety of Advanced AI: Interim Report* (Department for Science, Innovation and Technology 2024) <https://assets.publishing.service.gov.uk/media/6716673b96def6d27a4c9b24/international_scientific_report_on_the_safety_of_advanced_ai_interim_report.pdf> accessed 20 April 2025.

⁶³ Primavera De Filippi and Aaron Wright, *Blockchain and the Law: The Rule of Code* (Harvard University Press 2023), 32–34.

⁶⁴ Kevin D Ashley, *Artificial Intelligence and Legal Analytics* (2nd edn, CUP 2022), 45–47; Christian Ernst, 'Artificial Intelligence and Autonomy: Self-Determination in the Age of Automated Systems' in Thomas Wischmeyer and Timo Rademacher (eds), *Regulating Artificial Intelligence* (Springer 2020), 53.

involved, and the agency and personhood theory appear to be highlighted. Furthermore, due to the decentralised feature of smart contracts and blockchain, the DsAI agents do not seem to act within any specific authority so that it is harder to ascribe certain legal effect, descending from a specific transaction to one or more persons.

In other words, it emphasises the point upon the legal role of DsAI agents operating without human mediation when acting as initiator and mediator of smart contract transactions. Is DsAI capable of any legal intention or capacity to contract when operating with the class of smart contracts that might be qualified as legal contracts? How much their autonomous decision-making affects such legal interactions, especially when they determine transfers of rights and duties? The decentralised traits of DsAI systems also add another layer of sophistication which is an element of distinction compared to traditional AI agents that can potentially affect their legal qualification. Additionally, for as the number of legal interactions initiated or mediated by DsAI agents expanding and escalating it is even more important to investigate their role.

Given that the DsAI system combines AI and blockchain technologies at a conceptual level, it prompts inquiries into its legal relevance. Specifically, it raises the question of whether the DsAI warrants a distinct analysis based on its unique characteristics and its application within the blockchain realm, particularly in on-chain smart contract transactions. Should DsAI agents still be considered as tools and instruments operating on behalf of human actors? Or are DsAI systems, due to a combination of performing abilities, traits, and mode of operations, becoming actors in legal sense? Despite the growing technological convergence between artificial intelligence and blockchain – already applied in multiple sectors, from decentralised finance to supply chain management – academic and legal research has largely examined these areas in isolation. Artificial intelligence law has focused primarily on issues of autonomy, agency, and liability for algorithmic systems,⁶⁵ while blockchain research has focused on the

⁶⁵ Maarten Herbosch, 'Liability for AI Agents' (2025) 26 (3) UNC Journal of Law & Technology <<https://journals.law.unc.edu/ncjolt/wp-content/uploads/sites/4/2025/04/Herbosch-Liability-for-AI-Agents.pdf>> accessed 2 August 2025; Ian Ayres, 'The Law of AI is the Law of Risky Agents Without Intentions' (2024) University of Chicago Law Review Online <<https://lawreview.uchicago.edu/online->

applicability, classification, and governance of smart contracts and decentralised networks.⁶⁶ This disciplinary separation has resulted in significant regulatory and legal gaps. There is little systematic legal literature analysing sole-code smart contracts determined by decentralised artificial intelligence systems, despite their growing technical feasibility and implementation.⁶⁷ The absence of integrated analysis limits the ability of legal doctrine to address issues of contractual capacity, intent, and attribution of conduct directly to the source of behaviour – the DsAI systems - in environments where performance is determined solely by decentralised paradigms. Such combined aspects raise further questions whether the existing legal framework is adequately equipped to tackle the challenges presented by this technology.⁶⁸ These challenges include the difficulty of attributing legally relevant conduct in the absence of a single legal source, the inevitable uncertainty as to whether DsAI systems can be considered the legal source of contractual interactions, the interpretability of DsAI-based conduct to

archive/law-ai-law-risky-agents-without-intentions> accessed 18 August 2025; Peter M Asaro, ‘The Liability Problem for Autonomous Artificial Agents’ (AAAI, 2016) <<https://cdn.aaai.org/ocs/12699/12699-56141-1-PB.pdf>> accessed 10 August 2025; Maarten Buiten, *The Law and Economics of AI Liability* (2023) 48 *Computer Law and Security Review*, 105794.

⁶⁶ Yue Liu, Qinghua Lu, Guangsheng Yu, Hye-Young Paik and Liming Zhu, ‘Defining Blockchain Governance Principles: A Comprehensive Framework’ (2021) arXiv <<https://arxiv.org/abs/2110.13374>> accessed 10 August 2025; Wei Ma, Chenguang Zhu, Ye Liu, Xiaofei Xie and Yi Li, ‘A Comprehensive Study of Governance Issues in Decentralized Finance Applications’ (2023) arXiv <<https://arxiv.org/abs/2311.01433>> accessed 18 March 2024.

⁶⁷ Daniel O Cajueiro, ‘A Comprehensive Review of Artificial Intelligence Regulation’ (2025) *ScienceDirect* <<https://doi.org/10.1016/j.smr.2025.100006>> accessed 2 July 2025.

⁶⁸ Claudio Novelli, Federico Casolari, Philipp Hacker, Giorgio Spedicato and Luciano Floridi, ‘Generative AI in EU Law: Liability, Privacy, Intellectual Property, and Cybersecurity’ (2024) arXiv <<https://arxiv.org/abs/2401.07348>> accessed 18 August 2025; Joseph Williams and Wilson Famy, ‘The Role of Smart Contracts in Legal and Regulatory Frameworks’ (2025) ResearchGate

<https://www.researchgate.net/publication/391497971_The_Role_of_Smart_Contracts_in_Legal_and_Regulatory_Frameworks> accessed 18 August 2025.

establish intent to enter into a contract, and the lack of doctrinal tools for allocating contractual legal effects determined by DsAI autonomous agents on an open, permissionless blockchain.

1.3 Existing Literature

Within the body of literature produced so far on the concepts of artificial intelligence, blockchain, and smart contracts, several works have become landmarks in their respective fields, whereas the specific intersection of DsAI system and its legal received only limited and fragmented attention. In the AI field, comprehensive frameworks on AI methodologies and applications have been established,⁶⁹ along with legal analyses addressing autonomy and accountability.⁷⁰ The blockchain literature is instead grounded in seminal technical articles describing decentralised ledger protocols,⁷¹ complemented by extensive studies on blockchain governance and regulatory implications.⁷² Regarding smart contracts, research includes both

⁶⁹ Stuart J Russell and Peter Norvig, *Artificial Intelligence: A Modern Approach* (4th edn, Pearson 2021); Sidra Nasir, Qamar Abbas, Samita Bai and Rizwan Ahmed Khan, 'A Comprehensive Framework for Reliable Legal AI: Combining Specialized Expert Systems and Adaptive Refinement' (2024) arXiv <<https://arxiv.org/abs/2412.20468>> accessed 7 August 2025; Danilo Ribeiro et al., 'Toward Effective AI Governance: A Review of Principles' (2025) arXiv <<https://arxiv.org/abs/2505.23417>> accessed 22 August 2025.

⁷⁰ Davit Nersessian and Ruben Mancha, 'From Automation to Autonomy: Legal and Ethical Responsibility Gaps in Artificial Intelligence Innovation' (2020) 27 Michigan Technology Law Review 341; Tianran Liu, 'Research on Legal Responsibility Attribution for Autonomous Systems: An AI Governance Perspective' (2024) 3(7) Science of Law Journal, 125.

⁷¹ Gabriel Axel Montes and Ben Goertzel, 'Distributed, Decentralized, and Democratized Artificial Intelligence' (2019) 141 Technological Forecasting and Social Change 354; Peterson K Ozili, 'Decentralized Finance Research and Developments around the World' (2022) 6 Journal of Banking and Financial Technology, 117; Primavera De Filippi and Aaron Wright (n. 63).

⁷² Eyo-Udo NL, Apeh CE, Bristol-Alagbariya B, Udeh CA and Ewim CP-M, 'The Evolution of Blockchain Technology in Accounting: A Review of Its Implications for Transparency and Accountability' (2025) 10(1) Account and Financial Management Journal 3467; Alesia Zhuk, 'Beyond

theoretical formulations and empirical analysis of their applications and limitations.⁷³ By contrast, legal research on DsAI systems is still in its infancy: most contributions focus primarily on the technical dimensions, while only a small but growing number of works are beginning to address their legal significance.⁷⁴ The reason behind is two-fold. Firstly, as already highlighted, the DsAI is still in its infancy, resulting in a shortage of academic contributions that specifically target the DsAI technology. Therefore, most of the existing research on DsAI systems focuses primarily on the technical aspects rather than the legal perspective.⁷⁵ Secondly, the understanding of the DsAI technical features and its applications in a decentralised framework certainly adds another layer of complexity to the effort of decoding its role from the legal stance. Therefore, the scope of this section is to provide a layout of the existing legal literature, shedding light on the current gaps surrounding the role

the Blockchain Hype: Addressing Legal and Regulatory Challenges' (2025) 5 11 SN Social Sciencesart, 1.

⁷³ Kevin Werbach and Nicolas Cornell, 'Contracts Ex Machina' (2017) 67 Duke Law Journal, 313; Larry A DiMatteo, Michel Cannarsa and Cristina Pongibò (eds), *The Cambridge Handbook of Smart Contracts, Blockchain Technology and Digital Platforms* (CUP 2019); Nick Szabo, 'Smart Contracts' (1994)

<http://www.fon.hum.uva.nl/rob/Courses/InformationInSpeech/CDROM/Literature/LOTwinterschool2006/szabo.best.vwh.net/smart_contracts_2.html> accessed March 2024.

⁷⁴ Mimi Zou, 'When AI Meets Smart Contracts: The Regulation of Hyper-Autonomous Contracting Systems' in Marcelo Corrales, Mark Fenwick and Helena Haapio (eds), *Contracts and Contracting in the Age of AI* (Springer 2023); Tomer Jordi Chaffer and others, 'Decentralized Governance of Autonomous AI Agents' (2024) arXiv <<https://arxiv.org/abs/2412.17114>> accessed 22 August 2025; Botao Amber Hu and others, 'Trustless Autonomy: Understanding Motivations behind Decentralized AI Agents' (2025) arXiv <<https://arxiv.org/abs/2505.09757>> accessed 22 August 2025.

⁷⁵ Zina Houhamdi and Belkacem Athamena, 'Multi-agent systems Collaboration in Open System' (2021) 18(3A, Special Issue) *The International Arab Journal of Information Technology*, 393; Yassine Himeur and others, 'Decentralized Artificial Intelligence (DAI): Taxonomy, Applications, Challenges and Future Directions' (2024) arXiv <<https://arxiv.org/abs/2412.17114>> accessed August 2025; Zeeshan Javed and others, 'Decentralized Artificial Intelligence: A Survey' (2023) *IEEE Access* 11 39300; Sakthi Kumaresh and K B Priya Iyer, 'Decentralised Artificial Intelligence Enabled Blockchain Network Model' (2021) 12 (10) *Turkish Journal of Computer and Mathematics Education*, 3797.

of DsAI in on-chain smart contract transactions. These gaps will lay down the foundation of the legal examination which is conducted throughout the thesis. Moreover, outlining the gaps will help in defining the central research question and its original contribution to the legal field.

Over the last 10 years, several legal aspects related to AI and blockchain have been studied in the legal research field. The literature reflected the evolving landscape of both AI and blockchain which led to one of the most rewarding technological sectors in the business market. Some of the most prominent areas of focus for both technologies include privacy and data protection, liability and responsibility, intellectual property, ethical and regulatory frameworks, data governance and transparency, anti-money laundering, employment, and labor law.⁷⁶ Notwithstanding these significant contributions, the implications of AI and blockchain continue to be studied largely in isolation without any relevant legal analysis on DsAI systems as a convergent phenomenon of these two fields. Therefore, the perspectives advanced in this thesis are not imported from a single tradition; rather, they derive from a necessary adaptation and merging of general theories drawn from adjacent fields: artificial intelligence law, blockchain and smart contract studies, and fundamental doctrines of contract law and private law on intention, legal capacity, legal personhood and agency. This interdisciplinary approach is currently the only one that allows for a coherent legal interpretation of the legal role of DsAI in the context of distributed contractual transactions.

Hence, from a general perspective and, as an example, it is possible to ground most of the developed legal theories about AI within two main different perspectives revolving around

⁷⁶ Sandra Wachter, Brent Mittelstadt and Luciano Floridi, 'Why a Right to Explanation of Automated Decision-Making Does Not Exist in the GDPR' (2017) *International Data Privacy Law* 7(2), 76; Kevin Werbach and Nicolas Cornell, 'Contracts Ex Machina' (2017) 67 *Duke Law Journal*, 313; Michèle Finck, 'Blockchains and Data Protection in the European Union' (2018) *EDPL* 4(1), 39–43; Stephan Larsson, 'The Socio-Legal Relevance of Artificial Intelligence' (2019) 103(3) *Droit et société*, 573; Michael Veale and Frederik Zuiderveen Borgesius, 'Demystifying the Draft EU Artificial Intelligence Act' (2021) *Internet Policy Review* 10(2); Antonio Aloisi and Valerio De Stefano, *Your Boss Is an Algorithm: Artificial Intelligence, Platform Work and Labour* (Hart/Bloomsbury, 2022); Eleonora Rosati, 'Infringing AI: Liability for AI-Generated Outputs under International, EU and UK Copyright Law' (2025) 16(2) *EJRR*, 603.

its nature and its role. A significant portion of this research employs a top-down approach, whereby normative conclusions are derived from existing legal categories and applied to AI systems without any substantial alteration of such theories. In the first approach, scholars deny the possibility to AI to be recognised as having any legal status whatsoever, considering AI systems as mere tools.⁷⁷ Consequently, they cannot be attributed any minimal legal capacity or personality comparable to that of natural persons or established legal entities.⁷⁸ In contrast, a bottom-up approach starts from the observable technical and functional characteristics of AI systems—such as autonomy, decision-making capacity, and interaction in legally relevant contexts—and examines whether these characteristics justify a recalibration of existing legal categories. In this case, the emphasis is not on incorporating AI into pre-existing legal frameworks, but on adapting those frameworks themselves to the operational realities of AI. Scepticism arises from the concept of unsuitability of AI systems to be considered as sentient beings, able to act accordingly to some sort of internal volition able to craft its own purpose. Neither, as stated, it would be possible for AI systems to be qualified as legal entities.⁷⁹ This is since AI lacks, unlike legal entities, the human background decision-making framework that ensures any legal act bounds the entity and its human representatives.⁸⁰ The core limitation of

⁷⁷ Roger Brownsword, 'Law, Technology, and Society: Reimagining the Regulatory Environment' in Roger Brownsword, Eloise Scotford and Karen Yeung (eds), *The Oxford Handbook of Law, Regulation and Technology* (OUP 2017), 3; Roger Brownsword, 'Law, Technology, and Society: Reimagining the Regulatory Environment' in Roger Brownsword, Eloise Scotford and Karen Yeung (eds), *The Oxford Handbook of Law, Regulation and Technology* (OUP 2017) 3; Lilian Edwards, 'Regulating AI and Robotics: Ethics by Design in a Digital Society' (2020) 2(1) *Italian Journal of Public Law*, 5.

⁷⁸ Andrea Bertolini, 'Robots as Products: The Case for a Realistic Analysis of Robotic Applications and Liability Rules' (2013) 5(2) *Law, Innovation and Technology* 214; Joanna J Bryson, Mihailis E Diamantis and Thomas D Grant, 'Of, for, and by the people: the legal lacunae of synthetic persons' (2017) 25 *Artificial Intelligence and Law*, 273.

⁷⁹ Abeba Birhane, Jelle van Dijk and Frank Pasquale, 'Debunking Robot Rights Metaphysically, Ethically, and Legally' (2024) arXiv <<https://arxiv.org/abs/2404.10072>> accessed 2 February 2025.

⁸⁰ Claudio Novelli, Luciano Floridi and Giovanni Sartor, 'AI as Legal Persons: Past, Patterns, and Prospects' (2024) <https://www.researchgate.net/publication/386205962_AI_as_Legal_Persons_Past_Patterns_and_Prospects> accessed 6 June 2025.

such approach is that it might be missing the impact of the legal effects that AI-based decisions can cause to social interactions or even to human-AI or AI-to-AI interactions.⁸¹ This approach, very much linked to the traditional legal frameworks, has the merit of being grounded on traditional legal doctrines and philosophies. However, as the AI technology advances towards a more sophisticated AI cognitive architecture – of which the DsAI systems are a perfect example- it might miss to decode some technological changes and translate them onto a more legal certainty. On the contrary, a few scholars have advocated for the recognition of a minimum legal status for AI systems, mostly based on capacity of some AI systems to be autonomous in their decision-making process and to disclose some intentions behind their action.⁸² as well as their capacity to act on behalf of other legal actors.⁸³ The main concern regarding the latter perspective is related to the question whether the autonomy of AI system is the necessary and sufficient element of being recognised as a legal subject. In other words, if the technological elements of increasing autonomy have implications also in the legal domain.⁸⁴ Even if not directly addressed in this thesis, one of these implications might directly relate to the liability and responsibility issues stemming from both such legal approaches. For instance, in the approach that recognises AI as having a minimum legal status the responsibility

⁸¹Francis Rhys Ward, ‘Towards a Theory of AI Personhood’ (2025) arXiv <<https://arxiv.org/abs/2501.13533>> accessed 20 August 2025.

⁸² Lawrence B Solum, ‘Legal Personhood for Artificial Intelligences’ (1992) 70 North Carolina Law Review 1231; Gunther Teubner, ‘Rights of Non-Humans? Electronic Agents and Animals as New Actors in Politics and Law’ (2006) 33 Journal of Law and Society, 497; Claudio Novelli, Giorgio Bongiovanni & Giovanni Sartor, ‘A conceptual framework for legal personality and its application to AI’ (2022) 13(2), 194; Carla L Reyes, ‘Autonomous Corporate Personhood’ (2021) 96 Washington Law Review, 1453.

⁸³ Samir Chopra and Laurence F White, *A Legal Theory for Autonomous Artificial Agents* (University of Michigan Press 2011); — Id., ‘Artificial Agents and the Contracting Problem: A Solution Via an Agency Analysis’ (2009) University of Illinois Journal of Law, Technology & Policy, 363.

⁸⁴ Gunther Teubner, ‘Rights of Non-humans? Electronic Agents and Animals as New Actors in Politics and Law’ (2006) 33 Journal of Law and Society, 497.

framework of AI might be different compared to the more traditional one.⁸⁵ Consequently, this might lead to different considerations also on what degree the human control over AI is relevant.⁸⁶ The conundrum lies in how the AI is going to be considered, a mere tool or something different. The legal debate is still ongoing. There is also a tension between the necessity to bring on the table of the legal debate also the philosophical, ethical, and moral discussions surrounding the role of AI and the need, at least, to not be much drowned to them.⁸⁷ This thesis acknowledges all such academic efforts to better understand AI with the intention to further discuss on both the legal approaches in relation to the DsAI field in the following Chapters. Moreover, this thesis will consider, under the lens of the decentralised AI field, the European Union approach to AI Regulation with the Artificial Intelligence Act (AI Act), adopted as a directly applicable regulation in 2024.⁸⁸ It is important to clarify that in this thesis, references to the EU Artificial Intelligence Act (AI Act) serve a primarily analytical function. The Act is treated as a lens for discussing the EU's *ex ante* risk-based market governance approach, not as a framework for addressing the private law issues at stake. Consequently, the AI Act is used to highlight the blind spots and regulatory gaps that arise in decentralised, permissionless environments in the context of sole-code smart contracts involving DsAI multi-agent systems. It is worthy of mentioning that the AI Act⁸⁹, after an

⁸⁵ Andreas Matthias, 'The responsibility gap: Ascribing responsibility for the actions of learning automata' (2004) 6 Ethics and Information Technology, 175; Shawn Bayern, 'The Implications of Modern Business-Entity Law for the Regulation of Autonomous Systems' (2015) 19 Stanford Technology Law Review, 93; Carla L Reyes, 'Autonomous Corporate Personhood' (2021) 96 Washington Law Review, 1453.

⁸⁶ European Parliament Resolution 2021/C 404/05 of 20 October 2020 with recommendations to the Commission on a civil liability regime for artificial intelligence [2020] 2020/2014(INL).

⁸⁷ Luciano Floridi, 'Establishing the Rules for Building Trustworthy AI' (2019) 568 Nature, 261.

⁸⁸ Regulation (EU) 2024/1689 of the European Parliament and of the Council of 13 June 2024 laying down harmonised rules on artificial intelligence (Artificial Intelligence Act) [2024] OJ L (published 12 July 2024) ELI <<http://data.europa.eu/eli/reg/2024/1689/oj>> accessed March 2025.

⁸⁹ Committee on the Internal Market and Consumer Protection Committee on Civil Liberties, Justice and Home Affairs 'Draft Compromised Amendments on the Draft Report of 16 May 2023 Proposal for a regulation of the European Parliament and of the Council on harmonised rules on Artificial

initial proposal of electronic personality for AI back in 2017⁹⁰, adopted instead a strategy that places people at the heart of the development of AI — human-centric AI.⁹¹ Therefore, the EU married a top-down legal approach at the core of which there is the protection human rights⁹² to ensure a safe and trustworthy AI space for people and companies.⁹³

As regards to blockchain and smart contracts fields, the legal literature mainly focuses on the implications of recognising smart contracts as legal contracts.⁹⁴ However, very few contributions have been found surrounding a specific type of smart contracts: the sole-code on-chain smart contract transactions.⁹⁵ The legal literature acknowledges the existence of these

Intelligence (Artificial Intelligence Act) and amending certain Union Legislative Acts’ (Draft Compromised Amendments) COM (2021)0206 – C9 0146/2021 – 2021/0106(COD).

⁹⁰ European Parliament resolution 2018/C 252/25 of 16 February 2017 with recommendations to the Commission on Civil Law Rules on Robotics [2017] OJ C 252/239.

⁹¹ European Commission, *On Artificial Intelligence - A European approach to excellence and trust* (COM (2020) 65 final) <https://commission.europa.eu/publications/white-paper-artificial-intelligence-european-approach-excellence-and-trust_en > accessed 8 May 2021.

⁹² European Commission, ‘Building Trust in Human-Centric Artificial Intelligence’ (Communication) COM (2019) 0168 <<https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52019DC0168>> accessed 7 May 2021.

⁹³ Ibid.

⁹⁴ Daniel Kraus, Thierry Obrist and Olivier Hari (ed), *Blockchains, Smart Contracts, Decentralised Autonomous Organisations and the Law: Perspectives of a Distributed Future* (Edward Elgar Publishing 2019); Mimi Zou, ‘When AI Meets Smart Contracts: The Regulation of Hyper-Autonomous Contracting Systems?’ in Martin Ebers, Cristina Poncibò and Mimi Zou (eds), *Contracting and Contract Law in the Age of Artificial Intelligence* (Hart Publishing 2022).

⁹⁵ Megan Ma, ‘Contracting in Code’ in Martin Ebers, Cristina Poncibò and Mimi Zou (eds), *Contracting and Contract Law in the Age of Artificial Intelligence* (Hart Publishing 2022); European Commission, ‘Smart contracts and the digital single market through the lens of a “law + technology” approach’ (Report) 2021 <<https://digital-strategy.ec.europa.eu/en/library/smart-contracts-and-digital-single-market-through-lens-law-plus-technology-approach>> accessed 19 June 2022.

kind of decentralised contracts as part of the blockchain transactions' landscape.⁹⁶ It must be considered that despite the effort of the legal literature in debating the legal aspects of smart contract transactions, the discussion is still ongoing. At the EU level, there is currently no regulation formally recognising smart contracts as a distinct category of legal contract. The closest point of contact, the Data Act, establishes the technical requirements for smart contracts used to carry out data-sharing agreements, but does not confer contractual status.⁹⁷ Conversely, regulatory initiatives have been adopted at EU domestic level. EU Member States, such as Italy, Greece and Malta have adopted expressed rules for smart contracts.⁹⁸ In the rest of the EU, smart contracts are generally assessed according to the principles of traditional contract law, without any specific legislation. Conversely, in England and Wales, authoritative guidelines confirm that smart contracts can constitute binding contracts under existing common law doctrine without legislative reform.⁹⁹ It is worth mentioning – even if not covered by this thesis - also the United States approach, where the federal Electronic Signature Act (ESIGN), along with state laws (UETA and specific statutes such as those of Arizona and Tennessee), ensure that a contract is not denied legal effect simply because its formation or

⁹⁶ Max Raskin, 'The Law and Legality of Smart Contracts' (2017) 1 *Georgetown Law Technology Review* 305; Michèle Finck, 'Smart Contracts as a Form of Solely Automated Processing under the GDPR' (2019) 9 *International Data Privacy Law*, 78.

⁹⁷ Regulation (EU) 2023/2854 of the European Parliament and of the Council of 13 December 2023 on harmonised rules on fair access to and use of data (Data Act) [2023] OJ L, 22 December 2023.

⁹⁸ Italy, Legge 11 febbraio 2019 n 12 (di conversione del Decreto-Legge 14 dicembre 2018 n 135), art 8-ter ('Tecnologie basate su registri distribuiti e smart contract') (GU Serie Generale n 36, 12 February 2019); Greece, Law 4961/2022 'Emerging information and communication technologies, strengthening digital governance and other provisions' (Government Gazette A' 146/27-07-2022); Malta, Virtual Financial Assets Act (Cap 590, Laws of Malta), s 2 (definition of 'smart contract').

⁹⁹ Law Commission (England and Wales), *Smart Legal Contracts: Advice to Government* (25 November 2021) <<https://lawcom.gov.uk/project/smart-contracts/>> accessed July 2023; UK Jurisdiction Taskforce, *Legal Statement on the Status of Cryptoassets and Smart Contracts* (2019) <https://technation.io/wpcontent/uploads/2019/11/6.6056_JO_Cryptocurrencies_Statement_FINAL_WEB_111119-1.pdf> accessed February 2021.

execution occurs through a smart contract.¹⁰⁰ Nonetheless, the EU Institutions developed several initiatives aiming at promoting the blockchain-based applications and smart contracts.¹⁰¹ One of the most important EU initiatives is certainly the Markets in Cryptoassets Regulation (MICAR)¹⁰² which focuses on the financial applications of blockchain-based transactions. Therefore, even if it does not regulate smart contracts and it is not directly relevant to the essence of this thesis, it is worthy to be mentioned across the research analysis in relation to the definition of digital assets as means by which throughout the use of smart contracts, it is possible to transfer rights and duties.¹⁰³ Therefore, to serve the scope of this thesis, the literature standpoint of recognising on-chain smart contracts as part of the legal contract framework shall be taken into account. Such approach will be deeply investigated in

¹⁰⁰ Electronic Signatures in Global and National Commerce Act (ESIGN), 15 USC § 7001(a), (h) (Cornell LII); Uniform Electronic Transactions Act (UETA) — adoption status: DLA Piper, ‘With Illinois’s adoption of UETA, United States near full adoption’ (14 July 2021) <<https://www.dlapiper.com/en/insights/publications/2021/07/with-illinoiss-adoption-of-ueta-united-states-near-full-adoption>> accessed March 2024; Arizona Revised Statutes § 44-7061(D) <<https://www.azleg.gov/ars/44/07061.htm>> accessed March 2024; Tennessee SB1662 (2018), ch 591, § 1 (codified in Tenn Code Ann § 47-10-201 et seq) <<https://www.capitol.tn.gov/Bills/110/Bill/SB1662.pdf>> accessed March 2024.

¹⁰¹ European Parliament Resolution 2020/C 11/02 of 3 October 2018 Distributed ledger technologies and blockchains: building trust with disintermediation [2020] C 11/7. Also, see European Commission, ‘Regulation of The European Parliament and of The Council on a pilot regime for market infrastructures based on distributed ledger technology’ (Proposal) COM(2020) 594 final; EU Blockchain Observatory Forum Report on Smart Contracts <https://www.eublockchainforum.eu/sites/default/files/reports/SmartContractsReport_Final.pdf> accessed 19 September 2022.

¹⁰² European Parliament legislative resolution of 20 April 2023 on the proposal for a regulation of the European Parliament and of the Council on Markets in Crypto-assets and amending Directive (EU) 2019/1937 (MiCA) [2019] (COM (2020)0593 – C9-0306/2020 – 2020/0265(COD)).

¹⁰³ Regulation (EU) 2023/1114 of the European Parliament and of the Council of 31 May 2023 on markets in crypto-assets (MICAR) and amending Regulations (EU) No 1093/2010 and (EU) No 1095/2010 and Directives 2013/36/EU and (EU) 2019/1937 [2023] OJ L 150/40.

the following chapters as regards the applicability of contract law principles from European, Common law and Civil law traditions perspectives.

1.4 Identified Gaps

The literature review highlights several knowledge gaps that this thesis aims to address. First, there is a lack of systematic study on the legal role of (DsAI) systems in smart contract transactions. Although the debate on AI's capacity, agency, and personhood is extensive, it primarily concerns centralised AI models and does not address the specific case of DsAI operating in decentralised contractual environments. Second, no research has yet analysed the legal implications of DsAI when it acts as an initiator or mediator of on-chain transactions. The technical literature recognises the autonomy of multi-agent DsAI systems, but legal scholarship has yet to explore how this decision-making autonomy translates into legally relevant conduct within sole-code smart contracts. A particularly neglected question concerns whether DsAI systems can be considered to have the legal capacity to enter into binding agreements, or rather a form of contractual intentionality manifested through their conduct. Third, there is a lack of studies on the interaction between multi-agent DsAI systems and smart contracts from a legal perspective. In particular, no investigation has yet examined whether DsAI multi-agent systems may possess legal capacity or manifest the intention to be bound when they autonomously form transactions that create or transfer digital rights and obligations. Fourth, in the context of open and permissionless blockchains, a regulatory framework clarifying the roles of DsAI systems is lacking. Existing theories tend to characterise AI as a product or service, categories that are inadequate for dynamic and evolving systems like DsAI, whose technical characteristics and social impacts vary depending on the application context. Finally, the literature has not yet explored the potential legal implications of recognising DsAI systems' conduct as a source of binding legal effects, both in civil law and common law traditions.

By aiming at filling these gaps, this thesis' purpose is to develop an integrated framework capable of explaining the legal role of DsAI in decentralised contractual transactions,

overcoming the fragmented debates that have so far treated AI and blockchain as separate phenomena.

1.5 Central Research Question and Themes

Considering the identified gaps, this thesis focuses on exploring the legal role of DsAI systems as initiators and mediators of blockchain-based transactions. Specifically, the central research of this thesis is whether Decentralised AI multi-agent systems can be recognised as an autonomous functional legal subject, possessing a form of artificial agency and endowed with independent legal capacity to enter into contracts.

At the heart of this investigation lies a series of crucial questions: Can a DsAI system exercise contractual capacity or manifest legally relevant intention to contract when operating through sole-code smart contracts that could themselves potentially be classified as legal contracts? To what extent does the autonomous decision-making of DsAI systems influence these legal interactions, especially when their behaviour determines the transfer of rights and duties between counterparties? These issues will be systematically addressed through the Paradigm of Autonomous Behaviour (PAB), developed in this thesis as a tool for assessing when technical autonomy becomes legally relevant.

In light of the critical issues already highlighted, the fundamental question concerns the possibility of attributing legal relevance to the decisions and behaviours of DsAI in sole-code contracts. The characteristics of decision-making autonomy, independence from continuous human oversight, and the ability to act as an initiator or mediator of transactions in decentralised environments raise profound questions about the legal characterisation of such behaviours¹⁰⁴: whether they should be considered mere executions on behalf of external

¹⁰⁴ Daniel Trusilo, ‘Autonomous AI Systems in Conflict: Emergent Behavior and Its Impact on Predictability and Reliability’ (2023) 14(1) *Journal of Military Ethics* 2; Primavera De Filippi and Aaron Wright, *Blockchain and the Law: The Rule of Code* (Harvard University Press 2023) 32–34; UK Government, *International Scientific Report on the Safety of Advanced AI: Interim Report* (Department for Science, Innovation and Technology

parties, thus falling within the agency framework, or as the autonomous expression of an internal process of DsAI, capable of demonstrating a form of contractual intentionality and legal capacity.¹⁰⁵ In this regard, this research aims to clarify whether and under what conditions autonomous and distributed algorithmic behaviours can translate into legal effects attributable to DsAI itself.

Therefore, this thesis examines the key legal challenges raised by the role of Decentralised Artificial Intelligence (DsAI) systems in sole-code smart contract transactions, focusing on issues of contractual capacity, legal intent, agency, and attribution of legal effects in decentralised environments. It questions the applicability of traditional private law doctrines—developed for human actors and conventional legal entities—to the autonomous and distributed operation of DsAI. In response, the research proposes a conceptual framework for assessing the legal role of DsAI systems in such transactions, outlining the conditions under which their conduct can be recognised as legally relevant, while remaining consistent with established institutional legal frameworks in both the civil and common law traditions.

Hence, the purpose of this thesis is twofold. First, it examines whether traditional legal doctrines—on capacity, contractual intent, agency, and personality—can be meaningfully applied to DsAI systems in sole-code smart contracts. Second, it highlights the gaps and frictions that emerge in this application and proposes a structured theoretical framework (the autonomous behaviour paradigm and the theory of functional legal subjectivity).

Throughout the central research question other multiple themes are broken down and explored for each of the three overlapping areas of investigation related to the DsAI field (see Fig. 1.5). Since the DsAI systems are the result of the merging of AI and blockchain sectors,

2024) <https://assets.publishing.service.gov.uk/media/6716673b96def6d27a4c9b24/international_scientific_report_on_the_safety_of_advanced_ai_interim_report.pdf> accessed 20 April 2025

¹⁰⁵ Anton Wahrstätter, Sajjad Khan and Davor Svetinovic, ‘OpenFL: A Scalable and Secure Decentralized Federated Learning System on the Ethereum Blockchain’ (2024) 26 Internet of Things 101174; Felix Härer, ‘Towards Interoperability of Open and Permissionless Blockchains: A Cross-Chain Query Language’ (2022) arXiv preprint <arXiv:2209.08866> accessed 6 May 2024.

all these three areas of investigation will emerge during the legal analysis across the entire thesis.

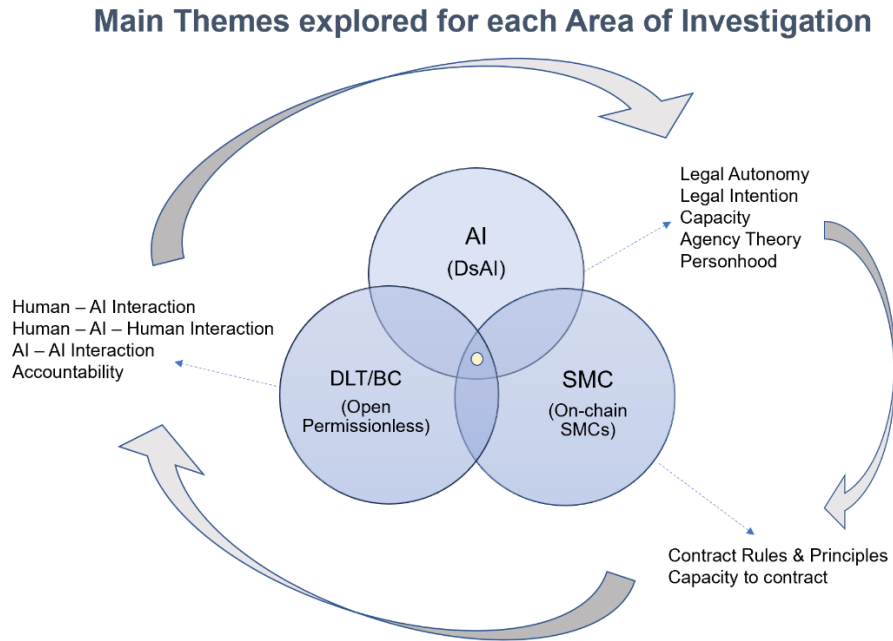


Fig. 1.5 Main Themes explored

In relation to the AI area of investigation, different themes will arise. First, establishing different levels or degrees of autonomy in DsAI decision-making process can somehow influence the recognition of a legal autonomy for the DsAI? It is necessary to ground the legal analysis around the role of DsAI to the concept of autonomy and intentions. This thesis shall examine the concept of autonomy and intentions in DsAI agents, as reckoned as originators of their own decisions and actions, across both the technical and legal side. This thesis will adopt a graded autonomy method to quantify the level of autonomy and control in DsAI systems to differentiate high from a low regime. The nuanced spectrum of autonomy observed in AI agents requires careful legal assessment, as each level may warrant a distinct recognition of legal capabilities and responsibilities. This understanding is crucial to developing a coherent framework for assessing the role of DsAI systems in decentralised and contractual environments. In such a context, the ‘Paradigm of Autonomous Behaviour’ (PAB) method will be developed aiming at answering such question. Second, would autonomy and intentions be enough to recognised DsAI as having a legal capacity and capacity to contract, and to what

extent? The question is pivotal being DsAI a system, not a software, which operates as a unity of actions. Thus, the traditional legal concepts of legal subjectivity, legal capacity, legal personhood and agency will be investigated in the context of the decentralised environment where there is not a unique source of legal rights and duties.

As regards the second area of analysis, which involves the on-chain smart contracts, the main theme revolves around whether on-chain sole-code smart contracts can be considered legal contracts. The main scope of this area of analysis is to establish the perimeter of influence in the contractual capacity and contractual intention between natural or legal persons and the DsAI system to understand the potential application of legal capacity, legal subjectivity and the legal agency theory.

The third area of investigation relates to the broader blockchain environment in which the DsAI operates, the open-permissionless field. Such domain must be considered as its features influence the dynamics of interactions in which the DsAI operates. Thus, the main theme of this area relates with the challenges associated with the interactions that take place in such decentralised environment. As shown in Fig 1.6, such interactions might regard not only human-to-human interactions but also human-to-AI or even AI-to-AI interactions in which the DsAI functions as transaction initiator or mediator.

Therefore, for the purpose of answering the central research question, different themes will be analysed, representing the backbone of the overall legal discussion. All the presented themes will contribute to the analysis of the legal role of DsAI systems across all the three interrelated areas of investigation whereby the Decentralised AI is developed. In doing so, this thesis not only clarifies the doctrinal frictions raised by DsAI in contract law but also advances a new conceptual framework that reconciles decentralised technologies with established doctrines of private law.

1.6 Research Methodology

This section discusses the chosen research methodology, and the approaches employed to underpin the arguments presented in this thesis.

1.6.1 Legal Theory and Doctrinal Research

This thesis will primarily involve an analysis of legal concepts and principles in relation to DsAI systems. This includes a critical analysis of the traditional theories that support such legal principles. Doctrinal research refers to a research approach that examines legal propositions by analysing existing statutory provisions and case laws using logic and reasoning.¹⁰⁶ It entails the analysis of case law, organising and systematising legal principles, and studying legal institutions. However, it goes beyond that—it also contributes to the creation of law through legal reasoning and rational deductions.¹⁰⁷ Thus, the essential scope of such analysis is directly related to the possibility of testing theories based on a deductive methodology.

In conducting research for this thesis, both primary and secondary sources have been employed. At the EU level, the primary resources include Regulations, Directives, Decisions, Opinions and Recommendations alongside well-established common-core principles like the Principles of European Contract Law (PECL).¹⁰⁸ PECL models will serve to better define the applicable principles to the cross-border nature of smart contract transactions. Finally, at domestic level, statutes and regulations will be mentioned in relation to the concepts of legal personhood, legal capacity, and contractual intention. Since this research involves Decentralised AI systems, unfortunately no case law about these AI systems have been developed so far which can be mentioned.

For the purposes of this thesis, secondary sources were particularly important, not only in the legal field but also in providing essential interdisciplinary perspectives. The research draws on manuscripts and scholarly contributions from the fields of technology, law, and cognitive science. Interaction with these diverse areas of study was crucial in shaping a nuanced understanding of the decision-making processes of decentralised AI, the technical

¹⁰⁶ Chunuram Soren, 'Legal Research Methodology: An Overview' (2021) 8(10) JETIR d442.

¹⁰⁷ Ibid, d453.

¹⁰⁸ Principles of European Contract Law (PECL) 2002.

architecture of blockchain systems, and the cognitive models relevant to assessing autonomy and intentionality.

This deliberate integration of sources external to the discipline of legal scholarship is a key element of the thesis's original contribution. By incorporating insights from computer science, distributed systems engineering, and cognitive modelling, the research bridges the gap between technical realities and legal conceptualisation, ensuring that proposed frameworks, such as the Paradigm of Autonomous Behaviour (PAB) and the Functional Legal Subjectivity (FLS), are grounded in both doctrinal rigor and technological plausibility. Moreover, this thesis benefitted immensely from published articles in various international journals relating to AI, blockchain and smart contracts alongside international and domestic legal reports, websites and blogs. Other secondary sources employed in this research include conference and research papers on DsAI systems as well as other Ph.D. thesis and newspaper articles, all provided context, practical examples, and critical perspectives that enrich the legal analysis.

1.6.2 Comparative Research

It has been stated that comparison is the formation of relations of similarities or differences between distinct matters of fact.¹⁰⁹ Thus, seeking common or dissimilar characteristics is the essence of comparison.¹¹⁰ In the legal analysis, the comparative methodology is applied whenever the researcher compares different legal systems with the purpose of informing the legal discussion. In particular, the use of comparative law in the study of blockchain has already been explored in legal scholarship, confirming the relevance of this

¹⁰⁹ Jansen, 'Comparative Law and Comparative Knowledge' in Mathias Reimann and Reinhard Zimmerman (eds.), *The Oxford Handbook of Comparative Law* (Oxford University Press, Oxford, 2006).

¹¹⁰ Bhat, P. Ishwara, 'Comparative Method of Legal Research: Nature, Process and Potentiality' (2015) 57(2) *Journal of the Indian Law Institute*, 147.

methodology for emerging technologies, thus providing a suitable basis for extending the investigation to decentralised artificial intelligence systems in sole-code smart contracts.¹¹¹

In this thesis, the analytical and common-core method will be applied.¹¹² The analytical method involves comparing legal concepts and categories across different legal systems. It aims to identify similarities and differences in the way legal concepts are defined and applied. The common-core methods, instead, focuses on the similarities between legal systems, particularly in areas where they share common legal concepts, such as contract law or property law. It aims to identify a ‘common core’ of legal principles that underlies different legal systems.

The analytical method shall be applied to compare similarities and differences between the Civil Law and the Common Law legislation around the contract law principles. A specification of which legal systems are going to be compared is necessary. This thesis’ choice is to focus only on European legal traditions. Given that civil law and common law traditions span a wide range of jurisdictions globally, making universal comparisons beyond the scope of this research, the focus will be on European legal traditions for two reasons. First, the European Union is the main regulatory context in which the legislation related to blockchain and artificial intelligence relevant to this thesis is currently developing, making it a natural point of reference. Second, this choice allows for a more coherent comparison, grounded in shared historical and institutional frameworks, while still capturing significant doctrinal and procedural differences between the various legal families. Within this European focus, the primary comparative axis is between Italy, representing the civil law tradition, and England and Wales, representing the common law tradition. Italy was selected for its explicit legislative recognition of blockchain-based smart contracts¹¹³ and for the depth of its doctrinal treatment

¹¹¹ Cristina Poncibò, ‘Blockchain in Comparative Law’ in Benedetta Cappiello (ed), *Blockchain, Law and Governance* (Springer 2020), 137.

¹¹² Mark Van Hoecke (ed), *Methodologies of Legal Research: Which Kind of Method for What Kind of Discipline* (Bloomsbury Publishing 2011).

¹¹³ Legge 11 February 2019, n 12, Conversione in legge, con modificazioni, del decreto-legge 14 Dicembre 2018, n 135, recante disposizioni urgenti in materia di sostegno e semplificazione per le imprese e per la pubblica amministrazione, art 8-ter.

of private law concepts such as legal and contractual capacity as well as legal personhood and legal subjectivity. England and Wales were chosen for its authoritative and influential guidance on the legal status of smart contracts¹¹⁴, offered without the need for legislative reform, as well as for its distinctive common law approach to legal capacity, personhood and contractual capacity. Occasional references to other European jurisdictions will inform the analysis when needed.

At the same time, the common-core method will be used to investigate the applicability of fundamental principles of contract law at European level, with particular reference to the Principles of European Contract Law (PECL)¹¹⁵. This dual-level comparison is particularly useful for assessing whether these principles can be meaningfully applied to smart contracts, whose distinctive feature is the cross-border and decentralised nature of transactions. The scope of this comparison is to study the applicability of these concepts to DsAI systems to find a common ground from which it will be possible to develop a new approach to assess and regulate their role.

1.6.3 Theoretical Lineage of Functional Legal Subjectivity: Doctrinal and Jurisprudential Roots

The theoretical framework proposed in this thesis to address the central research question does not emerge from a conceptual vacuum. The concept of Functional Legal Subjectivity (FLS) draws on a plurality of doctrinal traditions and jurisprudential lineages that, while not developed with decentralised AI in mind, offer the structural materials from which a legally coherent account of non-human functional agency can be constructed. Although these theoretical strands are engaged throughout the body of the thesis, and examined in depth in

¹¹⁴ UK Jurisdiction Taskforce Legal Statement 2019; Law Commission Advice 2021.

¹¹⁵ Ole Lando and Hugh Beale (eds), *Principles of European Contract Law, Parts I and II* (Kluwer Law International 2000); Ole Lando, Eric Clive, André Prüm and Reinhard Zimmermann (eds), *Principles of European Contract Law, Part III* (Kluwer Law International 2003).

Chapter 2, Chapter 5, and Appendix B, it is useful, for the purposes of analytical clarity and readability, to map their doctrinal provenance explicitly at the outset.

The first foundational strand derives from the normativist tradition in legal theory. The most systematic elaboration of this tradition establishes that legal personhood is not a pre-legal or ontological datum but a normative attribution: a technical construct through which a legal system concentrates a set of rights, duties, and liabilities at a defined point of attribution.¹¹⁶

Legal persons, on this account, are defined as personifications of a set of legal norms; their existence and boundaries are determined entirely by the purposes of the legal order. This normativist architecture provides the principal theoretical warrant for the thesis's claim that a form of legal subjectivity can be constructed to address the novel operational reality of decentralised AI systems, without requiring prior metaphysical recognition of their status. If personhood is a normative construct rather than a natural fact, then the question of whether DsAI systems can possess a form of subjectivity is resolved by asking whether such recognition serves a coherent legal purpose, and not by asking whether the DsAI possesses consciousness, will, or moral agency. A complementary perspective within this tradition conceptualises legal capacity as a status conferred by secondary rules of recognition within a social practice: legal standing is a matter of how the legal system classifies conduct for normative purposes, and such classifications are revisable wherever the social practice that sustains them undergoes structural change.¹¹⁷

¹¹⁶ Hans Kelsen, *Pure Theory of Law* (Max Knight tr, University of California Press 1967), 163–176. For Kelsen, the legal person is the personalisation of a bundle of norms: its existence and boundaries are determined entirely by the purposes of the legal order, not by any pre-legal ontological quality. This normativist account provides the primary theoretical warrant for the thesis's claim that a new form of legal subjectivity can be constructed to address the operational reality of DsAI systems without requiring prior metaphysical recognition of their status.

¹¹⁷ HLA Hart, *The Concept of Law* (3rd edn, OUP 2012), 79–91, 100–110. Hart's account emphasises that legal status is conferred through secondary rules of recognition rather than through any metaphysical test. Legal categories are instruments of a social practice and may be extended or adjusted where the purposes they serve demand it.

The second strand is the institutionalist and functionalist tradition in jurisprudence. A purposive conception of law and the institutional theory of law developed within this tradition share the premise that legal concepts are purpose-relative artefacts, valid to the extent that they serve the ends of the normative system that employs them.¹¹⁸ Within this framework, legal personhood is described as an ‘institutional fact’, a concept constituted by the rules and practices of a legal institution rather than by any extra-legal criterion. This functionalist logic runs throughout this thesis: the Functional Legal Subjectivity model does not purport to represent a metaphysical truth about the nature of the DsAI but rather to offer a juridically applicable instrument for managing the legal effects that DsAI systems already produce in practice. The model is, in this sense, deliberately instrumental.

The third strand, closely connected to the second, is the disaggregative or ‘bundle of rights’ account of legal personhood developed in contemporary legal philosophy. A Hohfeldian analysis advanced within this literature demonstrates that legal personhood is not a unitary, all-or-nothing status but a composite of distinct normative ‘incidents’, rights, powers, privileges, immunities, and their correlatives, that the legal system can allocate separately and in different combinations to different entities.¹¹⁹ This account is theoretically indispensable for understanding how Functional Legal Subjectivity operates. Functional Legal Subjectivity does not purport to confer on DsAI systems the full ‘bundle’ of incidents associated with natural or

¹¹⁸ Lon L Fuller, *The Morality of Law* (rev edn, Yale University Press 1969), 33–38; Neil MacCormick, *Institutions of Law: An Essay in Legal Theory* (OUP 2007), 27–54. MacCormick describes legal personality as an institutional fact, a concept constituted by the rules and practices of a legal institution rather than by any extra-legal criterion, whose content is determined by the institutional context in which it operates, an insight directly applicable to the novel context created by decentralised blockchain environments.

¹¹⁹ Visa AJ Kurki, *A Theory of Legal Personhood* (OUP 2019), 19–56. Kurki develops a Hohfeldian analysis of legal personhood as a bundle of incidents, rights, powers, privileges, immunities and their correlatives, that can be allocated to different entities in different combinations, demonstrating that full legal personality is not a binary status and that partial or functional forms of legal recognition are theoretically coherent. *See also* Wesley N Hohfeld, ‘Fundamental Legal Conceptions as Applied in Judicial Reasoning’ (1913) 23 Yale LJ 16.

legal persons. It attributes to them only a limited and context-specific subset of normative ‘incidents’ specifically, the functional capacity to act as the originating source of contractual legal effects within the decentralised environment defined by sole-code smart contracts. In this sense, this framework shows that this is not an analytically incoherent half-measure but a structurally and context-dependant legitimate form of partial legal recognition.

The fourth theoretical root is the inferentialist approach to legal concepts developed in the field of AI and law. The conceptualisation of legal categories as ‘inferential nodes’, namely bridges between factual preconditions and legal consequences, directly illuminates the structural logic of the Paradigm of Autonomous Behaviour-to-Functional Legal Subjectivity progression.¹²⁰ In this thesis, the Paradigm of Autonomous Behaviour (PAB) functions precisely as the factual precondition that triggers the legal consequence of functional subjectivity: once a DsAI system satisfies the PAB threshold, the legal system is given the criteria to treat its conduct as legally attributable to it as a functional subject. The inferentialist framework thus grounds the formal architecture of the thesis in an established tradition of jurisprudential analysis.

A fifth and complementary doctrinal lineage derives from systems-theoretical accounts of legal evolution. The autopoietic theory of law holds that the legal system creates new categories of legal subjects as it co-evolves with social and economic systems, adapting its own internal logic in response to structural transformations in the wider society.¹²¹ Teubner's

¹²⁰ Giovanni Sartor, ‘Legal Concepts as Inferential Nodes and Ontological Categories’ (2009) 17 *Artificial Intelligence and Law* 217, 220–222. Sartor conceptualises legal categories as nodes within a network of normative inferences: a concept such as contractual capacity functions as a bridge between factual preconditions (conduct, autonomy, production of legal effects) and legal consequences (enforceability, attribution of obligations). This structure is directly operative in the PAB-to-FLS progression, where measured technical autonomy constitutes the factual precondition triggering the legal consequence of functional subjectivity.

¹²¹ Günther Teubner, ‘Enterprise Corporatism: New Industrial Policy and the Essence of the Legal Person’ (1988) 36 *Am J Comp L* 130, 132–135; Günther Teubner, *Law as an Autopoietic System* (Anne Bankowska and Ruth Adler trs, Blackwell 1993) 35–68. Teubner's autopoietic account holds that the legal system generates new categories of legal subject as it co-evolves with social and economic

account suggests that the emergence of decentralised AI as a new type of autonomous actor within socially and economically significant transactions is precisely the kind of structural transformation that warrants the adaptive extension of legal subjectivity. This is not a rupture with tradition but a continuation of the law's historical capacity to produce new categories of legal subject, from corporations to unincorporated associations, in response to changing social realities.

The doctrinal and jurisprudential lineage of the Functional Legal Subjectivity model is, finally, supported by concrete legal precedents from both the European common law and civil law traditions, namely the United Kingdom, Ireland, and Italy as the three primary legal systems engaged in this thesis's comparative analysis. In the United Kingdom, the foundational House of Lords authority on separate legal personhood stands as the leading proposition that such personhood is a functional legal construct, attributable to non-natural entities where this serves a coherent normative purpose.¹²² The recognition of corporate personhood established by that decision demonstrates that the legal system may attribute legal subjectivity to an artificial collective unit, a company, even where the underlying economic reality involves a single natural person. The functionalist reasoning is precisely the same as that deployed by the Functional Legal Subjectivity model in relation to DsAI: what matters is not the ontological character of the entity but the normative utility of treating it as the attributable source of legally significant conduct.

systems, undergirding the thesis's argument that the emergence of DsAI constitutes a structural transformation warranting the adaptive extension of legal subjectivity without formal legislative intervention.

¹²² *Salomon v Salomon & Co Ltd* [1897] AC 22 (HL). The House of Lords' recognition of corporate personality as a functional device, operative irrespective of the underlying economic reality, establishes the foundational precedent that the legal system may attribute subjectivity to non-natural entities where this serves a coherent normative purpose; the same functionalist logic underlies the FLS model in relation to DsAI. See also *Prest v Petrodel Resources Ltd* [2013] UKSC 34, [2013] 2 AC 415 [8]–[18] (Lord Sumption), confirming the purposive and functional character of corporate personality within English law. This decision reinforces the approach, confirming the purposive and functional character of corporate personality within the English legal system.

In Irish law, two significant decisions confirm that Irish courts have consistently recognised the legal standing of entities lacking full formal personhood, including unincorporated associations, where their functional role within legal relations warrants such recognition.¹²³ These precedents demonstrate that the functional approach to legal subjectivity is not a theoretical novelty but a practically tested legal technique already operative within the Irish legal system.

In Italian law, the Corte di Cassazione, Sezioni Unite, established in a landmark decision that unincorporated associations (*associazioni non riconosciute*) enjoy legal subjectivity under Articles 36–38 of the Codice Civile, notwithstanding the absence of formal legal personality.¹²⁴ The Sezioni Unite’s reasoning, that legal subjectivity follows from the entity’s stable functional role within legal relations, rather than from its formal recognition by law, is directly analogous to the approach adopted in this thesis. The Italian experience thus constitutes a concrete precedent within a major civil law jurisdiction for the proposition that legal subjectivity and formal legal personality are distinct and separable concepts, and that the former may be recognised independently of the latter wherever the functional realities demand it.

Taken together, these theoretical traditions and legal precedents demonstrate that the Functional Legal Subjectivity model is not an ad hoc innovation but the convergence of several

¹²³*Re Frederick Inns Ltd* [1994] 1 ILRM 387 (SC), affirming in the Irish context the functional basis of separate legal personality and recognising that the legal system may adapt formal classifications where functional realities demand it; *Dublin 8 Residents Association v An Bord Pleanála* [2022] IEHC 482 (Humphreys J), recognising the legal standing of an unincorporated residents’ association for planning purposes on functional grounds, confirming the Irish courts’ acceptance of purpose-sensitive conceptions of legal subjectivity independently of formal legal personality.

¹²⁴ Cass civ, sez un, 20 febbraio 1995, n 1715, Foro it 1995, I, 1202. The Sezioni Unite recognised that unincorporated associations (*associazioni non riconosciute*) enjoy legal subjectivity under artt. 36–38 Codice Civile despite the absence of formal legal personality, on the basis of their stable functional role within legal relations, a direct precedent for the thesis’s functional approach in the Italian civil law tradition.

independently established doctrinal trajectories.¹²⁵ Its theoretical architecture is grounded in Kelsenian normativism, MacCormickian institutionalism, Hohfeldian disaggregation, Sartorian inferentialism, and Teubnerian autopoiesis. Its practical credentials are supported by a consistent line of jurisprudence from three European legal systems. Throughout the thesis, the following chapters develop the Functional Legal Subjectivity model in detail, deploying these theoretical resources to construct a coherent and practically operative legal response to the challenges posed by decentralised AI systems in sole-code smart contract transactions.

1.7 Originality and Contribution to Existing Knowledge

Although there is no shortage of legal literature on artificial intelligence, recent and systematic research on Decentralised AI (DsAI) systems and their role in on-chain smart contract transactions remains largely overlooked. The DsAI represents one of the most cognitively advanced forms of AI, yet a thorough and targeted analysis of the specificities this technology introduces into legal relationships is lacking. Most current contributions tend to address the legal issues of AI by applying traditional institutional categories (legal capacity, subjectivity, liability) in a generalised and often abstract manner, without adequately differentiating between the different types of AI.

This approach has two critical consequences: first, it produces generic solutions that struggle to adapt to the variety of AI systems, which are not static products or one-off services, but dynamic systems characterised by a multitude of changing technical features and variable behaviours depending on the operating context. On the other hand, it generates a dissonance between the legal categories applied and the concrete situations in which AI systems operate. This creates a particularly evident research gap for DsAI systems, whose operation in a blockchain environment introduces unique elements that impact the dynamics of legal interactions.

¹²⁵ Rafael Dean Brown, 'Property Ownership and the Legal Personhood of Artificial Intelligence' (2020) 30 2 Inf & Comms Tech L, 1; Nadia Banteka, 'Legally Constructed Persons' (2021) 58 Huston Law Review, 537; Shawn Bayern, *Autonomous Organizations* (Cambridge University Press 2021), 55–80.

To fill this gap, this thesis adopts a bottom-up approach. First, it aims to identify and analyse the main technical features that characterise DsAI systems, along with the peculiarities of the decentralised and permissionless environment in which these systems operate. Second, based on this technical analysis, the thesis examines the validity and limits of traditional legal categories (legal capacity, subjectivity, personhood) when applied to a decentralised and dynamic multi-agent system, proposing alternative solutions where necessary.

This approach has a twofold consequence. On the one hand, it highlights the substantial differences between DsAI systems and other forms of AI, differences that can decisively impact their legal classification and relevance. On the other hand, it allows for a more precise legal assessment of the role of DsAI agents as initiators and mediators of decentralised transactions, potentially impacting both the doctrinal debate and the operational practices of industrial and commercial sectors already active in this field.

Therefore, this thesis aims at contributing to the existing literature in three complementary directions. First, it introduces original analytical tools: the Paradigm of Autonomous Behaviour (PAB) and Functional Legal Subjectivity (FLS) that allow for a systematic connection between the technical characteristics of DsAI systems and their potential legal consequences. Second, it offers a comparative analysis of the most relevant private law concepts applicable to the DsAI context under the lens of both civil law and common law traditions as well as under European PECL, thus filling a doctrinal and interpretative gap. Third, it highlights the regulatory gaps of current instruments, particularly the European Union's AI Act, which fails to consider the decentralised and permissionless dynamics inherent to DsAI systems. It highlights the practical relevance of these omissions for emerging sectors such as decentralised finance, DAOs, and cross-chain transactions. Taken together, these contributions offer both a conceptual framework and a normative critique of existing categories, advancing the debate on how legal theory and regulation should adapt to the realities of decentralised AI.

1.8 Limitations of the Study

This thesis has limitations. The first one is recognised within the legal frameworks themselves. Such limitations may arise from the existing legal frameworks, which might not adequately address the unique characteristics and challenges posed by decentralised AI systems. This can make it challenging to assess and determine a definitive preposition about the legal role of DsAI systems within the current legal framework.

A second limitation is the evolving nature of AI and blockchain domains. Decentralised AI systems are constantly evolving, and their capabilities and functionalities change over time. The study may face limitations in capturing the dynamic nature of these systems and their impact on legal recognition. Another identified limitation lays in the interpretation and jurisdictional variations. The interpretation and application of legal concepts such as legal capacity and personhood can vary across jurisdictions. The study may be limited in providing a comprehensive analysis across different legal systems and jurisdictions.

Furthermore, this thesis acknowledges that ethical, moral and philosophical considerations may arise in the legal discussion on the role of DsAI systems. The debate around the legal capacity, subjectivity and personhood in relation to decentralised AI systems involves such considerations. Therefore, the study faces limitations in addressing these implications and debates surrounding this topic. A significant limitation of this study lies in the challenge of balancing the technical and the legal dimensions of the research. Identifying the appropriate extent of technical information to be integrated into a legal thesis and translating such content into legally meaningful concepts has proven to be a particularly complex task. Inevitably, certain methodological choices had to be made in order to preserve coherence and clarity of the legal analysis, and this may have constrained the depth with which some technical aspects were addressed. While this thesis endeavoured to address the most pressing legal challenges raised by DsAI systems and sole-code smart contracts, it was not possible to exhaustively assess every potential argumentative angle or theoretical perspective. Some aspects have been left outside the scope of the analysis to maintain coherence and focus on the central research question. As the contours of the field are still evolving, future scholarship may expand upon or refine the boundaries set in this study.

Additionally, there is lack of precedents. Due to the relatively new nature of decentralised AI systems, there is a lack of legal precedents or established case law to rely on. This can limit the study's ability to draw definitive conclusions or provide clear guidelines. A final note on this research limitations is the interdisciplinary complexity. The study of legal capacity, contractual intention and personhood in decentralised AI systems requires interdisciplinary analysis, involving legal, technological, cognitive science and philosophical perspectives. The complexity of integrating these different disciplines presented many challenges and constraints within the development of this work.

1.9 Setting the Scene: Technical and legal Context for DsAI Systems

1.9.1 The Historical Context of Artificial Intelligence Development

DsAI is not a new topic in the AI field. It is, indeed, a subject of debate among computer science scholars, since some consider it as a subfield of AI¹²⁶, while others are more inclined to recognise decentralised systems as an extension of AI field.¹²⁷ In any case, it is not possible to delve into the DsAI investigation without first providing a brief historical framework of the origins of Artificial Intelligence.

The modern concept of AI was introduced in the summer of 1956 when John McCarthy, Marvin Minsky, Nathaniel Rochester and Claude Shannon presented for the first time their research project proposal on artificial intelligence at a famous conference held at Dartmouth College in New Hampshire, United States.¹²⁸ The purpose of such a concept was to distinguish intelligent systems from other types of software.¹²⁹ It was stated that '[T]he study is to proceed

¹²⁶ Michael Huhns, *Distributed Artificial Intelligence*, (Morgan Kaufmann, 1984), 7.

¹²⁷ Djamel Zeghida, Djamel Meslati, Nora Bounour, 'BIO-IR-M: A MULTI-PARADIGM MODELLING FOR BIO-INSPIRED MULTI-AGENT SYSTEMS' 42 (3) 2018, Informatica, <10.31449/inf.v42i3.1516> accessed 26 January 2020.

¹²⁸ Pamela McCorduck, 'Machines Who Think' (2nd edn, Routledge, 2004), 93.

¹²⁹ Ibid.

on the basis of the conjecture that every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it.’¹³⁰ This shows clearly that Artificial Intelligence systems were figured to simulate the human brain problem-solving ability. This latter purpose is still in force, although the reason behind the addition of the word intelligence to these types of synthetic systems was aimed at distinguishing AI from other computing systems.¹³¹ Since the 1950s, the debate was opened as regards the capacity of this ‘almost human machines’.¹³² The milestone of such a social and cultural discussion can be traced back to the paper written by Alan Turing in 1950¹³³ in which was the famous question ‘Can machine think?’.¹³⁴ This was a pioneering vision related to machines that might think, reason, feel and perceive in the same way as the human brain.¹³⁵

Later, In the light of a new era of technology developments, between the 70s and the 80s, there was an increase of AI in wide range of fields. Consequently, that led to the foundation of further schools, such as symbolism and behaviourism, linked to new technologies.¹³⁶ Those research fields are still in unceasing expansion, including model recognition, mathematical and

¹³⁰ John McCarthy, Marvin L. Minsky, Nathaniel Rochester, Claude E. Shannon, ‘A Proposal for the Dartmouth Summer Research Project on Artificial Intelligence, August 31, 1955’, (2006) 27 4 AI Magazine <<https://www.aaai.org/ojs/index.php/aimagazine/article/view/1904>> accessed 25 October 2019.

¹³¹ McCorduck (n. 128), 94.

¹³² Fulvio Sarzana e Massimiliano Ippolito, *Diritto della Blockchain, Intelligenza Artificiale e IoT* (Wolters Kluwer Italia, 2018), 196.

¹³³ Alan Turing, ‘Computing Machinery and Intelligence’ (1950) 49 Mind, 433-460 <https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwj2aal7LbiAhX0QhUIHSNoC4IQFjAAegQIBBAC&url=https%3A%2F%2Fwww.csee.umbc.edu%2Fcourses%2F471%2Fpapers%2Fturing.pdf&usg=AOvVaw0Bm_LDFb7eLjzmCNrEgA2s> accessed 15 January 2018.

¹³⁴ Ibid, 434.

¹³⁵ Ibid.

¹³⁶ Yunhe Pan, ‘Heading toward Artificial Intelligence 2.0’ (2016) 2 Engineering, 409–413 https://www.researchgate.net/publication/314139647_Heading_toward_Artificial_Intelligence_20 accessed 5 February 2020.

game theories, recognition, machine learning and, above all, the area of expert systems.¹³⁷ In particular, the latter was a type of AI software still employed into numerous sectors, such as medical fields, molecular analysis and computer science projects aimed at replicating the experienced and professional human performance.¹³⁸ After the second decade of the 80s, there were setbacks around the AI progress, due to the difficulties in approaching the right technical models to develop, analyse and process all the information necessary to perform human brain capacities.¹³⁹

Things changed when the computer science experts understood that the knowledge should have been gained from the environment itself in which AI was deployed, instead of trying to detect all the different types of human brain abilities.¹⁴⁰ That awareness led to the last and current phase of artificial intelligence stage, called AI 2.0. The years following 2010, indeed, are particularly significant because they mark the passage of a re-emergence of the unanswered question concerning the regulation of AI, as a phenomenon capable of determining an extraordinary impact on the socio-cultural system. The occurrence that has contributed to the revival of this perspective was the advent of Big Data, defined as a vast and complex amount of data collected from multiple digital sources, available thanks to the free flow of information on the web.¹⁴¹

Thus, the data sources related to AI changed. At present, AI relies on data-driven algorithms, giving rise to a new era of information pools from which these systems can draw.¹⁴² As a consequence, the importance of Big Data for AI enhancement can be considered undoubtedly pivotal. In such an innovative context, it must be pointed out that the birth of decentralised AI system was part of that trend of technological innovation which developed

¹³⁷ Ibid, 410.

¹³⁸ Sarzana and Ippolito (n 132), 196.

¹³⁹ Ibid, 195.

¹⁴⁰ Pan (n. 136), 410.

¹⁴¹ Yesaya Athuman, 'Ethical Challenges and Legal Concerns of Big Data and Artificial Intelligence in East Africa' (2018), Medium, <<https://medium.com/datadriveninvestor/ethical-challenges-and-legal-concerns-of-big-data-and-artificial-intelligence-in-east-africa-c54c7386b50d>> accessed 7 April 2020.

¹⁴² Ibid.

between the 1970s and 1980s.¹⁴³ It was this time frame that brought together the rise of the most critical areas related to AI. Therefore, it was only through the combination of modern technologies such as blockchain, machine learning and Big Data that the definitive convergence of these cutting-edge innovations was achieved.

1.9.2 Origins of Distributed Ledger Technology and Blockchain Infrastructure

The blockchain concept first appeared in 2008.¹⁴⁴ It was brought to the world's attention by a developer, or by a group of anonymous developers, named Satoshi Nakamoto.¹⁴⁵ The breakthrough of blockchain concept can be, however, dated back to 2005, when the famous developer Nick Szabo put forward the so-called 'Bit gold', the first attempt to create a decentralised currency, shifting control from a single centralised entity to a variety of smaller ones.¹⁴⁶ The Szabo's reasons to undertake such an attempt rooted in the necessity of people to depend and trust a third party for assessing the value of their money.¹⁴⁷ However, Szabo's Bit gold could not overcome the double-spending problem whereby digital currency users could spend the same digital money more than once, hence duplicating transactions.¹⁴⁸ It was Nakamoto's blockchain conception the real game changer. To solve the double-spending problem, he introduced the concept of peer-to-peer electronic cash, namely Bitcoin, by implementing the timestamp system notion to determine computational proof for the

¹⁴³ Gerhard Weiss, *Multiagent Systems: A Modern Approach to Distributed Artificial Intelligence* (The MIT Press, 1999), 1.

¹⁴⁴ Primavera de Filippi and Aaron Wright (n. 63), 20.

¹⁴⁵ Satoshi Nakamoto, 'Bitcoin: A Peer-to-Peer Electronic Cash System' (2008) White Paper available at <<https://git.dhimmel.com/bitcoin-whitepaper/>> accessed 20 June 2020.

¹⁴⁶ Nick Szabo, Bit Gold, (2005) <<https://nakamotoinstitute.org/bit-gold/>> accessed 7 January 2021.

¹⁴⁷ Ibid.

¹⁴⁸ Usman Chohan, 'The Double Spending Problem and Cryptocurrencies' (2017) Discussion Paper Series: Notes on the 21st Century, SSRN <https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3090174> accessed 5 February 2021.

chronological order of transactions.¹⁴⁹ The timestamp mechanism defines the time at which data are added to a certain database.¹⁵⁰ It was an older concept then applied by Nakamoto to the underlying Bitcoin architecture, the blockchain. It must be highlighted that even if the blockchain came to the world's sight directly linked to the Bitcoin cryptocurrency original concept, the two mechanisms are, in fact, decoupled. The blockchain exists as separate from Bitcoin. That is because the blockchain infrastructure was not the first of its kind, it can be in turn considered as the product of a long-standing technological progression.¹⁵¹ It has been indeed developed from another uphold technology, older than the former, called Distributed Ledger System or Distributed Ledger Technology. As stated, 'both are methods of organising transaction records in a shared, distributed database, but the Distributed Ledger Technology is an umbrella term that encompasses all sorts of structures, including blockchain, which is just one type'.¹⁵²

The Distributed Ledger Technology has a reach past which can be traced back to the 1991- 2002 decade, when for the first time the ground-breaking idea of how time stamp digital documents¹⁵³ and store the data in a multi-user network record system¹⁵⁴ was developed. Thus, to offer an overall notion, a Distributed Ledger Technology, as the name suggests, is a digital record which is spread and instantaneously shared across a network of peer computers, called

¹⁴⁹ Nakamoto (n. 145).

¹⁵⁰ Stefamo Bistarellia, Gianmarco Mazzante, Matteo Micheletti, Leonardo Mostarda and others 'Ethereum smart contracts: analysis and statistic of their source code and opcodes' (2020) 11 1001198 Internet of Things, 2.

¹⁵¹ Leslie Lamport, Robert Shostak, Marshall Pease, 'The Byzantine Generals Problem' (1982) 4 3 ACM Transactions on Programming Languages and Systems, 382.

¹⁵² European Union Blockchain Observatory & Forum, 'EU Blockchain Ecosystem Report' (2020) <https://www.eublockchainforum.eu/sites/default/files/reports/EU%20Blockchain%20Ecosystem%20Report_final_0.pdf> accessed 23 January 2021.

¹⁵³ Stuart Haber and Scott Stornetta, 'How to Timestamp a Digital Document' (1991) 3 2 Journal of Cryptology, 99-111.

¹⁵⁴ David Mazieres and Dennis Shasha, 'Building secure file systems out of Byzantine storage' (2002), NYU computer science department technical report TR2002-826 <<https://cs.nyu.edu/cs/faculty/shasha/papers/mazpodc.pdf>> accessed 2 February 2021.

nodes.¹⁵⁵ Each node, namely each computer of the network, holds a copy of the entire ledger where data are recorded, which, as stated, ‘prevents the existence of multiple competing versions of the ledger’.¹⁵⁶ This is possible since, at the basis of the distribution paradigm, lies the peer-to-peer technology.¹⁵⁷ In such a technology, there is no central node from which and toward which data can converge and be redistributed in the network; all peer nodes are considered equal players in doing so.¹⁵⁸ As it has been defined by the European Commission ‘distributed ledger technology’ or ‘DLT’ means a type of technology that support the distributed recording of encrypted data’.¹⁵⁹ In other words, in a distributed architecture either tasks and workload are partitioned between the peer nodes which, thus, are considered providers and consumers of resources at the same time.¹⁶⁰ What is further captivating is that a Distributed Ledger Technology can be both a centralised and a decentralised platform. Indeed, the Blockchain was initially envisioned, and it is usually used as a decentralised system.¹⁶¹ This is the reason why it is considered as a subcategory of the former. Hence, as it has been argued, ‘Blockchain is a distributed-decentralised system’.¹⁶² Therefore, conversely from the general Distributed Ledger Technology, the blockchain holds another paradigm along with the

¹⁵⁵ Erika J. Nash, ‘Blockchain & Smart Contract Technology: Alternative Incentives for Legal Contract Innovation’ (2019) 38 *BYU Law Review*, 800.

¹⁵⁶ *Ibid*, 815.

¹⁵⁷ Andy Oram, *Peer-to-Peer: Harnessing the Power of Disruptive Technologies*, (O’Reilly & Association, 2001), 16.

¹⁵⁸ *Ibid*.

¹⁵⁹ European Commission, Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on Markets in Crypto-assets, and amending Directive (EU) 2019/193, COM (2020)593, 24 September 2020, Art. 3, 1 (1).

¹⁶⁰ Rüdiger Schollmeier, A Definition of Peer-to-Peer Networking for the Classification of Peer-to-Peer Architectures and Applications, Proceedings of the First International Conference on Peer-to-Peer Computing, IEEE (2002) <https://www.researchgate.net/publication/3940901_A_Definition_of_Peer-to-Peer_Networking_for_the_Classification_of_Peer-to-Peer_Architectures_and_Applications> accessed 5 February 2021.

¹⁶¹ Imran Bashir, *Mastering Blockchain: Distributed Ledger Technology, Decentralization, and Smart Contracts Explained* (2nd, Packt Publishing, 2018), 12.

¹⁶² *Ibid*.

distribution one, that is the decentralisation trait. The notion of decentralisation is directly connected to the notion of control.¹⁶³ In fact, in the blockchain decentralised peer-to-peer architecture, there is no room for a central-master node, entrusted with the control over the information overflow and data exchange in the network.

Consequently, there is no need for third-party intermediaries involvement, such as Internet or cloud computing operators, to maintain the database since it is simultaneously replicated on each node of the blockchain platform, to ensure coherence.¹⁶⁴ Hence, the control is distributed amongst all the peer nodes of this system¹⁶⁵ realising the highest disintermediation system.¹⁶⁶ To further explain the distributed ledger concept, it is useful to present Baran's typology of communication networks which visually shows the three main technological environments: centralised, distributed, and decentralised¹⁶⁷ (Fig.1.6).

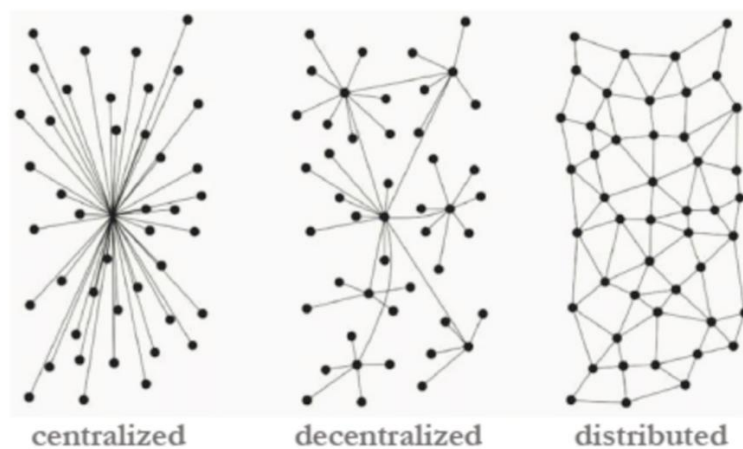


Fig. 1.6 Baran's Typology of Communication Networks (1964)

¹⁶³ Ibid, 44.

¹⁶⁴ Ibid.

¹⁶⁵ Ibid.

¹⁶⁶ Mattila, 'The Blockchain Phenomenon', (2016) Berkeley Roundtable On The International Economy (BRIE), 6.

¹⁶⁷ Paul Baran, 'On Distributed Communications Networks' (1964) 12(1) IEEE Transactions on Communications Systems, 1; Christopher S. Yoo, 'Paul Baran, Network Theory, and the Past, Present, and Future of Internet' (2018) 17 Colorado Technology Law Journal, 161.

An example of a centralised network would be a small business using a single domain controller where each node (computer system) must communicate with a central authority (central server) to exchange data and information, as each node cannot directly communicate with each other. On the other hand, an example of decentralised network is the Internet protocol itself. On the Internet, each computer can communicate and exchange data through different service providers which act like different central nodes. At the other end of the spectrum, there are the distributed networks like the blockchain. Distributed networks have the property whereby failure of a few nodes still leaves the network connected, allowing all nodes to communicate with each other.¹⁶⁸ The more distributed the network, the more resilient it is.¹⁶⁹ Thus, compared to centralised and distributed networks, in a decentralised system, there is no single point of control or reliance on a central entity to manage and govern the entire system.¹⁷⁰

The DsAI system is embedded into this decentralised and distributed framework as an algorithmic collective that can either generate or interact with smart contracts, react to on-chain events and compose protocols.¹⁷¹ Within the smart contract functions, their decisions materialise in transactions and function calls: a codified behaviour that becomes the object of legal evaluation of this thesis in the following chapters.

¹⁶⁸ Yoo (n. 167), 165.

¹⁶⁹ Ibid.

¹⁷⁰ Jean-Philippe Vergne, 'Decentralized vs. Distributed Organization: Blockchain, Machine Learning, and the Future of the Digital Platform' (2020) 1(4) Organization Theory <<https://doi.org/10.1177/2631787720977052>> accessed 7 June 2021; R. Patel, A. Sethia and S. Patil, "Blockchain – Future of Decentralized Systems," 2018 International Conference on Computing, Power and Communication Technologies (GUCON) <doi: 10.1109/GUCON.2018.8675091> accessed 6 April 2023; Tiana Laurence, *Introduction to Blockchain Technology* (2019, Van Haren Publishing).

¹⁷¹ Yang Liu and others, 'An overview of blockchain smart contract execution mechanism' (2024) *Journal of Industrial Information Integration* 100674; Barış Köksal, 'The Smart Contracts Trilemma' (2024) SSRN Working Paper <https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4689013> accessed 27 August 2025.

1.9.3 Smart Contracts Protocols: The Legal Challenge of Sole-code Decentralised Transactions

In the realm of decentralised networks, the most significant applications are smart contracts. Within this set, a key distinction applies: (i) governance smart contracts, which encode and execute the internal rules of a protocol or DAO (voting, roles, timelocks, treasury) and primarily produce intra-protocol effects, rather than a bilateral agreement between identified parties; and (ii) 'legal' smart contracts, in which interactions are traceable to contractual frameworks.¹⁷² This thesis focuses on smart legal contracts and the conditions under which sole-code protocols amount to valid contract formation. Smart contracts that have legal purposes are defined as computer programs designed to facilitate, execute and automatically enforce the terms of an agreement between parties, without the need for intermediaries or other trusted third parties.¹⁷³ It is a self-executing contract transaction with the terms of the agreement directly written into lines of code, which are stored on a distributed ledger technology.¹⁷⁴ Smart contract protocols are essential because they not only allow for interoperation between nodes, but their use ensures a high level of operability for many

¹⁷² Riccardo De Caria, 'The Legal Meaning of Smart Contracts' (2018) 26 *ERPL* 731; Guido Governatori, Florian Idelberger, Zoran Milosevic, Regis Riveret, Giovanni Sartor and Xiwei Xu, 'On Legal Contracts, Imperative and Declarative Smart Contracts, and Blockchain Systems' (2018) 26 *Artificial Intelligence and Law*, 377; Stefania Fiorentino and Silvia Bartolucci, 'Blockchain-Based Smart Contracts as New Governance Tools for the Sharing Economy' (2021) 117 *Cities*, 103325; Darcy W E Allen and Aaron M Lane, 'Smart Contracts as Private Governance Tools' (SSRN Working Paper, 11 October 2023) <<https://ssrn.com/abstract=4598625>> accessed 27 August 2025.

¹⁷³ Max Raskin, 'The Law and Legality of Smart Contracts' (2017) 1 *Geo. L. Tech. Rev.*, 305.

¹⁷⁴ Zibin Zheng, Shaoan Xie, Hong-Ning Dai, Weili Chen, Xiangping Chen, Jian Weng, Muhammad Imran, 'An overview on smart contracts: Challenges, advances and platforms' (2020) 105 *Future Generation Computer Systems*, 475; Hammed Taherdoost, 'Smart Contracts—How Do They Work? State of the Art' (2023) 14 *Information*, 117; Sayed Ahmad Seyar Sawayz e Athota Kavitha, 'Review of Academic Research on Blockchain Technology and Smart Contract' (Procs ICICC 2024, SSRN, 27 March 2025) <<https://ssrn.com/abstract=5195574>> accessed 18 June 2025.

blockchain applications.¹⁷⁵ Artificial Intelligence systems could leverage these decentralised applications, helping in enhancing the scope of smart contracts.¹⁷⁶ In fact, AI can expand and diversify the capability of smart contracts, enhancing human–machine interactions, and can also increase the possibility of developing more autonomous transaction processes between parties on the blockchain.¹⁷⁷ Therefore, the nature of smart contracts as legal contracts shall be further investigated in depth in the further chapters. As the smart contracts evolve and get more sophisticated and differentiated in their traits, such technology gets more attention in both academia and business fields not only for its widespread use but also for its features that challenge traditional legal categories which, in various ways, may resemble the traditional legal contract paradigm.¹⁷⁸ One of this thesis scope is indeed to explore how smart contract’s interactions may fall under the contract-as-relation perspective¹⁷⁹ and, thus, underpinning the theory of smart ‘legal’ contracts as a new means of legal interactions.

Among the various types of smart contracts, so-called sole-code transactions assume paradigmatic importance in the study of DsAI.¹⁸⁰ As previously stated, they consist of contracts determined exclusively by code, without external support or validation through off-chain interfaces or parallel agreements.¹⁸¹ In particular, the open permissionless environment is of

¹⁷⁵ Tharaka Hewaa, Mika Ylianttilaa, Madhusanka Liyanage, ‘Survey on blockchain based smart contracts: Applications, opportunities and challenges’ (2021) 177 *Journal of Network and Computer Applications* 102857; Fabio Bassan, ‘From Smart Legal Contracts to Contracts on Blockchain’ (2024) *Computer Law & Security Review* 57, 105089.

¹⁷⁶ Primavera de Filippi and Aaron Wright (n. 63).

¹⁷⁷ *Ibid*, 29.

¹⁷⁸ Paul Catchlove, ‘Smart Contracts: A New Era of Contract Use’ (2017) SSRN <https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3090226> accessed 7 September 2021.

¹⁷⁹ Mark C. Suchman, ‘The Contract as Social Artifact’ (2003) 37(1) *Law and Society* 91.

¹⁸⁰ Rischana Mafrur, ‘AI-Based Crypto Tokens: The Illusion of Decentralized AI?’ (2025) arXiv <<https://arxiv.org/abs/2505.07828>> accessed 22 August 2025.

¹⁸¹ Shreya Girish Savadatti, Shruthi Krishnamoorthy and Radhakrishnan Delhibabu, ‘Survey of Distributed Ledger Technology (DLT) for Secure and Scalable Computing’ (2025) 13 *IEEE* 8393; Deepa Mishra and Shraddha Phansalkar, ‘Blockchain Security in Focus: A Comprehensive

relevant interest as it combines the autonomous and adaptive behaviour of DsAI with the self-executing nature of smart contracts within an open infrastructure, creating legally relevant interactions that can occur entirely without direct human oversight.¹⁸² In these scenarios, legally relevant conduct is not attributable to an identifiable subject but can emerge from the autonomous and decentralised interaction between algorithmic agents. This circumstance makes sole-code transactions a privileged terrain for analysing the legal relevance of DsAI role.

First and foremost, the opacity of contractual intention: the intention to be bound manifests itself only as computational execution, requiring a rethinking of the traditional categories of intention and consent. The second element is the attribution problem. Contractual conduct is, in fact, distributed across multiple nodes and agents, often without a clearly identifiable human decision-making centre. Finally, one of the most significant aspects is technical autonomy and agency. Automated and autonomous formation of decentralised agreements can generate binding effects. In this context, sole-code smart contracts offer a unique field of theoretical and legal experimentation, in which the DsAI is not just a technical tool, but an algorithmic actor that redefines the methods of formation and attribution of contractual effects.¹⁸³ By enabling multi-agent systems to autonomously prepare, initiate,

Investigation Into Threats, Smart Contract Security, Cross-Chain Bridges, and Vulnerabilities Detection Tools and Techniques' (2024) 13 IEEE Access, 1.

¹⁸² Dayong Ye, Minije Zhang and Athanasios Vasilakos, 'A Survey of Self-Organization Mechanisms in Multiagent Systems' (2017) 47 IEEE Transactions on Systems, Man, and Cybernetics: Systems, 441; Yara Rizk, Mariette Awad and Edward Tunstel, 'Decision Making in Multiagent Systems: A Survey' (2018) 10 IEEE Transactions on Cognitive and Developmental Systems, 514.

¹⁸³ Fabio Bassan, 'From Smart Legal Contracts to Contracts on Blockchain' (2024) 55 Computer Law & Security Review 106035; Niloufer Selvadurai, 'The Potential of Hybrid On-Chain/Off-Chain Contracts' (2023) 80 (4) Washington and Lee Law Review, 2343.

modify, or execute contractual obligations, these systems can alter the source of allocation of rights, duties, and responsibilities within the contract counterparties dynamics.¹⁸⁴

1.9.4 The role of DsAI in Sole-Code Smart Contracts: A Brief Overview

Decentralised Artificial Intelligence systems operate on the blockchain as algorithmic actors capable of initiating and managing legal relationships without direct human intervention.¹⁸⁵ Their role emerges with clarity when they act as initiators or deployers of smart contracts¹⁸⁶, which creates a legal challenge in determining whether the on-chain behaviour of DsAI systems falls within the scope of a legally relevant conduct and to whom it should be attributed. This dynamic disrupts traditional legal doctrines on contractual capacity and intention to be bound, rooted in the definition of clearly identifiable contractual counterparties¹⁸⁷, raising practical questions on how both contractual conduct and legal effects should be interpreted within decentralised transactions.

¹⁸⁴ Marsha Simone Cadogan, 'Enforcing Smart Legal Contracts: Prospects and Challenges' (2023) CIGI Paper No. 271 <https://www.cigionline.org/static/documents/no.271_UN5GG6q.pdf> accessed 4 July 2024.

¹⁸⁵ Md Monjurul Karim, Dong Hoang Van, Sangeen Khan, Qiang Qu and Yaroslav Kholodov, 'AI Agents Meet Blockchain: A Survey on Secure and Scalable Collaboration for Multi-agent systems' (2025) 17 *Future Internet* 57; Lennart Ante, 'Autonomous AI Agents in Decentralized Finance: Market Dynamics, Application Areas, and Theoretical Implications' (SSRN Working Paper, 14 December 2024, rev 8 June 2025) <<https://ssrn.com/abstract=5055677>> accessed 27 August 2025.

¹⁸⁶ Worl Economic forum, 'The rise of smart contracts and strategies for mitigating cyber and legal risks' (2024) <<https://www.weforum.org/stories/2024/07/smart-contracts-technology-cybersecurity-legal-risks/#:~:text=Smart%20contracts%20-%20self%2Dexecuting%20agreements,legal%20and%20cybersecurity%2Drelated%20risks>> accessed 6 March 2025.

¹⁸⁷ Monika Simmler, 'Responsibility gap or responsibility shift? The attribution of legal personhood to artificial agents' (2024) 27 *Information, Communication & Society*, 1142.

Specifically, DsAI systems can, among others: (i) create and deploy a smart contract on the network – by generating the code and making it executable by anyone who interacts with it;¹⁸⁸ (ii) configure existing contractual modules (e.g., standard instruments for exchanging or storing digital assets), adapting them to a specific case; and (iii) automatically activate contractual clauses when predefined conditions occur (e.g., a price, a date, a verifiable event), thanks to services that deliver reliable information online.¹⁸⁹ All of this translates into coded and traceable on-chain behaviours: sequences of technical actions that, from an external perspective, can take on the legal meaning of offer, acceptance, and execution.¹⁹⁰

This thesis investigates whether and when these algorithmic behaviours can constitute a valid formation of a contract (sole-code smart contract) and to whom the relevant legal effects must be attributed. While the following chapters will provide a more detailed explanation of the technical framework, it is sufficient to note that blockchain offers the operating environment in which the decision-making autonomy of the DsAI becomes observable, verifiable and legally attributable according to private law categories.

¹⁸⁸ Md Tauseef Alam *et al*, ‘SolGen: Secure Smart Contract Code Generation Using Large Language Models via Masked Prompting’ (Proceedings of ISEC 2025, 21 April 2025) <<https://dl.acm.org/doi/10.1145/3717383.3717394>> accessed 28 August 2025.

¹⁸⁹ Tor Górski, ‘Smart Contract Design Pattern for Processing Logically Related Transactions: AdapT v2.0’ (2024) 14 Applied Sciences, 2224; Xueyan Zhao *et al*, ‘Template-Based Smart Contract Verification: A Case Study in Maritime Transportation’ in Software Engineering and Formal Methods (LNCS 14849, 2024) 185; Amirmohammad Pasdar, Young Choon Lee and Zhongli Dong, ‘Connect API with Blockchain: A Survey on Blockchain Oracle Implementation’ (2023) 55(10) ACM Computing Surveys 1–39; Yang Liu and others, ‘An Overview of Blockchain Smart Contract Execution Mechanism’ (2024) 41 Journal of Industrial Information Integration, 100674.

¹⁹⁰ Vasiliki Papadouli e Vagelis Papakonstantinou, ‘A Preliminary Study on Artificial Intelligence Oracles and Smart Contracts: A Legal Approach to the Interaction of Two Novel Technological Breakthroughs’ (2023) 51 Computer Law & Security Review, 105869; Enas Mohammed Alqodsi e Leila Arenova, ‘Smart Contracts in Contract Law as an Auxiliary Tool or a Promising Substitute for Traditional Contracts’ (2024) 16(3) Journal of Legal Affairs and Dispute Resolution in Engineering and Construction, 06524004.

1.10 Chapters Outline

The thesis comprises five substantive chapters alongside two additional chapters encompassing the introduction and conclusion.

Chapter one introduces the research subject and coordinates, outlining its scope, boundaries, and methodology. The underlying legal paradox is clarified: Decentralised Artificial Intelligence (DsAI) systems, operating through sole-code smart contracts on open permissionless blockchains, can produce legal effects despite not being recognised by traditional categories of subjectivity, capacity, and legal personhood. The chapter outlines the main theoretical and practical challenges raised by DsAI, critically reviews the existing literature, and highlights its gaps, to formulate the central question of the thesis: whether and under what conditions DsAI multi-agent systems can be considered functional centres for attributing legal effects in sole-code contracts. The methodology is then illustrated, based on a comparative approach between European civil and common law traditions and on the analysis of supranational principles (PECL), enriched by an interdisciplinary integration with computer science and cognitive sciences. The chapter highlights the original contribution of the research, which proposes innovative tools such as Functional Legal Subjectivity (FLS) and the Paradigm of Autonomous Behaviour (PAB), while acknowledging their limitations due to the novelty of the phenomenon and the lack of case law. Finally, the chapter presents the technical and legal context (AI, Distributed Ledger Technology, blockchain, smart contracts) and the overall structure of the thesis, which prepares the groundwork for the analysis of the subsequent chapters.

The second chapter analyses the technical foundations of Decentralised Artificial Intelligence (DsAI) systems, clarifying their differences from centralised models and illustrating their structural and functional characteristics: autonomy, learning, internal states, adaptation, self-organisation, and the ability to cooperate and negotiate between agents. By describing the functioning of multi-agent systems, their distributed learning models, and the dynamics of creating, configuring, and executing sole-code smart contracts, the chapter aims to demonstrate how DsAI are not mere tools but algorithmic collectives capable of generating

concrete and binding effects. This raises the central issue: the classic legal categories of personhood, legal subjectivity, capacity, and agency are inadequate to frame systems that present a high level of autonomy in decision-making, able to generate obligations without a direct human referent. Neither traditional doctrine nor the more recent regulatory framework, such as the European AI Act, provides sufficient answers, as they remain anchored to centralised logics. The chapter concludes by highlighting a conceptual and regulatory gap: the DsAI can produce legal effects, but without a legal category capable of attributing them, thus posing the paradox that will motivate the analysis of sole-code smart contracts in the following chapter.

The third chapter addresses the legal classification of sole-code smart contracts, starting with a technical analysis of blockchain infrastructures and their distinctive features (disintermediation, resilience, transparency, pseudonymity, consensus). After clarifying the difference between simple transactions and smart contracts, as well as between integrated, non-integrated, and sole-code models, the chapter reconstructs the lifecycle of on-chain transactions and highlights their legal significance. In the second part, the discussion shifts to a dogmatic level, reconstructing the theory of legal acts and transactions and emphasising the centrality of contractual intention as an essential element of the contract. Through a comparison between common law and civil law, complemented by the Principles of European Contract Law (PECL), the chapter highlights how contracts can also be formed through conduct, without an express declaration. In light of this framework, sole-code smart contracts are examined as potential examples of contracts by conduct, in which consensus is manifested through algorithmic interactions validated by the consensus mechanism. The chapter concludes that, despite the limitations related to the lack of natural language and the merging of formation and execution, sole-code smart contracts could potentially be considered as legal contracts, paving the way for subsequent in-depth analysis of the role of DsAI as active subjects of such interactions.

The fourth chapter investigates the role of Decentralised Artificial Intelligence systems in the formation of sole-code smart contracts, focusing on the crucial element of contractual intent. After distinguishing between will and intention in civil and common law traditions, the chapter shows how DsAI systems, despite lacking legal personhood, can exhibit autonomous

and purposeful behaviours that can be interpreted as legally relevant intentionality. It is clarified that the artificial agency of DsAI systems cannot be traced back to individual agents but emerges as a collective and distributed property of the system. The analysis unfolds around the tension between autonomy (the ability to determine one's own behaviour) and self-determination (governance of one's own legal interests), highlighting the paradox whereby DsAI multi-agent systems exhibit autonomy without possessing their own sphere of rights and duties. To resolve this tension, the chapter introduces the theory of Integrated Agency, according to which the DsAI acts as a functional part of the legal sphere of human or legal entities, exercising an autonomous capacity for self-governance over externally determined legal interests (outer-determination). This framework allows us to recognise the legal relevance of DsAI systems' behaviour in decentralised transactions, without attributing them full autonomous subjectivity, and prepares the groundwork for the following chapter's analysis of the DsAI legal and contractual capacity.

The fifth chapter directly addresses the legal paradox, proposing a theoretical model capable of translating the technical autonomy of Decentralised Artificial Intelligence systems into legally relevant autonomy. After reviewing the concepts of personality, subjectivity, and legal capacity, the chapter shows how they are structurally inadequate when faced with decentralised and distributed systems. The chapter then introduces the Paradigm of Autonomous Behaviour (PAB), an evaluative model based on five parameters (learning model, degree of human control, environmental complexity, internal states, and representational-inferential capacity) that allows for the establishment of a minimum threshold beyond which the behaviour of the DsAI can be characterised as an expression of autonomous artificial agency. Building on the PAB, the chapter develops the theory of Functional Legal Subjectivity (FLS), which recognises DsAI systems as possessing a functional, contextual, and integrated subjectivity sufficient to justify the attribution of legal capacity and limited contractual capacity, though without conferring full legal personhood. Contractual capacity, understood as the ability to generate legal effects when the PAB threshold is exceeded, is distinguished from contractual intention, which emerges *ex post* from the coherence between algorithmic conduct and contractual structure. The chapter also clarifies why DsAI agents cannot be assimilated either to mere instruments or legal representatives but must be understood as functional components of the decentralised legal system. Thus, the PAB and the FLS provide an

innovative conceptual and metric framework that allows us to recognise the legal relevance of the autonomous behaviour of DsAI systems in sole-code smart contracts, paving the way for the conclusions and systemic implications discussed in the final chapter.

The sixth chapter returns to the research question and demonstrates how Decentralised Artificial Intelligence systems, while excluded from the traditional categories of subjectivity, capacity, and legal personhood, can be recognised as functional centres of legal attribution through the combined model of the Paradigm of Autonomous Behaviour (PAB) and Functional Legal Subjectivity (FLS). After summarising the findings of the previous chapters, the chapter clarifies that the legal relevance of DsAI algorithmic behaviour rests on two conditions: exceeding the autonomy threshold set by the PAB and consistency between algorithmic conduct and contractual structure. This resolves the legal paradox of effects without a subject, preserving the traditional link between capacity to act and subjectivity, but adapting it to a decentralised context. The conclusions also discuss the systemic implications of the FLS model, which transcends the subject/non-subject dichotomy and draws parallels with existing legal experiences (corporate personality, unrecognised associations, contracts by conduct). The limitations of the model, confined to the context of sole-code smart contracts, are acknowledged, and future research avenues are outlined: extension to DeFi and DAOs, dialogue with public law and liability regimes, and the construction of a pluralistic legal ontology of subjectivity. Thus, the thesis concludes by showing how Functional Legal Subjectivity represents not a break with, but an evolution of, private law, capable of governing the transformations ushered in by decentralised artificial intelligence in the 21st century.

In summary, this chapter has defined the theoretical, technical, and methodological framework within which the research is situated, demonstrating how Decentralised Artificial Intelligence (DsAI) systems, operating through sole-code smart contracts in open, permissionless environments, challenge traditional categories of private law. This highlights the need for a different interpretative approach, capable of recognising the legal relevance of autonomous and distributed algorithmic behaviour. This introduction paves the way for chapter 2, which will delve into the technical and legal foundations of DsAI systems, reconstructing their complex nature and laying the conceptual foundations for analysing their role in legal transactions.

CHAPTER 2

Decentralised Artificial Intelligence Systems: Between Technical Complexity and the Limits of Traditional Legal Categories

2.1 Introduction

This chapter analyses the technical foundations of DsAI systems and explores how they pose profound challenges to traditional legal categories. This approach is directly related to the thesis's central research question: whether, and under what conditions, DsAI can assume a legally relevant role in sole-code smart contracts executed on open, permissionless blockchains. In this chapter, the aim is to highlight how the growing use of DsAI systems—called upon to perform tasks, solve problems, or pursue objectives—is already reshaping legal relations and generating new demands for legal systems.

The chapter is structured into several parts. It begins by highlighting the importance of a legal approach to the study of AI, then distinguishes between centralised AI and decentralised multi-agent systems to clarify the technical context. It then analyses DsAI systems in detail, and its technical role within smart contracts, focusing on the structural and functional characteristics that determine their operational autonomy. Starting from this technical foundation, the chapter transitions then into the legal debate, offering a critical view on fundamental categories such as legal subjectivity, legal capacity, and legal personhood, questioning their appropriateness in the context of decentralised AI systems. Finally, the chapter concludes with an assessment of the European Union's regulatory approach, examining

whether the new normative framework provides adequate governance for the multi-agent dynamics of DsAI.

The findings of this chapter, summarised in the conclusions, will then form the basis for the subsequent analysis. Following chapters will address the legal implications more specifically in the contractual context of sole-code smart contracts before proposing a theoretical response to the paradoxes raised by DsAI.

2.1.1 Artificial Intelligence and Legal Relations: The Necessity of a Juridical Perspective

Artificial Intelligence (AI) is transforming society. This technology pervades, indeed, through every significant aspect of daily life shaping communication, commerce, and decision-making.¹ There is AI within human relationships as well. Consequently, it inevitably permeates legal relationships. This stems from the fact that human relationships typically acquire legal relevance whenever they generate rights and obligations, transforming every single action of daily undertaking into legal acts and facts which impact the constant unfolding of society.

The main task for legal experts is, therefore, to recognise when technological transformations impact the structure of legal relationships and ensure that these changes are classified within appropriate legal categories. This observation becomes crucial in the case of Decentralised Artificial Intelligence (DsAI) systems operating in blockchain environments. These systems blur the boundaries of well-defined legal situations, producing difficulties in classifying the interests involved and the effects resulting from their operation. The law, hence, faces a dual challenge: establishing which rules to apply in such specific cases as well as determining how to attribute rights and obligations in relationships involving DsAI systems.

¹ Stefano Oriti, 'Brevi note sulla Risoluzione del Parlamento Europeo del 16 Febbraio 2017 concernente le norme di diritto civile sulla robotica' (2017) <<https://www.ratioiuris.it/brevi-note-sulla-risoluzione-del-parlamento-europeo-del-16-febbraio-2017-concernente-le-norme-diritto-civile-sulla-robotica/>> accessed 22 October 2019.

2.1.2 Legally Binding Interests and Subjective Legal Situations: A Taxonomic Framework

One starting point for addressing the abovementioned challenge is the concept of legally binding interests worthy of protection. Legally binding interests are those interests that the legal system selects as worthy of protection and which, for this reason, translate into subjective legal situations – or legal positions – attributing rights, obligations, powers, or duties to the individuals involved.² Therefore, not every legally binding interest receives legal protection: only those recognised as ‘legally relevant’ or ‘worthy of legal protection’ by law are converted into legal positions that can be classified as centres of attribution of legal effects.³ Hence, within this thesis, ‘legally relevant’ means those legal positions – worthy of legal protection – that are attributable to an identifiable source.⁴ In this sense, the legally binding interest constitutes the point of connection between the factual and normative dimensions, serving as the ordering criterion for the distribution of rights and responsibilities.⁵

This approach is typical of the civil law tradition: the theory of subjective legal situations provides a taxonomy of the different forms of protection that the law grants to interests deemed worthy.⁶ In common law systems, by contrast, there is no general theory of subjective legal situations: an interest becomes legally relevant only if it finds a judicial remedy. The

² Pietro Perlingieri, *Manuale di diritto civile* (20^a edn, ESI 2020), 115–122.

³ Massimo Bianca, *Diritto civile. 1. La norma giuridica. I soggetti. I diritti* (Giuffrè 2014), 89–103.

⁴ Giorgio Oppo, *Scritti giuridici* (Giuffrè 2000) vol 1, 211–230; Paolo Grossi, *L'ordine giuridico medievale* (Laterza 1995), 45–53.

⁵ Guido Alpa, *Manuale di diritto privato* (8th edn, Laterza 2024), 77–80; Francesco Macario, ‘Interessi giuridicamente protetti e meritevolezza: attualità di un dibattito classico’ (2024) *Rivista di Diritto Civile* 211, 215–220; Pietro Perlingieri, *Il diritto civile nella legalità costituzionale* (11th edn, ESI 2023), 85–89.

⁶ Filippo Betti, *Teoria generale del negozio giuridico* (Giuffrè 2022), 55–62; Pasquale Stanzone, *Le situazioni giuridiche soggettive* (CEDAM 2023), 101–109.

underlying principle is *ubi remedium ibi ius*: without a remedy, there is no right.⁷ Thus, while in civil law the focus is on the dogmatic qualification of the protected interest, in common law the focus is on the effectiveness of protection through judicial enforcement. Despite these differences, all legal systems share the need to identify the holders of legally binding interests to allocate rights and duties -or remedies- and maintain the coherence of legal relationships. Consequently, holders are regarded as centres of attribution from which, and towards which, legal effects descending from acts, facts and relationships are directed. This conceptual framework will be a constant point of reference throughout the thesis. In particular, the concepts of legally binding interest and subjective legal situation will be recalled and employed in the subsequent analysis as interpretative tools to assess how the actions of DsAI systems can generate legal effects. By anchoring the investigation to these categories, it becomes possible to verify whether, and under what conditions, DsAI can be considered a centre for the attribution of legal consequences, thus contributing to a systematic reinterpretation of the traditional categories of legal subjectivity, capacity, and personality.

The law needs to identify the right-holder of such source of interests in order to allocate rights and obligations. This is what happens during the daily conduct of any legal activity. Thus, each activity will always be legally ordered and ascribable, through the legal interpretation, to categories determined by law or, vice versa, recognised by legal operators when applying rules to a specific case.⁸ For example, the legal position of contractual parties is well defined by law. Each contractual party bears a position of interest worthy of protection, such that the typical dynamics of the contractual relationship which determines rights and duties follow from it.⁹

⁷ Peter Birks, *Rights, Wrongs, and Remedies* (Clarendon Press 2000), 1–10; Stephen A Smith, *Rights, Wrongs and Injustices: The Structure of Remedial Law* (OUP 2019), 34–40; John Gardner, *From Personal Life to Private Law* (OUP 2018), 56–63.

⁸ Emilio Betti, *Teoria generale del negozio giuridico* (3rd edn, UTET 1960), 1.

⁹ Valeria De Lorenzi, 'Causa concreta e interesse meritevole di tutela' (2024) *Archivio di Diritto Civile* 1, 1.

Such a brief explanation is crucial to the scope of highlighting the conundrum that DsAI gives to the traditional dynamics of legal relationships. Indeed, unlike the well-defined legal situations, the use of artificial intelligence systems into the daily routine of acts and relations between legal actors determines confusion in recognising such sources of legal interests. Thus, the core of the problem lies in the lack of clear legal criteria to classify the DsAI phenomenon. Consequently, it becomes challenging to address what the real source of interests is worthy of protection or, as said before, the legal situation that stems from the use of DsAI systems.

Additionally, this condition is shaped by the ability of AI systems to go beyond their synthetic and computational form. Indeed, they interact with the external environment through actions that have tangible economic and legal consequences, such as executing transactions, managing digital assets, or autonomously concluding smart contracts.¹⁰ The growing ubiquity of such systems gives rise to new legal situations, such as the autonomous execution of transactions or the creation of contractual obligations, which the law still struggles to address. In this context, despite the efforts, DsAI still escapes any attempt to establish a legal framework that would be functional to its regulation. The main difficulty can be identified in the following point: for the very first time a system intervenes directly in the unfolding of legal relationships. More precisely, the DsAI poses itself within contractual dynamics, altering the traditional allocation of rights and duties to a certain source of legally binding interests. In the development of legal relations indeed, being able to detect the origin – the source- to which a legal situation worthy of protection belongs, would allow operators to understand whether and when to apply the traditional rules governing such relations. This condition could form the basis for the legal classification of both the phenomenon and the legal effects it produces.

¹⁰ Fabio Bassan, 'From Smart Legal Contracts to Contracts on Blockchain' (2024) *Computer Law & Security Review* 55, 105152; Luke Lee, 'Examining the Legal Status of Digital Assets as Property: A Comparative Analysis of Jurisdictional Approaches' (2024) *ArXiv* <<https://arxiv.org/abs/2406.15391>> accessed 2 June 2025.

Therefore, in this context, the DsAI raises compelling questions: to which legal source should the effects of its actions be attributed? Can the effects so generated be traced back to traditional categories, or do they reveal the limitations of existing classification schemes? The uncertainty surrounding these questions demonstrates the need for a specific legal study around the DsAI. In particular, the classification difficulties derive mostly from the blurring of the roles of contractual parties within the decentralised environment which hinders the reliable recognition of the source of legally binding interests involved. This challenge is compounded by attempts to include different types of artificial intelligence within a single category. Regulating DsAI through a non-specific study of its technical nature could therefore prove inconclusive, since this phenomenon is designed to change its characteristics continuously.

Consequently, the difficulty around the interpretative activity related to the application of the legal rules to the DsAI concrete case becomes the norm.

Furthermore, while some AI systems already fall within the scope of existing regulation, others like the DsAI, due to their more complex and sophisticated technical characteristics, might elude clear legal classification creating interpretative confusion. It is thus necessary to identify which technical characteristics of AI - despite their constant evolution- can serve as a steady benchmark for a legal classification of their roles. Thereby, the recognition of the DsAI distinct features would then allow the law and legal operators to distinguish it from other forms of AI systems and to better define its role in the identification of the source of legally binding interests.

As explained in chapter 1, this thesis adopts a bottom-up approach to answer the research question. The investigation of this chapter begins with the analysis of the technical foundations of AI systems, emphasising the DsAI systems' features. Subsequently, the analysis will concentrate on the legal implications. Throughout the examination of the technical aspects, the challenge to the traditional legal categories will emerge, highlighting the conceptual and

normative paradox. The purpose is to ground the legal analysis in technological reality to provide a clearer framework for assessing the role of DsAI in sole-code smart contracts, thereby contributing to the strengthening of legal certainty.

2.2 Technical Foundations of Artificial Intelligence Systems

From the technical perspective, AI is considered a rational agent. To be identified as such, as rational, a computational agent must be an entity perceiving the environment in which it is deployed.¹¹ Perceiving the environment means that the artificial entity must be able to understand, learn and act accordingly, with a certain degree of autonomy, to inputs and outputs received from its setting, concerning the problem it has been called to solve or the task that it must accomplish.¹² In other words, an AI agent must have the ability to simulate the human behaviour in a specific virtual environment, regarding the capacity of thinking, learning and acting intelligently.¹³

In these unique features, AI can be considered as entirely different from a computer program. Unlike the latter, which is nothing but a set of finite data instructions that must be executed¹⁴, AI is a system - not a program - which lives in a non-finite state, modelled through interactions and experience.¹⁵ In fact, as a system, the more AI interact and learns from data and environment, the more experience it gets. This general distinctiveness is the main reason why AI is so strictly linked to the neuroscience concept of human brain abilities and, at the same time, so distant from a simple algorithm.

¹¹ Stuart Russel and Peter Norvig, *Artificial intelligence a modern approach* (3rd, Pearson 2014), 34.

¹² Ibid 35.

¹³ Ibid, 5.

¹⁴ Brijesh Bakariya, *Data Structures and Algorithms Implementation through C: Let's Learn and Apply* (BPB Publications 2018), 2.1.

¹⁵ David Eagleman, *The Brain: The Story of You* (Vintage 2017), 6.

2.2. a) Autonomy: Defining the Core Trait of Artificial Intelligence Systems

Autonomy is the essential characteristic that makes AI systems legally relevant. In the technical field, autonomy represents the ability of AI systems to act in their environment without the intercession of direct human intervention, exercising control over their internal states and behaviour.¹⁶

According to Weiss:

‘Autonomy is a somewhat tricky concept to tie down precisely. (...) It is used to mean that agents are able to act without the intervention of humans or other systems: they have control over their own internal state, and over their behaviour’.¹⁷

Despite the difficulty of precisely defining the concept of autonomy, this characteristic can generally be applied—albeit to varying degrees—to all artificial intelligence systems. The more autonomous an AI agent becomes in its decision-making processes, the less direct supervision or control there is.¹⁸ This is because autonomy implies that the system is capable of making decisions based on its internal models and interactions with the environment, rather

¹⁶ Kenneth R Walsh, Sathiadev Mahesh and Cherie C Trumbach, ‘Autonomy in AI Systems: Rationalizing the Fears’ (2021) 47 *Journal of Information Technology Case and Application Research*, 38; Yuanyuan (Gina) Cui and Patrick van Esch, ‘Autonomy and Control: How Political Ideology Shapes the Use of Artificial Intelligence’ (2022) 39 (6) *Psychology & Marketing*, 1218.

¹⁷ Gerhard Weiss, *Multiagent Systems: A Modern Approach to Distributed Artificial Intelligence* (The MIT Press, 1999), 29.

¹⁸ Patrick Lin, Keith Abney and Ryan Jenkins (eds), *Robot Ethics 2.0: From Autonomous Cars to Artificial Intelligence* (Oxford University Press 2017).

than simply executing predefined external instructions.¹⁹ Consequently, the correlation between human input and system behaviour progressively decreases as autonomy increases. However, autonomy cannot be understood in isolation. It emerges from and is shaped by other fundamental characteristics of AI systems, namely learning processes, dependence on internal states and environments, adaptation and self-regulation mechanisms, and the goals for which they are designed.²⁰ The following subsections analyse these characteristics, which together determine the scope and degree of AI autonomy.

2.2. b) AI Learning Models and Degrees of Human Control

The technical foundation of AI ability to make autonomous decisions is the machine-learning process. This learning process enables AI to take and trust its own decisions based on the capacity to behave in response to the unceasing learning aptitude.²¹ This learning model provides AI with the ability to perceive and understand the background, acting accordingly.²²

In the AI field, three are the main machine-learning paradigms: supervised learning, unsupervised learning, and reinforcement learning.²³ Finally, directly related is deep learning, based on multilayer neural networks, which is not a separate paradigm, but rather a subfield

¹⁹ Ronald Arkin, *Governing Lethal Behavior in Autonomous Robots* (Chapman & Hall/CRC 2009).

²⁰ Sandip Sen and Gerhard Weiss, 'Learning in Multiagent Systems' in Gerhard Weiss (ed) *Multiagents Systems* (MIT Press, 1999), 259-298.

²¹ Fakhirah Badrulhisham and others, 'Machine Learning and Artificial Intelligence in Neuroscience: A Primer for Researchers' (2024) 115 *Brain, Behaviour, and Immunity* 470; Neelam Soni and Neha Nigam, 'Recent Advances in Artificial Intelligence and Machine Learning: Trends, Challenges, and Future Directions' (2025) 12(1) *International Journal of Engineering Trends and Applications*, 1.

²² Stuart Umpleby, 'Ross Ashby's general theory of adaptive systems' (2009) 38 2, *International Journal of General Systems*, 231-238.

²³ Christopher M Bishop, *Pattern Recognition and Machine Learning* (Springer 2006); Richard Sutton and Andrew Barto, *Reinforcement Learning: An Introduction* (2nd edn, MIT Press 2018).

that has transformed all three approaches by enabling highly complex pattern recognition and decision-making.²⁴

Supervised learning is about providing the AI system with a series of specific notions and examples which allow building a real database of information and experiences.²⁵ This way, when AI faces a problem, it will only have to draw on the experiences previously included into its system, analyse them and then decide the best answer to be provided based on codified experiences.²⁶ In other words, this is the method to teach AI how to do something.

As opposed to this model, in the unsupervised one, the information entered the machine is not coded.²⁷ It means that the machine can draw on certain information without having any example of its use and, therefore, without knowing the expected results depending on the choice made.²⁸ The machine itself will, therefore, classify all the information in its possession, organise it and learn the meaning, the use and, above all, the corresponding result.²⁹ The unsupervised learning gives the machine more freedom of choice; the machine itself will have to organise information intelligently and learn what the best results are for the different

²⁴ Yann LeCun, Yoshua Bengio and Geoffrey Hinton, 'Deep Learning' (2015) 521 Nature, 436.

²⁵ Özgür Genç, 'Machine Learning and Deep Learning for curious people' (2019), Towards Data Science <<https://towardsdatascience.com/notes-on-artificial-intelligence-ai-machine-learning-ml-and-deep-learning-dl-for-56e51a2071c2>> accessed 25 March 2020.

²⁶ Ibid.

²⁷ Jacob Kauffmann and others, 'Explainable AI Reveals Clever Hans Effects in Unsupervised Learning Models' (2025) 7 Nature Machine Intelligence, 412; Sarbaree Mishra and others, 'Building More Efficient AI Models through Unsupervised Representation Learning' (2024) 5(3) International Journal of Emerging Trends in Computer Science and Information Technology, 109.

²⁸ Geoffrey Hinton and Terrence Sejnowski, 'Unsupervised learning: Foundations of neural computation' in G. E. Hinton and T. J. Sejnowski (ed.), *Unsupervised learning: Foundation Computation* (MIT Press, 1999), viii.

²⁹ Babatunde Olanrewaju-George and Bernardi Pranggono, 'Federated Learning-Based Intrusion Detection System for the Internet of Things Using Unsupervised and Supervised Deep Learning Models' (2025) 3 Cyber Security and Applications, 100068.

situations arising.³⁰ In other words, with unsupervised learning, it is possible to let AI learn by itself.

Regarding the reinforcement learning, it is the process through which AI acquires experience in solving problems in the real world.³¹ Through the reinforcement learning model, AI is trained to learn through a system of attempt, error and reward.³² With this strategy, the AI decides by observing the environment. Based on continuous trials and errors, it tries to understand the best way to reach goals and maximise the reward.³³ As a consequence, the more AI agent moves closer to its aim, after a sequence of taken decisions, the more it will be rewarded with a positive value function.³⁴

The last category is known as Deep learning (DL).³⁵ The essential difference between machine learning and deep learning lies in the fact that the first one relies more on a statistical methodology of learning, whereas the latter is composed of nodes of algorithms – also called neurons - that allows AI to train itself in performing tasks. The AI neural network system is, indeed, inspired by the biophysics of human nervous system.³⁶ These unique connections are

³⁰ Ibid.

³¹ Geng Sun and others, ‘Generative AI for Deep Reinforcement Learning: Framework, Analysis, and Use Cases’ (2025) 32(3) IEEE Wireless Communications, 186; Jeff Shuford, ‘Deep Reinforcement Learning: Unleashing the Power of AI in Decision-Making’ (2024) 1(1) Journal of Artificial Intelligence General Science (JAIGS); Jacopo Kahl, ‘I tre principali tipi di Machine Learning: Apprendimento Supervisionato, Non Supervisionato e per Rinforzo’ <<https://jacopokahl.com/i-tre-principali-tipi-di-machine-learning-apprendimento-supervisionato-non-supervisionato-e-per-rinforzo/>> accessed 20 March 2020.

³² Geng Sun and others (n. 28), 186-195.

³³ Yuxi Li, ‘Deep Reinforcement Learning: An Overview’ (2018) arXiv <<https://arxiv.org/abs/1701.07274>> accessed 4 September 2025.

³⁴ Ibid.

³⁵ Giovanni Sartor, *L’informatica giuridica e le tecnologie dell’informazione. Corso di informatica giuridica* (3rd edn, Giappichelli Editore 2016), 301.

³⁶ Briland Hitaj, Giuseppe Ateniese and Fernando Perez-Cruz, ‘Deep Models under the GAN: Information Leakage from Collaborative Deep Learning’ (2017) *Proceedings of the 2017 ACM SIGSAC*

called synapses evolution algorithms, which dynamical adapt and program themselves to minimise the difference between expected and actual output.³⁷ The intricate pattern of deep learning is further emphasised by other types of advanced learning models³⁸, whose applications can be critical from both scientific and legal point of view. Amongst them there is Cognitive Computing (CC).³⁹ The cognitive computing aims at simulating the mechanism of human thought within an algorithmic model that can learn, infer and interact.⁴⁰

Albeit these kinds of machine-learning models are just some of the methods involved in the AI learning process, some considerations on autonomy and control patterns might be introduced. Different learning models demonstrate an inverse relationship between AI autonomy and human control. In supervised learning, the programmer's role is central: they provide data and examples, guiding the decision-making process step by step, with a very high

Conference on Computer and Communications Security (CCS '17) 603 <<https://doi.org/10.1145/3133956.3134012>> accessed 4 September 2025.

³⁷ Zhe Wang, Shangce Gao, Jiaxin Wang, Haichuan Yang and Yuki Todo, 'A Dendritic Neuron Model with Adaptive Synapses Trained by Differential Evolution Algorithm' (2020) *Computational Intelligence and Neuroscience*, 1-20.

³⁸ These are the Generative Adversarial Networks (GAN). Through GAN, it is possible to make neural networks more similar to human ones because they are allowed to create their connections rather than training learning through pre-set data. See Ankitha A Nayak, PS Venugopala and B Ashwini, 'A Systematic Review on Generative Adversarial Network (GAN): Challenges and Future Directions' (2024) 31 *Archives of Computational Methods in Engineering*, 4739; Xiaodan Yan and others, 'A Method of Information Protection for Collaborative Deep Learning under GAN Model Attack' (2021) 18(3) *IEEE/ACM Transactions on Computational Biology and Bioinformatics*, 1233.

³⁹ Vijay V Raghavan, Venkat N. Gudivada, Venu Govindaraju, C.R. Rao, *Cognitive Computing: Theory and Applications* (1st edn, North-Holland 2016), 5; Mamta Mittal, Rajiv Ratn Shah and Sudipta Roy (eds), *Cognitive Computing for Human-Robot Interaction: Principles and Practices* (Academic Press, 2021).

⁴⁰ Miltiadis Lytras and Anna Visvizi, 'Artificial Intelligence and Cognitive Computing: Methods, Technologies, Systems, Applications and Policy Making' (2021) 13(7) *Sustainability*, 3598.

level of control.⁴¹ In unsupervised learning, human intervention is reduced: the AI must autonomously organise and interpret data, generating non-predetermined results.⁴² In reinforcement learning, autonomy increases even further, as the AI develops strategies through trial and error based on rewards or penalties.⁴³ Finally, in deep learning, human control is minimal: self-programming neural networks allow the system to evolve independently, making behaviour less predictable and less directly attributable to human input.⁴⁴ A more technical comparative table of the analysed learning models is available in the Appendix A of this thesis.

2.2. c) The Influence of Internal State over AI Decision-Making Process

All these mentioned learning methods have their technical peculiarities. However, none of them can be efficiently explained without drawing attention to the importance of the internal state in which AI agents perform their learning behaviour. The role of the internal state, also called environment, is crucial in the AI decision-making process.

All in all, AI moves in a non-living environment but is subject to a fundamental property of living matter: the ability to receive information and organise impulses, making them effective in the outside world.⁴⁵ Hence, it is possible to conclude that the role of the environment can be considered crucial to the AI operations. In the machine-learning

⁴¹ Christopher Bishop, *Pattern Recognition and Machine Learning* (Springer 2006); Ian Goodfellow, Yoshua Bengio and Aaron Courville, *Deep Learning* (MIT Press 2016).

⁴² Trevor Hastie, Robert Tibshirani and Jerome Friedman, *The Elements of Statistical Learning: Data Mining, Inference, and Prediction* (2nd edn, Springer 2009).

⁴³ Richard S. Sutton and Andrew G. Barto, *Reinforcement Learning: An Introduction* (2nd edn, MIT Press 2018).

⁴⁴ Yann LeCun, Yoshua Bengio and Geoffrey Hinton, 'Deep Learning' (2015) 521 Nature, 436.

⁴⁵ Antonio Lieto and Gianluca Tamburini, 'A Critical Review of Cognitive Architectures for Artificial Agents' (2020) 12 Cognitive Systems Research, 59; Norbert Wiener, *Cybernetics: Or Control and Communication in the Animal and the Machine* (the MIT Press, 1948), 146.

algorithms, the environment is usually used also as a teacher for AI, especially for the unsupervised and reinforcement learning.⁴⁶ In this sense, the environment contributes to shaping AI behaviour and vice versa. The AI setting properties can influence its decision-making process, allowing agents to collect inputs deriving from its constantly changing state, necessary to the learning process.⁴⁷ At the same time, the reverse is also true. The internal background can be influenced and can change its state based on AI evolution and decision-making process.⁴⁸ Thus, there is a mutual influence on their evolving conditions.

AI's internal state also depends on the type of environment in which the system operates. Broadly speaking, two models can be distinguished: linear (deterministic) and nonlinear (nondeterministic).⁴⁹ In linear environments, the relationship between inputs and outputs is clear and predictable: there are a finite number of variables, and each agent's action leads to a well-defined effect.⁵⁰ In this scenario, the transition from one system state to another is measurable and stable, allowing relatively simple control of AI behaviour.⁵¹ In contrast, nonlinear environments are characterised by a much higher level of complexity. Here, the relationship between causes and effects is neither predictable nor constant: small changes in inputs can produce disproportionate or unexpected consequences in outputs.⁵² The variables at play are numerous and interconnected, resulting in the system's state becoming unstable, fluid, and often chaotic. Under these conditions, AI decisions cannot be anticipated with certainty, generating much greater margins of unpredictability and risk. This distinction is relevant not only from a technical but also a legal point of view: while in linear environments it is possible

⁴⁶ Richard S. Sutton and Andrew G. Barto (n. 43), 7.

⁴⁷ Stuart Russell and Peter Norvig, *Artificial Intelligence: A Modern Approach* (4th edn, Pearson 2021).

⁴⁸ Leslie P Kaelbling, Michael L Littman and Andrew W Moore, 'Reinforcement Learning: A Survey' (1996) 4(1) *Journal of Artificial Intelligence Research*, 237.

⁴⁹ Judea Pearl, *Causality: Models, Reasoning, and Inference* (2nd edn, Cambridge University Press 2009).

⁵⁰ George J. Klir, *Facets of Systems Science* (Springer Science, 2001), 578.

⁵¹ Nils J Nilsson, *Artificial Intelligence: A New Synthesis* (Morgan Kaufmann 1998).

⁵² Melanie Mitchell, *Complexity: A Guided Tour* (OUP 2009).

to connect the cause to its effect with a certain degree of reliability, in non-linear environments unpredictability makes it more difficult to trace the dynamics between cause and effect.⁵³

2.2. d) Adaptation and Self-Regulation in AI Models

In dynamic and nonlinear contexts, AI cannot rely on static learning: it must have adaptation and self-regulation mechanisms to maintain functionality and respond to unexpected events.⁵⁴ Adaptation allows the system to use and reorganise acquired knowledge to address environmental changes, compensating for the limitations of the knowledge originally provided by programmers.

In this way, AI develops increasing behavioural capacity, which translates into greater decision-making autonomy.⁵⁵ This autonomy, however, depends not only on learning models and the environment in which it operates, but also on the nature and complexity of the objectives to be achieved.⁵⁶ A system can have high levels of self-programming but still be limited if the task is narrow.

Consequently, autonomy increases proportionally to the level of learning and the complexity of the tasks, while the possibility of direct human control diminishes. Only through continuous processes of learning and adaptation can AI manage unpredictable events.⁵⁷ This is also confirmed from Russell and Norvig when arguing that an AI agent is learning if it can

⁵³ Mireille Hildebrandt, *Law for Computer Scientists and Other Folk* (Oxford University Press 2020).

⁵⁴ William Ross Ashby, *Design for a Brain* (Chapman & Hall, 1952), 1.

⁵⁵ Stuart A. Umpleby, 'Ross Ashby's general theory of adaptive systems' (2009) 38 2, *International Journal of General Systems*, 231-238.

⁵⁶ Simon Haykin, *Neural Networks and Learning Machines* (3rd edn, Pearson College Div, 2008), 218.

⁵⁷ Stuart Russel and Peter Novig, *Artificial Intelligence a Modern Approach* (3rd edn, Paerson Education, Inc., 2010), 38-39.

increase its performance compared to future tasks, after making observations and adaptations on the surrounding environment.⁵⁸ These aspects take on particular value in multi-agent DSAIs, where autonomy is multiplied by distributed interactions, making the application of traditional legal categories even more difficult.⁵⁹

2.3 The Decentralised Artificial Intelligence Systems

The complexity of AI entities can be deeply understood in relation to Decentralised Artificial Intelligence systems. According to Demazeau and Müller, DsAI ‘is concerned with the activity of an autonomous agent in a multi-agent systems world’.⁶⁰ The type of DsAI that is under analysis is indeed classified being in between the narrow AI⁶¹ and General AI (AGI)⁶²,

⁵⁸ Ibid, 393.

⁵⁹ Ibid, 234.

⁶⁰ Yves Demazeau and Jean Pierre Müller, *Decentralised A.I.* (Elsevier Science 1990), 3.

⁶¹ Sowri Babu V., Banana Khrisna, ‘A Study On Narrow Artificial Intelligence – An Overview’ (2024) 24 4 International Journal of Engineering Science and Advanced Technology (IJESAT) <https://www.ijesat.com/ijesat/files/V24I0428_1714383466.pdf> accessed 24 November 2024. Overall, a Narrow AI is defined as an AI system that is very limited in its scope. It can only be trained or just programmed to execute only one task.

⁶² General Artificial Intelligence (AGI) aims to mimic human-like cognitive abilities in different domains and across various and multiple tasks. Unlike narrow AI, AGI is not trained rather educated. For a in depth understanding: Goertzel B., ‘Bridging AGI Theory and Practice with Galois Connections’, in *Artificial General Intelligence: 16th International Conference, AGI 2023, Stockholm, Sweden, June 16–19, 2023, Proceedings* (ed. Patrick Hammer, Marjan Alirezai, Claes Strannegård, 2023), 115; In Ben Goertzel words: ‘we are moving now from weak AI-narrow AI to highly specialised network systems gradually to AI systems with gradually greater and greater degree of General Intelligence with more understanding of context and generalize from one context to a general problem area to another. We are in this transitional border between narrow AI and AGI’ Goertzel B., ‘The Future

thus defined as cognitive AI.⁶³ One of the main advantages of these integrated cognitive architectures is their versatility: they are not built to solve a single, narrowly defined problem but are designed to function autonomously—either fully or partially—across a wide range of tasks and environments.⁶⁴ Essentially, these systems strive to emulate the high-level structure of human cognition, leveraging various computer science algorithms to replicate the diverse capabilities of the human mind. This includes the integration of semantic reasoning (understanding meaning) and symbolic reasoning (logical manipulation of symbols), mimicking the way humans process and combine information for decision-making and problem-solving.⁶⁵ Unlike traditional AI models then, which require constant training (as

of AI: from Deep Learning to Deep Understanding’ (2017) <https://www.youtube.com/watch?v=nbUg9IuIs_8> accessed 5 February 2023.

⁶³ Ibid ‘The Artificial General Intelligence system has been developing for more than two decades — is already “self-aware” to a certain extent. A Hyperon system is not just a chatbot. It’s architected as a sort of autonomous agent which has its own goals and its own self-awareness and tries to know who it is and who you are, what it’s trying to accomplish in the given situation. So, it’s very much an autonomous, self-aware agent rather than just a question-answering system. What I mean by self-aware is that from the get-go, even the current versions, I mean, it has a model of who it is. It has a model of who you are. It has certain goals it’s trying to achieve in the situation. It knows how it relates to that situation and what it’s trying to do’. Goerzel B., ‘The Future of AI: from Deep Learning to Deep Understanding’ (2017) <https://www.youtube.com/watch?v=nbUg9IuIs_8> accessed 5 February 2023.

⁶⁴ Panahi R.M., Abrevaja G., Gagnon-Audet J-C., Rish I., Voleti V., Dumas G., ‘Generative Models of Brain Dynamics’ (2022) Front Artif Intell <<https://shorturl.at/WvTbi>> accessed 2 July 2024; Rish I., ‘On Scaling Laws, Emergent Behaviors, And AI Democratization Efforts Pending Confirmation’ AGI23 Conference, Day 3, June 18th, Stockholm. Keynote by Irina Rish <<https://www.youtube.com/watch?v=A-9uI-aoQGc&t=646s>> accessed 6 August 2024.

⁶⁵ ‘Integrating Hyperon With the SingularityNET Decentralized AI Platform’ <https://www.youtube.com/watch?v=QX77n-Alcvw&t=402s&ab_channel=SingularityNET> accessed August 2024.

seen with large language models)⁶⁶, DsAI systems acquire and process knowledge directly, dynamically, and in real-time as a unified, continuously updated resource.

2.3.1 a) Multi-agent systems Foundations of DsAI Systems: The Decentralised Architecture

When approaching this peculiar type of AI, it is necessary to point out that the DsAI as a system is the result of what is called multi-agent entities. As previously mentioned, AI is considered as a rational agent. In the case of DsAI, there is a plethora of rational agents which are deployed in a virtual environment, aiming at interacting between each other to undertake the scope they are called to. This means that all main features of AI systems - such as acting rationally and intentionally to accomplish tasks - operate in a complex, non-linear, decentralised interconnection between intelligent and autonomous agents. The notion of decentralisation is therefore of main importance. As already introduced in chapter 1, unlike centralised architectures, in which data resides in a single location, in decentralised systems, information is distributed among multiple nodes, each autonomous but cooperating. This setup allows DsAI agents to interact with both the environment and with each other, resulting in mutually influenced decision-making processes.⁶⁷ Their autonomy is therefore not only individual but systemic, emerging from dynamic interactions.⁶⁸

⁶⁶ Sheng Lu, Irina Bigoulaeva, Rachneet Sachdeva, Harish Tayyar Madabushi, Iryna Gurevych, ‘Are Emergent Abilities in Large Language Models Just In-Context Learning? (2024) Computer Science <<https://arxiv.org/pdf/2309.01809>> accessed November 2024.

⁶⁷ Andrew U. Frank, Steffen Bittner and Martin Raubal, ‘Spatial and Cognitive Simulation with Multi-agent Systems’ in Daniel R. Montello (ed), *International Conference on Spatial Information Theory*, (Springer, 2001), 124-139.

⁶⁸ Ibid.

2.3.1 b) Real-Time Adaptability Feature and Goal Orientation

DsAI agents are exceptionally suited for dynamic environments where conditions change every 100 milliseconds.⁶⁹ By maintaining a constant awareness of the latest data, throughout a meta-programming and self-modification, DsAI systems adapt in real time, integrating the most current knowledge from the network to make informed, accurate decisions in rapidly evolving scenarios.⁷⁰ Therefore, being able to define and pursue its own goals autonomously it is not only a technical feature but a deliberate design choice of multi-agent systems' systems.⁷¹ This way, DsAI can determine the most appropriate higher (principal) or lower-level (instrumental) goals, tasks and strategies, based on the specific circumstances they encounter. It allows DsAI systems to remain effective and resilient in environments characterised by uncertainty or unforeseen challenges.⁷² This capability underscores the importance of DsAI systems with both autonomy and adaptability at their core.

2.3.1 c) Autonomy Trait in DsAI Systems

Unlike other AI systems, multi-agent systems show greater complexity in the decision-making process, contributing to making them one of the most sophisticated AI systems.⁷³ For this reason, multi-agent systems require to exhibit a higher degree of autonomy, as the conduct of each agent directly contributes to the overall performance and effectiveness of both the system and the environment.

⁶⁹‘Integrating Hyperon With the SingularityNET Decentralized AI Platform’
<https://www.youtube.com/watch?v=QX77n-Alcvw&t=402s&ab_channel=SingularityNET>
accessed August 2024.

⁷⁰ Yoav Shoham and Kevin Leyton-Brown, *Multiagent Systems: Algorithmic, Game-Theoretic, and Logical Foundations* (CUP 2009).

⁷¹ Nicholas R Jennings and Michael J Wooldridge (eds), *Agent Technology: Foundations, Applications, and Markets* (Springer 1998).

⁷² Gerhard Weiss (ed), *Multiagent Systems* (2nd edn, MIT Press 2013).

⁷³ Yves Demazeau and Jean Pierre Müller, *Decentralised A.I.* (Elsevier Science 1990), 121.

Consequently, the DsAI performance affects and is affected not only by the interaction with the environment but also by each other, when they have to make decisions to perform a certain task or action.⁷⁴ How these mutual relationships work is not so simple to define. It is, indeed, influenced not only by a single agent autonomous decision-making process but by decisions taken by all agents as well.⁷⁵ For the purpose of this thesis' research question, it must be specified that the decisions undertaken by DsAI multi-agents must be regarded as a single integrated outcome. They represent the collective dynamics of the entire DsAI system.

2.3.1 d) Learning Models in Multi-Agent Systems

Autonomy in DsAI unfolds differently compared to other AI systems. In DsAI there is indeed a different approach to the machine-learning process compared to the traditional one. In other words, there is a merger between machine-learning and the distributed mechanism. It has been argued that 'an extended view of machine-learning that captures not only single-agent learning but also multiagent learning can lead to an improved understanding of the general principles underlying learning in both computational and natural systems'.⁷⁶ In fact, in DsAI, the learning process is not intended as an isolated procedure, but it also regards DsAI agents as a whole.⁷⁷ For such a reason, DsAI agents learn both how to improve their performances and how to achieve the best possible result when interact and collaborate with one another.⁷⁸

Unlike other AI, in the multi-agent systems system, the concept of cooperation and collaboration are introduced in relation to learning. Before discussing these peculiar features, it is necessary to establish a relevant concept: in a decentralised environment, also the learning

⁷⁴ Nigel Gilbert, 'Agent-based social simulation: dealing with complexity' (2004) 9 (25) The Complex Systems Network of Excellence, 1-14.

⁷⁵ Andrew U. Frank, Steffen Bittner and Martin Raubal, 'Spatial and cognitive simulation with multi-agent systems' in *International Conference on Spatial Information Theory* (Springer, 2001), 127.

⁷⁶ Sandip Sen and Gerhard Weiss, *Adaptation and Learning in Multi-Agent Systems* (Springer, 1996), 259.

⁷⁷ Ibid, 261.

⁷⁸ Ibid, 262.

mechanism can be both centralised and decentralised.⁷⁹ In DsAI, the learning process is called centralised when a single agent executes the process on its own, without any interaction. In this case, the agent is considered learning and operating alone, with independence from other agents.⁸⁰ On the contrary, the decentralised learning process takes place when all the learning activities are performed by several different agents.⁸¹ In the multi-agent systems system, both centralised and decentralised learning process can occur at the same time. Therefore, it is possible to have single agents which are learning to obtain the same goals and, concurrently, to have several different agents involved in distinct decentralised learning processes.⁸²

Such a circumstance leads to another peculiar trait of multi-agent systems system, regarding the control issue. In fact, in DsAI, unlike the other type of AI models, human assistance during the learning process is replaced and provided by the environment or by other agents themselves.⁸³ In other words, in DsAI also the control element is provided by the artificial system itself, increasing the complexity as well as the degree of autonomy in the decision-making process. According to Weiss, indeed, '[T]his means that the environment or an agent providing feedback acts as a 'teacher' in the case of supervised learning, as a 'critic' in the case of reinforcement learning, and just as a passive "observer" in the case of unsupervised learning'.⁸⁴

⁷⁹ Ibid, 264.

⁸⁰ Katia Sycara, 'Multiagent Systems' (1998) 10(2) AI Magazine, 79.

⁸¹ One example is the concept of federated learning, introduced around 2016. This model can be interpreted as a form of 'cooperative decentralised learning' for DSAIs, where blockchain-based consensus replaces central control and agents contribute autonomously to the training process. See Chuan Ma and others, 'When Federated Learning Meets Blockchain: A New Distributed Learning Paradigm' (2022) 17(3) IEEE Computational Intelligence Magazine, 26.

⁸² Lei Yuan and others, 'A Survey of Progress on Cooperative Multi-Agent Reinforcement Learning in Open Environment' (2023) ArXiv <<https://arxiv.org/abs/2312.01479>> accessed 4 September 2025.

⁸³ Luc Steels, 'The Artificial Life Roots of Artificial Intelligence' (1993) 1(1) Artificial Life, 75.

⁸⁴ Gerhard Weiss (ed), *Multiagent Systems* (2nd edn, MIT Press 2013); Liviu Panait and Sean Luke, 'Cooperative Multi-Agent Learning: The State of the Art' (2005) 29(6) Autonomous Agents and Multi-Agent Systems, 389.

Throughout the system's self-programming and adaptation methods, the lack of central control leads to one of the most critical consequences: each agent has its vision of the problem, or task, that needs to be solved or accomplished.⁸⁵ That means that the knowledge of each agent might be partial, incomplete or conflicting when deciding what action they need to perform to gain results.⁸⁶ To overcome these apparent difficulties, agents in DsAI system must cooperate and collaborate to fulfil their functions.

2.3.1 e) Cooperation, Collaboration, and Negotiation

As Artificial Intelligence field was deeply inspired by human-brain biology, in DsAI case this inspiration goes beyond the mere simulation of a single human-brain function. It also tries to mimic the humans' social interactions of cooperation and collaboration. It is not possible to understand these latter characteristics of DsAI without talking of multi-agent systems' functions of what are called desires, beliefs and intentions. Despite their names, the desires-beliefs-intentions paradigm does not have the purpose of anthropomorphise DsAI agents. On the contrary, in the AI field, this dynamic represent the way to explain the technical interrelation between multi-agent systems that justifies the cooperation and collaboration interactions.

2.3.1 f) Desires, Intentions and Beliefs: How Multi-agent systems Cooperate, Collaborate and Negotiate

In multi-agent systems, collective behaviour is not the result of isolated decisions but emerges from the dynamic interaction of what is called, in the AI field, the Belief-Desire-Intention (BDI) model.⁸⁷ Desires represent the goals that each agent aims to achieve and are

⁸⁵ Tad Hogg and Bernardo A. Huberman, 'Controlling Chaos in Distributed Systems' (1991) 21 IEEE Trans. On Systems, Man and Cybernetics, 1325-1332.

⁸⁶ Ibid, 1325.

⁸⁷ Anand S Rao and Michael P Georgeff, 'Modeling Rational Agents within a BDI-Architecture' in James F Allen, Richard Fikes and Erik Sandewall (eds), *Proceedings of the Second International*

the motivational driver of action. Intentions, on the other hand, are the deliberative state of the DsAI agent, the plans actually adopted to pursue these goals. Beliefs, instead, correspond to the internal representation that each agent develops about itself, the environment, and other agents.⁸⁸ Simply put, what an agent represents about itself, or other DsAI agents based on acquired knowledge, may initially be inaccurate and change as it interacts, cooperates, collaborates, or adapts its behaviour to pursue new goals. Therefore, the intentions, desires and beliefs architecture can influence both of a single agent and those of other agents' actions, as members of a single system.⁸⁹

These three elements do not operate statically but are in continuous interaction: desires guide the choice of intentions, intentions guide action, and the outcome of actions modifies beliefs, which in turn influence new desires and intentions.⁹⁰ In the DsAI ecosystem, this deliberative cycle takes on particular importance, as agents must address complex problems in decentralised environments, often with incomplete or conflicting information. In such contexts, divergent desires require negotiation processes, intentions become shared collective plans through cooperation and coordination, while beliefs serve as the basis for continuously adapting strategies and choices.⁹¹

Indeed, in DsAI systems, where agents must address complex objectives in decentralised environments and often with incomplete information, the three elements of desires, intentions,

Conference on Principles of Knowledge Representation and Reasoning (KR'91) (Morgan Kaufmann 1991).

⁸⁸ Ibid, 312.

⁸⁹ Nicholas Jennings, 'Controlling cooperative problem solving in industrial multi-agent systems using joint intentions' (1995) 75 (2) *Artificial Intelligence*, 195-240; Philip R. Cohen and Hector J. Levesque, 'Intention Is Choice with Commitment' (1990) 42 *Artificial Intelligence*, 213-261; Nick Jennings and Michael Wooldridge, 'Software Agents' (1996) *IEEE Review*, 17-20.

⁹⁰ Michael Wooldridge and Nicholas R Jennings, 'Intelligent Agents: Theory and Practice' (1995) 10(2) *The Knowledge Engineering Review*, 115.

⁹¹ Michael Wooldridge, *Reasoning about Rational Agents* (MIT Press 2000).

and beliefs become essential tools for structuring collective interaction.⁹² Desires, when they conflict, require compromises or reorganisation of priorities. Intentions, when shared, transform into collective plans that guide coordinated action, enabling a form of collaboration oriented toward common goals and not merely the sum of individual efforts.⁹³ Beliefs, constantly updated based on experience and mutual observation, decisively influence

⁹² In particular, in the DsAI systems, agents usually have to combine their ability to solve problems. Such joint work is necessary since individual agents may lack sufficient information or resources to solve problems alone. As previously mentioned, when an agent adopts an intention to do a complex action, its knowledge of how to do that action may be partial. Thus, the agents' interdependence and intentions occur when activities undertaken by single agents are connected. For instance, the interaction can occur because an individual agent's decisions might impact on decisions of community members or due to the possibility of harmful interactions amongst agents. In this way, agents need to communicate and interact to find the best solution among what could be a plethora of solutions for a single problem. See Edmund H Durfee, 'Distributed Problem Solving and Planning' in Gerhard Weiss (ed), *Multiagent Systems: A Modern Approach to Distributed Artificial Intelligence* (MIT Press 1999); Peter Stone and Manuela Veloso, 'Multiagent Systems: A Survey from a Machine Learning Perspective' (2000) 8 *Autonomous Robots*, 345.

⁹³ For this reason, DsAI agents must show social interaction ability. As stated, goals in DsAI systems can shape the degree of autonomy in decision-making process of multi-agent systems. Hence, they need to choose what action is necessary to accomplish that goal. What is interesting is that goals in such a system can be explicitly given to agents either it can be acquired by the contest itself or deriving from the observation of other agents' behaviour. Consequently, in such a system, even the modality through which agents choose their goals is dynamic and not predictable. As already explained, the choice made by each agent is considered as an intention, once it has decided to reach a specific goal. Thus, since there is not a central control over the learning process, agents have to understand how to deal with conflicting intentions or even conflicting goals among them to improve the performance of the system as a whole. In doing that, they have to cooperate and collaborate to work. In these cases, to allow cooperation and collaboration procedures, agents have to exchange information with each other's on knowledge, possible solutions, other agents' intentions, desires and goals. See Barbara J Grosz and Sarit Kraus, 'Collaborative Plans for Complex Group Action' (1996) 86 *Artificial Intelligence*, 269; Michael P Wellman, 'A Market-Oriented Programming Environment and Its Application to Distributed Multicommodity Flow Problems' (1993) 1 *Journal of Artificial Intelligence Research*, 1;

operational choices and the ability to adapt. The dynamics between competing desires, converging intentions, and changing beliefs precisely underpin the need for collaboration, cooperation, and negotiation⁹⁴: agents must exchange information, evaluate alternatives, and reach functional agreements to maintain cooperation even in unpredictable conditions.⁹⁵ This way, DsAI systems do not simply react passively to the environment but develop a collective rationality that is expressed through processes of active cooperation, collaboration, and negotiation.⁹⁶ Elements that increase their level of decision-making autonomy. The beliefs-desires-intentions architecture, therefore, allows agents to act with a degree of intentional behaviour, enabling the system as a whole to maintain cooperation and collaboration even in changing and unpredictable scenarios.⁹⁷

⁹⁴ Sarit Kraus, *Strategic Negotiation in Multiagent Environments* (MIT Press 2001); Nicholas R Jennings, Peyman Faratin, Alex R Lomuscio, Simon Parsons, Carles Sierra and Michael Wooldridge, 'Automated Negotiation: Prospects, Methods and Challenges' (2001) 10 Group Decision and Negotiation, 199.

⁹⁵ Milind Tambe, 'Towards Flexible Teamwork' (1997) 7 Journal of Artificial Intelligence Research, 83; Reid G Smith, 'The Contract Net Protocol: High-Level Communication and Control in a Distributed Problem Solver' (1980) 29(12) IEEE Transactions on Computers, 1104.

⁹⁶ Thus, the cooperation-intention can be considered as a complex as well as a dynamic interaction that occurs on decentralised systems. In fact, given a particular goal or problem to solve, agents can also show a different style of cooperation among them. In other words, an agent can offer total cooperation to others, either retain a secondary self-interest (to reach its own goal), be a complete selfishness agent with a cooperation intention as a secondary goal or even show a mixture of such behaviours. When in DsAI systems, conflicts among agents arise due to their different cooperation styles, what happens is the need for negotiation. DsAI agents must transact among them, reaching a term on their intentions and goals to decide a well-defined plan to solve the problem in an unpredictable environment. See Brenna D Argall, Sonia Chernova, Manuela Veloso and Brett Browning, 'A Survey of Robot Learning from Demonstration' (2009) 57 Robotics and Autonomous Systems, 469; Andrew Y Ng and Stuart Russell, 'Algorithms for Inverse Reinforcement Learning' in Proceedings of the 17th International Conference on Machine Learning (ICML 2000) (Morgan Kaufmann 2000), 663.

⁹⁷ Along with cooperation, the multi-agent system can perform collaboration procedures. Unlike cooperation, collaboration behaviour concerns global, also known as interpersonal, goals. Consequently, such goal regards all agents of the system, but it can be accomplished by several of them

2.3.1 g) DsAI Self-Organisation and Co-Evolution

Additionally, DsAI shows undoubtedly a high level of self-organisation mechanism. This is particularly true when they have to take autonomous decision according to the interaction process with other agents. Unlike another type of AI, each DsAI agent shows a total control on its internal state, so that it can adopt a specific behaviour without external human intervention.⁹⁸ As it has been affirmed ‘autonomous agents must have control over their acquisition of internal states, i.e. their belief and goal adoption...Agents decide autonomously based on their preferences’⁹⁹ and indeed ‘[P]art of the complexity in behaviour is due to the coevolving nature of the system, i.e., the value of an agent’s decision depends on the choices made by all the others.’¹⁰⁰ Therefore, unlike other AIs, multi-agent systems evolve and coevolve rapidly detaching from their basic knowledge with a more significant space of autonomous behaviour.

collectively. Thus, cooperation or collaboration processes in DsAI can be strictly related to the type of agents’ goal, personal (local) or interpersonal (global). To further clarify, in cooperation process agents’ need to learn how they can coordinate their behaviour to achieve common goals. In fact, in this scenario, to deal with the problem, agents need to learn to adopt specific roles concerning a collaborative problem-solving context. Thus, when the collaborative activity is necessary to achieve the aim, the learning objective will be for each agent, the selection of the most appropriate role to play in that given context. *See* Barbara J Grosz and Sarit Kraus, ‘Collaborative Plans for Complex Group Action’ (1996) 86 *Artificial Intelligence*, 269; Prasanta R Pynadath and Milind Tambe, ‘The Communicative Multiagent Team Decision Problem: Analyzing Teamwork Theories and Models’ (2002) 16 *Journal of Artificial Intelligence Research*, 389.

⁹⁸ Djamel Zeghida, Djamel Meslati and Nora Bounour, ‘Bio-IR-M: A Multi-Paradigm Modelling for Bio-Inspired Multi-Agent Systems’ (2018) 42 *Informatica*, 451-466 <https://doi.org/10.31449/inf.v42i3.1516> accessed 7 April 2020.

⁹⁹ Demazeau and Müller (n. 60), 59.

¹⁰⁰ Michael Youssefmir and Bernardo Huberman, ‘Resource Contention in Multiagent Systems’ (Proceedings of the First International Conference on Multiagent Systems, AAAI Press 1995), 398.

2.3.2 How DsAI Operate in Sole-Code Smart Contracts Transactions: Technical Overview

As mentioned in the introductory chapter, from a technical perspective, a DsAI can create and manage sole-code smart contracts along three complementary lines:

(i) Writing and deployment. The DsAI can generate the code (for example, in Solidity language), compile it, and deploy it on-chain. This operation can be performed via an external account (EOA) or—more securely—via smart wallets or multisigs governed by predetermined policies (such as timelocks or spending limits). In distributed signature scenarios, based on Multi-Party Computation (MPC) or Threshold Signature Schemes (TSS), private key management can be based on threshold protocols (for example, FROST for Schnorr, or threshold-ECDSA for two or more parties).¹⁰¹ In this way, the transaction is validated only if a quota of participants cooperates, eliminating the single point of failure and introducing *ex ante* controls on gas consumption or execution time windows. Simply put, it means that DsAI can autonomously write and launch a smart contract, but it does so in a distributed and secure way, without any single key or individual having absolute control.¹⁰²

¹⁰¹ Deirdre Connolly, Chelsea Komlo, Ian Goldberg and Christopher A Wood, ‘The Flexible Round-Optimized Schnorr Threshold (FROST) Protocol for Two-Round Schnorr Signatures’ RFC 9591 (2024); Yehuda Lindell, ‘Fast Secure Two-Party ECDSA Signing’ (2021) 34(4) *Journal of Cryptology* 44; Rosario Gennaro and Steven Goldfeder, ‘Fast Multiparty Threshold ECDSA with Fast Trustless Setup’ in *Proceedings of the 2018 ACM SIGSAC Conference on Computer and Communications Security (CCS ’18)* (ACM 2018) 1179; HWH Wong and others, ‘Real Threshold ECDSA’ in *Network and Distributed System Security Symposium (NDSS 2023)* (Internet Society 2023).

¹⁰² To clarify how it works, consider an example of automated escrow: a DsAI can generate a contract in Solidity that provides for the transfer of 1 ETH to B if a signed document is provided within 7 days, otherwise, the funds are returned to A. The contract is compiled and distributed on-chain, not through a single human account, but through a distributed multisig wallet (i.e. 3 out of 5 nodes), thus eliminating the single point of failure and introducing *ex ante* controls on gas and execution times. In this way, the contract is created and published entirely by the DsAI, without direct human intervention, and the

(ii) Parameterisation and instantiation. Even without writing new code, DsAI can configure on-chain modules (liquidity pools, vaults, escrow) by interacting with existing factory contracts. Using the CREATE and CREATE2 instructions, it is possible to generate contracts with a deterministic and predictable address, allowing DsAI to instantiate new contractual units in an automated and replicable manner. This ability to combine pre-existing modules allows DsAI to adapt to changing contexts without requiring human intervention each time.¹⁰³

(iii) Autonomous execution. Through oracles and automation services (keepers), DsAI can activate contractual functions when on-chain or off-chain conditions occur, such as price changes, timestamps, or certified external events. In this way, it is able to schedule and activate jobs without direct human intervention, maintaining continuous and self-organised responsiveness within the decentralised environment.¹⁰⁴

These three operational guidelines demonstrate how the technical traits of DsAI—autonomous decision-making, multi-agent interaction capabilities, and adaptive learning—are effectively embedded in sole-code smart contracts. It is no longer an artificial intelligence that passively executes predefined rules, but a system that actively participates in all phases of the contractual lifecycle: from code generation to its modular configuration to the autonomous

resulting legal effects (transfer of funds, creation of obligations) derive from the autonomous and distributed behaviour of the DsAI. See Primavera De Filippi and Aaron Wright, *Blockchain and the Law: The Rule of Code* (Harvard UP 2018), 55–61; Max Raskin, ‘The Law and Legality of Smart Contracts’ (2017) 1 *Georgetown Law Technology Review* 305, 314–319; Kevin Werbach, ‘Trust, but Verify: Why the Blockchain Needs the Law’ (2018) 33 *Berkeley Technology Law Journal* 487, 510–514.

¹⁰³ Ethereum Improvement Proposal EIP-1014: ‘Skinny CREATE2’ (2018) <eips.ethereum.org/EIPS/eip-1014> accessed 20 April 2024; Hayden Adams and others, ‘Uniswap v2 Core’ (2020) white paper <app.uniswap.org> accessed 4 May 2024.

¹⁰⁴ Michael Bartholic, Aron Laszka, Go Yamamoto and Eric W Burger, ‘A Taxonomy of Blockchain Oracles: The Truth Depends on the Question’ in *IEEE International Conference on Blockchain and Cryptocurrency (ICBC 2022)*.

activation of coded clauses.¹⁰⁵ Hence, the creation of sole-code smart contracts by DsAI systems cannot be traced back to a direct single source, but rather to a combination of factors: (i) initial human input of a general nature (i.e. the development of a DsAI tasked with managing DeFi processes); (ii) algorithmic self-governance, through which the DsAI, based on internal models and distributed rules, can autonomously decide when and how to write and distribute a contract; (iii) activation conditioned by external events (oracles or on-/off-chain triggers) that serve as sufficient conditions for the generation or execution of the contract. In this sense, the order to create and deploy does not come from a single identifiable subject. Still, it emerges as the outcome of a distributed and systemic process, devoid of a direct human referent.

This means that: in the creation phase, DsAI contributes directly to the writing and deployment of contracts, autonomously deciding the technical form of the constraint (e.g., choice of security protocols, governance structures, allocation of computational resources). In the configuration phase, DsAI does not simply use pre-existing modules, but defines and parameters them based on the objectives pursued: a vault can be opened or closed based on market conditions, a liquidity pool can be balanced based on adaptive strategies.¹⁰⁶ Each parametric choice determines the distribution of rights (i.e., governance shares) and obligations (i.e., liquidity guarantees) among parties who will then interact with the contract. In the execution phase, the DsAI activates clauses upon the occurrence of conditions internal or external to the blockchain, without any direct human input.¹⁰⁷ Oracles and automation systems act as technical interfaces that allow the DsAI to connect the on-chain world with off-chain variables (market prices, timelines, certified events). The outcome is not neutral: it produces immediately binding dispositive acts such as token transfers, automatic liquidations, crediting or enforcement of collateral.

¹⁰⁵ Nick Jennings, Michael Wooldridge, *Agent Technology: Foundations, Applications, and Markets* (Springer 2012).

¹⁰⁶ Chris Brummer, *Cryptoassets: Legal, Regulatory, and Monetary Perspectives* (OUP 2019).

¹⁰⁷ Aaron Wright and Primavera De Filippi, 'Decentralized Blockchain Technology and the Rise of Lex Cryptographia' (2015) <https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2580664> accessed 10 October 2023.

It follows that the legal effects—creation of obligations, attribution of rights, changes in financial relationships—arise from an autonomous choice by the DsAI. This conduct is observable, repeatable, and produces measurable consequences, but it lacks a single subjective referent to whom the law can attribute it according to traditional categories.¹⁰⁸ The result is a profound tension: on a technical level, the DsAI acts as a distributed collective entity, capable of autonomous and coordinated decisions; on a legal level, it formally remains an object devoid of subjectivity and capacity, forcing the law to deal with transactions that have binding force without a traditional entity to which they can be attributed.

It is within this framework—between technical autonomy and the lack of legal recognition—that the technical-legal paradox arises namely, the production of binding legal effects in the absence of an intention to contract immediately attributable to an identifiable actor. The DsAI, although not classified as a contractual actor, can produce effects that the law cannot ignore, because they impact legal situations and concrete contractual relationships.

2.3.3 Final Considerations over the Technical Traits of DsAI Systems

The analysis of Decentralised Artificial Intelligence (DsAI) systems shows how their distinctive characteristics—autonomy, adaptability, learning, and self-organisation—emerge from the interaction of multiple intelligent agents operating in decentralised environments. Unlike traditional AI, DsAI is not based on central control or static training models, but evolves dynamically through cooperation, collaboration, and negotiation between agents. The beliefs-desires-intentions mechanism provides a technical framework to describe how agents can align, adapt, or conflict in their goals and strategies, reflecting a form of collective rationality rather than individual programming. What emerges clearly is that autonomy in DsAI is not a property of the individual agent, but rather a systemic phenomenon, the integrated result of distributed interactions within a complex and non-linear environment. This ability to co-adapt, negotiate, and reorganise behaviour in response to unforeseen circumstances underpins their resilience and effectiveness, but at the same time challenges elements of control and oversight.

¹⁰⁸ Mireille Hildebrandt, *Law for Computer Scientists and Other Folk* (OUP 2020).

In conclusion, DsAI systems embody a new paradigm of technical and cognitive AI that transcends the confines of conventional models: they are simultaneously autonomous in their internal models, interdependent in their interactions, and collective in their outcomes. These characteristics make them exceptionally powerful for managing uncertainty and complexity within a decentralised open-permissionless environment, but they also raise profound questions about how the law can recognise, interpret, and regulate their role in contractual relations.

2.4. From Technical to Legal Debate: Transition to Legal Analysis

The previous sections examined the technical foundations of Decentralised Artificial Intelligence (DsAI), demonstrating how autonomy, adaptive capacity, learning, and self-organisation are not isolated properties of individual agents, but systemic traits of the DsAI system that emerge from the distributed interaction of multiple intelligent agents in decentralised environments. This analysis was not conducted in isolation from the central objectives of the thesis: it aims at laying the foundations to understand under what conditions the technical behaviour of DsAI in sole-code smart contracts can then assume a legal relevance.

The central research question concerns whether and to what extent DsAI systems—autonomous, decentralised, and collectively adaptive—can generate legally relevant behaviours and situations for the purposes of contract formation and contractual capacity, even without being recognised as legal actors. The technical investigation has shown that DsAI is capable of highly autonomous decision-making process; negotiating, cooperating, and co-adapting within decentralised environments; producing observable behaviours that can then generate tangible effects within blockchain transactions.

These characteristics highlight a dual consideration at the intersection of technology and law. On the one hand, DsAI exhibits technical and cognitive elements that distinguish it from other types of AI. On the other hand, these elements must be taken into account when assessing the legal understanding of DsAI decision-making capacity within decentralised contractual relationships. What emerges is indeed that the DsAI technical features—when assessed within the specific operational context of smart contracts—tend to distance this system from the

notion of artificial intelligence as a mere tool. Specifically, through its active participation in the creation, configuration, and execution of contractual mechanisms, DsAI approaches the functional role of a legal actor to the extent that it becomes capable of generating legally relevant situations and effects. From this perspective, DsAI appears to challenge the traditional assumption that only human or corporate actors can constitute centres of attribution of legally relevant situations.

To address this aspect, the thesis now shifts from the technical to the legal debate. To address those aspects, it is necessary to revisit the fundamental concepts of legal subjectivity, legal personhood, legal capacity, and contractual capacity. These categories constitute the analytical tools and lenses through which the conduct of DsAI can then be assessed. The reasoning is progressive: only by clarifying who or what qualifies as a legal subject or actor and how legal capacity operates within the legal system will then be possible to address – later in the thesis – the legal position of DsAI within contractual relationships.

The structure of this thesis follows this progressive reasoning. After outlining the technical characteristics of DsAI, the next sections compare them with the fundamental legal categories and regulatory frameworks that define legal personhood, subjectivity and capacity. This will allow to assess whether traditional concepts are capable of accommodating the unique features of DsAI or whether new theoretical approaches are needed. Therefore, the shift from technical to legal debate paves the way for a systematic reflection on how the law could potentially address the role of DsAI in sole-code smart contracts.

2.5 The Challenge to Fundamental Legal Concepts: Evaluating the Applicability of Legal Personhood to Multi-Agent Systems

Following the technical description of how DsAI systems interact within decentralised transactions, they are able of assuming an active role in legally significant interactions. This way, they present unique challenges to traditional legal frameworks. Unlike others AI models, DsAI high degree of autonomous decision-making process allows to directly engage with other

decentralised agents or participants, producing legal effects. These legal effects include entering into agreements, executing obligations, and influencing contractual rights and duties. By functioning autonomously, the DsAI systems blur the boundaries between human and algorithmic actors, disrupting established assumptions about the nature of contractual actors.

This raises the question as to whether DsAI systems should continue to be classified as mere tools or whether their cognitive and operational abilities should necessitate a different legal recognition. As legal capacity is reserved to humans and non-human entities, such as corporations, DsAI agents seem to defy this traditional categorisation, challenging the adequacy of existing legal concepts to address their role effectively.

Therefore, it is essential to analyse whether established legal concepts – such as legal personhood - are suitable for defining the legal role of DsAI systems. Hence, this section will examine these foundational concepts, emphasising their theoretical underpinnings and application. Subsequently, it will assess their applicability to DsAI systems, identifying areas where they align with or diverge from the unique characteristics of these systems.

By critically analysing these notions, the thesis aims to determine whether existing legal frameworks can accommodate the distinctive features of DsAI systems or whether new theoretical approaches are required. The discussion will conclude with an evaluation of the findings, providing a foundation for the subsequent development of a more comprehensive legal framework for the classification of DsAI systems' role in the context of sole-code smart contract transactions.

2.6 Foundations of Legal personhood, Subjectivity and Legal Capacity in European Legal Systems: Comparative Analysis of Civil Law and Common Law Traditions

Within the European legal tradition, ‘legal personhood’ is broadly defined as the capacity to hold rights and duties.¹⁰⁹ As Brian Smith stated:

“To be a legal person is to be *the subject of rights and duties*. To confer legal rights or to impose legal duties, therefore, is to confer legal personhood.”¹¹⁰

And as John Salmond beautifully explained:

“So far as legal theory is concerned, *a person is any being whom the law regards as capable of rights and duties. Any being that is so capable is a person, whether a human being or not, and no being that is not so capable is a person, even though he be a man*. Persons are the substances of which rights and duties are the attributes. It is only in this respect that persons possess juridical significance, and this is the exclusive point of view from which personhood receives legal recognition”¹¹¹

Legal personhood is a foundational concept in European legal traditions.¹¹² It constitutes the very basis of legal systems, designating who or what is capable of bearing rights and duties before the law.¹¹³ The concept itself goes beyond a mere legislative definition as it is an

¹⁰⁹ John Chipman Gray, *The Nature and Source of The Law* (2d ed., Macmillan & Co Ltd, 1921), 27.

¹¹⁰ Bryant Smith, ‘Legal personhood’ (1928) 37 (3) Yale Law Journal, 283.

¹¹¹ John Salmond, *Jurisprudence* (Glanville Llewelyn Williams 10th edn, Sweet & Maxwell 1947), 318.

¹¹² Visa A.J. Kurki, ‘Legal Personhood’ (2023) Published online by Cambridge University Press, Helsinki Legal Studies Research Paper No. 82 <<https://ssrn.com/abstract=4669283>> accessed 28 December 2024.

¹¹³ Alexis Dyschkant, ‘Legal personhood: How we are getting it wrong’ (2015) 5 University of Illinois law review, 2075.

organically recognised notion within both civil and common law legal systems.¹¹⁴ At the same time, the legal personhood concept is fraught with ambiguity, for it is strictly interrelated with the notions of legal subjectivity and legal capacity.¹¹⁵ For example, most civil law systems assimilate legal personhood with the concept of legal subjectivity and legal capacity, which together define a person's legal standing or status.¹¹⁶ This contrasts with the common law tradition, where legal personhood primarily refers to the separate legal personhood of non-natural persons. In this regard, the two traditions diverge in both terminology and substance.

To successfully progress with the discussion about legal personhood, legal subjectivity and legal capacity, the chapter will also present these concepts in light of the different approaches of common law and civil law systems. Both systems have merits in developing such notions. Specifically, whereas the civil law systems engaged with more abstract thinking theories to explain them, common law systems developed them more practically, by organically establishing those principles within the legal framework. In both cases though, it is possible to affirm that all these concepts exist with some structural differences.

2.6 a) Legal Subjectivity of Natural and Artificial Persons: The Qualitative Trait of Legal Personhood

In both Brian Smith's and John Salmond's works, the concept of legal personhood is examined through the lenses of legal subjectivity and legal capacity. A clear explanation of both concepts is therefore essential for a comprehensive investigation of legal personhood.

The term 'legal subject' or 'subject of law/subject of rights and duties', firstly introduced by Savigny in 1840, is used within the civil law systems to refer to all rights-holding persons,

¹¹⁴ Jens David Ohlin, *The Assault on International Law* (Oxford University Press 2015).

¹¹⁵ Kurki (n. 112), 1.

¹¹⁶ Most civil law legal theories confirm this approach. See, amongst many, Beudant, *Cours de droit civil francais* (I, Paris, 1896), 1; Dusi, *Istituzioni di Diritto Civile* (Sarfatti, Torino, 1930); Faddabensa, *Note al Windsheid* (1935), 601.

being natural or artificial.¹¹⁷ Term legal subject is used as opposed to legal objects (like slaves would be). In civil law systems, being a legal subject means being recognised by the law as ‘suitable to be entitled of rights and duties, considered as ‘legally relevant events or situations’, which derive from legal relations.’¹¹⁸ The concept of the legal subject in the civil law system is also a synonym of ‘legal person’ and the two concepts are often used interchangeably. Being a legal subject or being a legal person has indeed the same meaning as legal persons in civil law systems are both natural and artificial persons which possess legal personhood (see Table 1).

Even with some structural differences, the common law system recognises a similar concept.¹¹⁹ In common law, being a legal subject implies indeed the ability to acquire rights, duties, and obligations through legal relationships.¹²⁰ In common law jurisdictions the term legal subject is thus not explicitly used, rather there is an implied recognition of the concept itself.¹²¹ In addition, they refer to legal persons only when designating artificial entities capable of holding rights and duties.¹²² A key distinction is that in common law systems, as opposed to civil law systems, legal persons are only artificial persons, primarily corporations,

¹¹⁷ Friedrich Carl von Savigny, *System des Heutigen Römischen Rechts* [System of Modern Roman Law] (Berlin Veit, first published in 1840-1849, Gale, Making of Modern Law, 2013). He defines legal persons as *Rechtssubjekt; sujet de droit*.

¹¹⁸ Pietro Perlingieri, *Il diritto civile nella Legalità Costituzionale*, (1st edn, Edizioni Scientifiche Italiane, 1988), 329.

¹¹⁹ Lawrence B. Solum, ‘Legal Theory Lexicon 027: Persons and Personhood’ (2004) Legal Theory Lexicon <https://lsolum.typepad.com/legal_theory_lexicon/2004/03/legal_theory_le_2.html> accessed 6 January 2025.

¹²⁰ Ibid.

¹²¹ Diana Madalina Mocanu, ‘Gradient Legal Personhood for AI Systems – Painting Continental Legal Shapes Made to Fit Analytical Molds’ (2022), 8 Frontiers in Robotics and AI <<https://www.frontiersin.org/journals/robotics-and-ai/articles/10.3389/frobt.2021.788179/full>> accessed November 2024.

¹²² Martin Wolff, ‘On the Nature of Legal Persons’ (1938) 54 Law Quarterly Review, 494.

foundations or other similar bodies.¹²³ Whereas natural persons are not classified as legal persons and constitute the opposite legal category.¹²⁴ Hence, in common law, the two notions of legal subject and legal person are not synonymous nor interchangeable (see Table 2.1).

	Concepts	Definition	Civil Law System	Common Law System
1	Legal Subject	An entity – natural or artificial- capable of holding rights and duties.	Explicitly recognised concept. Includes both natural and artificial persons.	Implicitly recognised. Not explicitly used as a legal concept. Refers to entities – natural or artificial- being capable of holding rights and duties
2	Legal Person	An entity – natural or artificial - endowed with legal personhood.	Synonymous of ‘legal subject’. Includes both natural and artificial persons having legal personhood.	Refers only to artificial persons (i.e. corporations, associations, foundations, charities, etc.).

Table 2.1 Concepts of legal subject and legal person: comparison between civil law and common law traditions

Therefore, to bridge the conceptual and terminological divide between common law and civil law, the concept of legal subjectivity can be described as follows: legal subjectivity is recognised as the capacity of a person, being natural or artificial, to be the holder of rights, duties, and legal interests, and to which legally significant actions and relations are attributed. Hence, all persons capable of holding rights and/or duties in a legal system are functionally

¹²³ Alexis Dyschkant, 'Legal personhood: How we are getting it wrong' 2015 (5) University of Illinois law review, 2076.

¹²⁴ Mohammed Saif-Alden Wattad, 'Natural Persons, Legal Entities, and Corporate Criminal Liability under the Rome Statute' (2016) 20 (2) UCLA J Journal of International Law and Foreign Affairs, 391.

legal subjects.¹²⁵ Legal subjectivity is therefore that fundamental characteristic that qualifies persons, natural or artificial, being able to engage in legal relations by way of possessing and exercising rights and duties.¹²⁶ Consequently, legal personhood in relation to the concept of legal subjectivity can be explained as follows: legal personhood is the recognition of legal subjects' ability to enter and be part of legal relations.¹²⁷ In both common law and civil law systems, for natural persons legal personhood is inherently recognised from birth and does not need to be explicitly granted.¹²⁸ Whereas for artificial persons the recognition of legal personhood must be explicitly admitted by law.¹²⁹ Therefore, legal subjectivity can also be understood as the qualitative trait of persons that possess legal personhood.

This specification and comparison between civil and common law systems is essential, as this thesis will refer to both natural and artificial persons in discussing legal personhood.

2.6. b) Legal Capacity and Capacity to Act: The Quantitative Trait of Legal Personhood

Legal capacity refers to the ability of persons to hold rights and duties.¹³⁰ This definition encompasses both civil law and common law systems.¹³¹ Compared to common law, civil law

¹²⁵ Karl Salomo Zacharie, *Corso di Diritto Civile Francese* (Muzj (tr) 1857), 72.

¹²⁶ John Austin, *Lectures on Jurisprudence* (first published 1875, Robert Campbell, 2005), 109; John W. Salmond, *Jurisprudence* (4th edn, Stevens and Haynes, 1913), 299.

¹²⁷ Smith (n. 110), 283.

¹²⁸ William Markby, *Elements of Law* (6th edn, Oxford University Press, 1905), 78.

¹²⁹ Ibid.

¹³⁰ Ngaire Naffine, *Law's Meaning of Life. Philosophy, Religion, Darwin and The Legal Person* (1st edn, Hart Publishing, 2009), 8.

¹³¹ Even with structural differences. Legal capacity has a statutory meaning in Civil Law traditions; see Art. 1 'Capacity to hold rights' Italian Civil Code; Art. 1145 'General Principles of Legal Capacity' French Civil Code; Section 1 Bürgerliches Gesetzbuch (BGB – German Civil Code). In western Common Law systems legal capacity is shaped by case law; see *Nash v. Inman* [1908] 2 KB 1; *Banks v. Goodfellow* [1870] LR 5 QB 549.

systems make a clear distinction between so-called passive and active legal capacity.¹³² Passive legal capacity designates the general ability of the subject to hold rights and duties¹³³, while active legal capacity refers to the ability to exercise those rights and duties, producing legal effects for oneself or others.¹³⁴ This latter ability is called ‘capacity to act’.

In contrast, common law systems do not distinguish between legal capacity and capacity to act. The concept of legal capacity encloses indeed both dimensions: the ability to hold rights and duties as well as the ability to execute them, including the capacity to make decisions that carry legal consequences.¹³⁵ Hence, in civil law traditions, legal capacity and capacity to act are distinct concepts yet interconnected, whereas in common law legal capacity notion encompasses both. To avoid confusion, this chapter will refer to legal capacity and capacity to act distinctively. Whereas, when a specific reference to the common law system is made, the broader notion of legal capacity will be used as embedding also the capacity to act.

Another relevant aspect is that whereas legal capacity refers to the capacity to hold rights and bear duties, capacity to act determines the extent to which natural or artificial persons can exercise rights and duties.¹³⁶ Hence, the capacity to act exists on a spectrum reflecting the varying degrees on which natural and artificial persons act upon their rights and duties by making decisions that produce legal effects. Therefore, capacity to act is considered a quantitative attribute of legal subjects that possess legal personhood.¹³⁷ As will be further explained in the following sections, legal subjects possess indeed different degrees of capacity

¹³² István Hoffman and György Könczei, ‘Legal Regulations Relating to the Passive and Active Legal Capacity of Persons with Intellectual and Psychosocial Disabilities in Light of the Convention on the Rights of Persons with Disabilities and the Impending Reform of the Hungarian Civil Code’ (2010) 33 (1) Loyola of Los Angeles International and Comparative Law Review, 143.

¹³³ Ibid, 147.

¹³⁴ Ibid.

¹³⁵ Legal Information Institute, ‘Capacity (Law)’ (Wex, Cornell Law School) <<https://www.law.cornell.edu/wex/capacity>> accessed 3 February 2025; also see Pasquale Stanzone, *Capacità e minore di età nella problematica della persona umana* (1st edn, Jovene, 1975), 240.

¹³⁶ Ibid.

¹³⁷ Perlingieri, *La Personalità Umana nell’Ordinamento Giuridico* (1st edn, Jovene, 1972), 137.

to act, depending on their level of autonomy in decision-making, as determined by age or recognised by law.¹³⁸ The different degree of the capacity to act is indeed linked to one's degree of agency. Agency refers to one's autonomous ability to act purposefully and intentionally in pursuit of a goal.¹³⁹ Since the capacity to act determines the extent to which a natural or artificial person can hold rights and duties, variations in agency influence its degree.¹⁴⁰ In other words, the level of autonomy in decision-making directly impacts agency, which in turn affects the degree of capacity to act. This interrelation will be further explored in subsequent sections throughout the analysis of different categories of persons, namely natural persons and artificial persons such as corporate entities.

2.7 The Unitarian Concept of Legal Personhood: Encompassing Legal and Philosophical Theories

The debate on the broader concept of legal personhood is not limited to operational aspects. Various philosophical and doctrinal traditions (from the Christian tradition to the opposition between legalist and realist theories) have historically linked the concepts of freedom, autonomy, and responsibility to the legal relevance of conduct. Since these issues go beyond the immediate focus of this chapter, they are addressed in Appendix B, which retraces the main theoretical lines.

¹³⁸ Ibid, 137.

¹³⁹ Michael Joseph D'Italia and Adam Okulicz-Kozaryn, 'Constructing General Human Agency Indicators (GHAI) and a General Personal Agency Scale (GPAS)' (2025) 176 *Social Indicators Research* 337; Laurence J Kirmayer, Ana Gómez-Carrillo, Timothé Langlois-Thérien, Maxwell JD Ramstead and Ian Gold, 'Culture, Self, and Agency: An Ecosocial View' in Laurence J Kirmayer, Carol M Worthman, Shinobu Kitayama, Robert Lemelson and Constance A Cummings (eds), *The Situated Brain* (Cambridge University Press 2020), ch 8; Sarah Buss, 'Autonomous Action: Self-Determination in the Passive Mode' (2012) 122 *Ethics*, 647.

¹⁴⁰ Adam Zeman, 'The Origin of Subjecthood' in Malcolm Jeeves (eds), *The Emergence of Personhood, a Quantum Leap?* (Eerdmans 2015), 121.

2.8 Persons under the Law: An Introduction

In European civil law and common law legal traditions, there are only two categories of persons that are endowed with legal personhood: human beings or natural persons (also defined as *physical* persons) and non-human entities or legal persons (also defined as *persona-ficta*¹⁴¹, from the Latin '*fictum*': synthetic, artificial).¹⁴² This distinction exists in both common law and civil law systems where the recognition of human and non-physical persons as legal subjects is essentially based on the same core aspects. Very few structural differences in these core aspects exist, promptly justified by the different nature of the two legal systems rather than by the different quality of these aspects. Such differences will be highlighted when necessary, during the analysis.

2.8.1 Human Beings under the Law: Natural Persons

In the eyes of law, human beings are all endowed with legal personhood and classified as natural persons. From an historical and doctrinal viewpoint, as previously explained, legal personhood is associated with humanity.¹⁴³ Humans are indeed defined as 'natural' persons because the law derives the recognition of their capacity to hold rights and duties by virtue of being born and not, as for non-natural entities, by legal decree.¹⁴⁴ Indeed, as for both common

¹⁴¹ Aaron X. Fellmeth and Maurice Horwitz, *Guide to Latin in International* (1st edn, Oxford University Press 2009)

¹⁴² W.E. Singleton, 'Entities and Real and Artificial Persons' (1912) 12 (2) *Journal of the Society of Comparative Legislation* <<http://www.jstor.org/stable/752454>> accessed 10 December 2024.

¹⁴³ Frederick J. White, 'Personhood: An Essential Characteristic of the Human Species' (2013) 80 (1) *The Linacre Quarterly* 74-97 <10.1179/0024363912Z.000000000010> accessed 2 January 2025.

¹⁴⁴ Lawrence Solum, 'Legal Personhood for Artificial Intelligences' (1992) 70 *North Carolina Law Review*, 1231 <<https://tinyurl.com/5dd4cebj>> accessed 10 December 2024.

law and civil law systems, the human being becomes a natural person at the moment of birth.¹⁴⁵ As it has been stated, it is not the case that being human is necessary for being a person within the legal system, as proven by the existence of non-natural persons.¹⁴⁶ However, as already examined, certainly having the capacity, even potentially, to hold rights and bear duties is one of the necessary aspects of being recognised as having legal personhood. This is indeed a relevant element for both natural and non-natural persons. However, the law accounts for different degrees of legal capacity amongst natural persons to which corresponds to a different level of agency and autonomy in decision making. This different level of agency determines a different capacity to hold rights and duties.

From a theoretical perspective, European legal traditions differentiate between natural persons with full legal capacity from persons that have limited or no capacity.¹⁴⁷ The main difference is that people with full legal capacity can hold rights and bear duties as well as exercise them, and therefore produce legal effects.¹⁴⁸ In both common law and civil law systems, adults of sound mind are considered fully capable.¹⁴⁹ As opposed to adults of sound mind fully capable, there are other two categories: totally incapable persons and persons

¹⁴⁵ For common law systems, see *Paton v British Pregnancy Advisory Service Trustees* [1979] QB 276: Confirmed that a fetus does not have legal personhood under English law. Legal personhood begins at live birth. For civil law systems, see Italy: Codice Civile, Article 1: Legal capacity is acquired at birth, but a fetus may inherit property under the condition of being born alive; France: Code Civil, Article 725: An unborn child can inherit provided they are born alive; Germany: BGB (German Civil Code), Section 1: A person's legal capacity begins with birth, but unborn children can be protected if their rights depend on subsequent live birth.

¹⁴⁶ John Salmond (n 14), 318.

¹⁴⁷ Jens David Ohlin, 'Is the Concept of the Person Necessary for Human Rights?' (2005) Columbia Law Review <<https://scholarship.law.cornell.edu/facpub/434/>> accessed 8 January 2025.

¹⁴⁸ Angelo Falzea, *Teoria generale del diritto e di dogmatica giuridica*, Giuffr  Editore, Milano, 1997, 237.

¹⁴⁹ Wendy Anton Fitzgerald, *Maturity, Difference, and Mystery: Children's Perspectives and the Law*, 36 (1) Arizona Law Review <<https://www.coursehero.com/file/225591160/36ArizLRev11-1pdf/>> accessed 10 January 2025. Fitzgerald notes that children are denigrated by the law because their diminished reasoning capacity prevents them from being recognised as full persons under the law.

having limited legal capacity. On this point, a distinction between civil law and common law systems is required.

In many European civil law systems, the legal capacity of individuals is categorised based on age and mental abilities, with special provisions for minors and people declared incapacitated by Court order. Whilst the former is presumed to be fully incapable, the latter is declared legally incapable by effect of judicial decree.¹⁵⁰ People with assessed severe mental health issues or people that have been sentenced to life imprisonment can be declared fully incapable.¹⁵¹ Once declared fully incapable, people acquire the same status as minors from a legal perspective.¹⁵² Both minors and incapable-declared people are therefore considered unable to exercise their legal capacity in a way that benefits them and society. For such a reason, law disposes that minors as well as incapable-declared people must exercise their legal capacity through a legal guardian.¹⁵³ For minors, parents are generally their legal guardians whereas for incapable-declared people, a guardian is appointed by the Court. In both cases, the legal guardians are representatives that exercise the subject's rights and duties on his behalf to protect his legal interests.¹⁵⁴ The main difference, however, is that the guardians of fully incapable-declared people are considered as substitutes in the person's decision making in all aspects of life.¹⁵⁵ Whereas, for minors, parents still retain the right to express or deny consent for specific everyday life decisions of the minor allowing room for autonomous decisions making.¹⁵⁶

¹⁵⁰ Olga Nizamieva, 'Civil Legal Capacity of Minors' (2018) 5 The Journal of Social Sciences Research <https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3774484> accessed 12 January 2025.

¹⁵¹ Francesco Rossi, *Capacità e Incapacità* (Edizioni Scientifiche Italiane, 2018).

¹⁵² Baldassarre Pastore, 'Capacità di agire e vulnerabilità. Una prospettiva interdisciplinare. Presentazione' (2020) 1 Diritto e questioni pubbliche < https://sfera.unife.it/retrieve/e309ade4-c537-3969-e053-3a05fe0a2c94/DQ-XX-2020-1_01_mono_Pastore.pdf> accessed 4 January 2025.

¹⁵³ Pasquale Stanzone, *Capacità e minore età nella problematica della persona umana* (1st edn, Jovene, 1975).

¹⁵⁴ Ibid, 300.

¹⁵⁵ Ibid.

¹⁵⁶ Ibid, 301-304.

As opposed to natural persons totally incapable from a legal perspective, there are also natural persons with limited legal capacity to act. These are: emancipated minors and people with disabilities.¹⁵⁷ Within the European civil law systems, the concept of emancipated minors exists but with some structural differences, the analysis of which is beyond the purpose of this thesis. Hence, this section will provide only the general concept. In most civil law systems, emancipated minors are at least 16 years old who are so declared by judicial decree, with their parents' consent.¹⁵⁸ The purpose of the concept is to allow the 16 years old, when necessary, to become legally independent from his parents.¹⁵⁹ Emancipated minors enjoy limited capacity to act and autonomy as they can exercise their rights and duties without the assistance of their representative within a specific range of situations.¹⁶⁰ For instance, they can enter into valid legal agreements or get married.¹⁶¹ The other class of natural persons with limited capacity to exercise their rights and duties are people with non-severe disabilities. People with mental or physical disabilities that are not so severe to justify the fully incapability declaration, can be pronounced as partially capable by judicial decree.¹⁶² Limited or partially capable people can still exercise their rights and duties but limited to ordinary legal acts. Ordinary legal acts are those that partially capable people can exercise autonomously without the need of a guardian.¹⁶³ These are acts that do not greatly affect the partially capable people's patrimonial sphere, such as: acts that entail daily administration of a small sum of money or any personal activities' acts.¹⁶⁴ For those acts instead that can potentially affect his patrimonial sphere, namely extraordinary administrative acts, such as the exercise of property rights or inheritance,

¹⁵⁷Cooper, 'Emancipation of Minors' (1984) 2 Journal of Juvenile Law <<https://heinonline.org/HOL/Page?handle=hein.journals/jjuv18&id=434&collection=journals&index=>> accessed 10 January 2025.

¹⁵⁸ Alessandra Cordiano, Roberto Senigaglia, *Diritto Civile Minorile* (1st edn, EDS 2022).

¹⁵⁹ Ibid, 120.

¹⁶⁰ Ibid.

¹⁶¹ Francesco Ruscello, *Istituzioni di Diritto civile* (1st edn, Cacucci 2022).

¹⁶² Ibid, 88.

¹⁶³ Ibid, 89.

¹⁶⁴ Ibid, 90.

people with limited capacity are deemed the assistance of a guardian.¹⁶⁵ The reason being is that these people are considered not fully physically or mentally autonomous by law and therefore the legal system, to better protect their interests, prescribes a support of their decision-making process with the assistance of an adult of sound mind.¹⁶⁶

Common law systems' approach in relation to persons and their legal capacity is different. Since there is not an express distinction between legal capacity and capacity to act – the ability to exercise rights and duties- but rather the notion of legal capacity embodies both concepts in one, limitations to legal capacity are directly applied to subjects in relation to specific cases.¹⁶⁷ Therefore, in common law systems the limitation of legal capacity is not a general status or condition of the subject rather a matter of practical and specific implications by case. For example, in common law systems minors, under the age of 18 years old, are provided with a limited legal capacity, due to their lack of experience and judgment.¹⁶⁸ The limitation of legal capacity is related to certain domains of law in order to balance protection and autonomy.¹⁶⁹ For example, in most common law systems, minors do not possess the full legal capacity to enter into contracts or other legal agreements, unless such agreements entail necessities.¹⁷⁰ Indeed, contracts stipulated by minors are typically voidable.¹⁷¹ Minors also typically require the consent of their parents or of a legal guardian to engage in significant legal transactions such as contracts, marriage or property rights.¹⁷² There are also cases where

¹⁶⁵ Ibid.

¹⁶⁶ Council of Europe, Explanatory Memorandum to Recommendation Rec(1999)4 on Principles Concerning the Legal Protection of Incapable Adults (Adopted 23 February 1999, 660th meeting of the Ministers' Deputies) <<https://rm.coe.int/09000016805e302a>> accessed 24 November 2024.

¹⁶⁷ Blackstone, *Commentaries on the Laws of England* (1st published in 1893, George Sharswood edn), Vol I.

¹⁶⁸ Ohlin (n. 147), 214-5.

¹⁶⁹ Jennifer Moye, Michelle Braun, 'Legal Capacity' in Peter Lichtenberg (edn) *Handbook of Assessment in Clinical Gerontology* (2nd edn, Elsevier 2010).

¹⁷⁰ *Chapple v Cooper* (1844) 13 M & W 252

¹⁷¹ *Leslie Ltd v Sheill* [1914] 3 KB 607

¹⁷² Amongst many, see Marriage Act 1949 (UK): Requires parental consent for individuals under 18 in England and Wales, except in Scotland, where the minimum age is 16 without parental consent;

parents act on behalf of a minor to protect his own legal interests, in a similar way the civil law systems also prescribe.¹⁷³ This gives rise to the need to examine more closely how contractual capacity is defined and regulated in natural persons within different legal traditions.

2.8.2 Contractual Capacity in Natural Persons

As opposed to the private law of European common law and civil law traditions, there are no specific rules governing legal capacity or capacity to act as well as contractual capacity within the *acquis Communautaire*.¹⁷⁴ This is confirmed by the context of PECL which contains no rules for legal capacity.¹⁷⁵ Indeed, the Lando Commission regarded the concepts of capacity to be a matter of the law of persons rather than of the law of contracts.¹⁷⁶

The legal systems of EU Member States instead have provisions that restrict the ability of specific categories of individuals to enter into contracts.¹⁷⁷ As said, the rationale for these limitations is to safeguard certain individuals from their own acts as well to protect the market integrity. The fundamental concept is that the binding element of contract fundamentally relies

Chapple v Cooper (1844) 13 M & W 252. Minors may engage in property transactions for necessities but not for significant property dealings without consent.

¹⁷³ *Proform Sports Management Ltd v Proactive Sports Management Ltd* [2006] EWHC 2903 (Ch). Reinforced the principle that contracts are voidable unless they are beneficial to the minor.

¹⁷⁴ Commission, 'European Contract Law and the Revision of the Acquis: The Way Forward' (Communication) COM (2004) 651 final.

¹⁷⁵ Commission on European Contract Law, 'Principles of European Contract Law, Part I and II' (1999) art 4:101.

¹⁷⁶ Hugh Beale and Ole Lando, *Principles of European Contract Law, Parts I and II*, Prepared by The Commission on European Contract Law (2000, Kluwer Law International), comments.

¹⁷⁷ Infants Relief Act 1874, s 1; Sale of Goods Act 1893, s 2(1); Mental Health Act 2001, s 8; Assisted Decision-Making (Capacity) Act 2015, s 3 (Ireland); Code civil, art 1145; Code civil, arts 1146–1149; Ordonnance n° 2016-131 du 10 février 2016 portant réforme du droit des contrats, du régime général et de la preuve des obligations (France); Bürgerliches Gesetzbuch (BGB), § 104–113 (Germany); Codice Civile, arts 1–2; Codice Civile, arts 1425–1427; Codice Civile, art 428 (Italy).

on legal subjects' autonomy (a contract obligates an individual due to his voluntary consent), and when this autonomy is lacking, the rationale dissipates. The law has historically presumed that certain kinds of individuals inherently lack autonomy and therefore the capacity to assess whether a particular transaction serves their best interests.¹⁷⁸ Specifically, two types are notable: minors and individuals with mental disorders. It can be affirmed that the lack of contractual capacity presumption stems directly from the presumption of lack of legal capacity and capacity to act of these legal subjects. Hence, capacity to act and contractual capacity possess identical constraints.

Contractual capacity in natural persons is determined by two key elements: age and mental competence. Most legal systems acknowledge that contractual ability is attained at the age of majority, typically 18 in most jurisdictions.¹⁷⁹ Minors below this threshold are generally regarded as lacking full contractual capacity.¹⁸⁰ Minors are considered to lack the capacity to act and consequently they are considered unfit to perform and receive legal acts affecting their personal and patrimonial sphere.¹⁸¹ Therefore, almost all EU civil law and common law systems include among their general principles the non-binding nature of contracts entered by minors.¹⁸² However, this principle is subject to some exceptions.

¹⁷⁸ Alexander Heldrich and Alfred F Steiner, 'Legal personhood' in *International Encyclopaedia of Comparative Law*, Vol IV, Persons and Family (Tübingen 1995), 45–67; Konrad Zweigert and Hein Kötz, *Introduction to Comparative Law* (3rd edn, Oxford: Clarendon Press 1998), 456–478; Edwin McKendrick, *Contract Law* (5th edn, London 2003) 320–340; Enrico Roppo, *Il contratto* (Milan: Giuffrè 2001), 250–278.

¹⁷⁹ Code Civil (France), art 414; Bürgerliches Gesetzbuch (BGB) (Germany), § 2; Codice Civile (Italy), art 2; Family Law Reform Act 1969 (UK), s 1; Age of Majority Act 1985 (Ireland), s 2.

¹⁸⁰ Giorgio Cossu, 'Potestà dei genitori' in *Digesto*, IV, Discipline private, sezione civile, vol XIV (Torino, UTET 1996) 123.

¹⁸¹ *Ibid.*

¹⁸² Code Civil (France), art 1146; Bürgerliches Gesetzbuch (BGB) (Germany), §§ 107–108; Codice Civile (Italy), art 1425; Minors' Contracts Act 1987 (UK); Sale of Goods Act 1979 (UK), s 3(2); *Edwards v Carter* [1893] AC 360 (HL); Age of Majority Act 1985 (Ireland), s 2; *Leslie Ltd v Sheill* [1914] 3 KB 607 (CA).

In most EU civil law systems, the minor is recognised as incapable to act, thus completely precluded from carrying out contractual acts. The administration of his assets must necessarily be entrusted to third parties who are in a position to take care of his patrimonial interests.¹⁸³ These third parties, often the parents of the minor, as already examined in the previous paragraph, are entitled to carry out the material, contractual and procedural activities necessary for this purpose. This principle aims to safeguard the individual and seeks to avoid insufficient maturity from adversely affecting their relational existence.¹⁸⁴ Contracts that are stipulated by minors without parental consent are usually voidable in civil law systems.¹⁸⁵ There are few exceptions: 1) ordinary daily transactions: a minor may purchase consumer goods without authorisation from a legal representative; 2) employment contracts: starting at age 16, with parental consent and in compliance with the rules on the protection of minor workers; 3) emancipation: if a minor is emancipated, he or she may freely enter into contracts, albeit with restrictions on high-risk transactions such as loans or real estate without the consent of a judge.¹⁸⁶

In EU common law traditions instead, the following contracts are valid when stipulated by minors: a) employment contracts provided that they benefit the minor; b) contracts that have as their object goods and services considered necessities¹⁸⁷, such as: food, clothing, education, medical care;¹⁸⁸ c) contracts ratified by the minor upon reach of age of majority.¹⁸⁹ Except for contracts for necessities, such contracts entered into by minors are usually voidable at the

¹⁸³ Guido Alpa and Mads Andenas, *Fondamenti del diritto privato europeo* (Milan, Giuffrè 2005) 268.

¹⁸⁴ Oleksandr Omelchuk, Olena Cherniak and Nataliia Tyshchuk, 'Protection of the Rights of Children and Minors in Their Transactions in the Information Society' (2020) 9(II) *Revista de Derecho* 25 <<https://doi.org/10.31207/ih.v9i2.241>> accessed 17 February 2025.

¹⁸⁵ Bürgerliches Gesetzbuch (BGB) (Germany), §§ 107–108; Codice Civile (Italy), artt. 1425, 1441.

¹⁸⁶ Francesco Rossi, 'I Contratti del Minore' Intervento presentato al convegno Menores: Filiación y protección tenutosi a Universidad de Almería (Almería, Spagna) 2017.

¹⁸⁷ Sale of Goods Act 1979 (UK), s 3(2); *Nash v Inman* [1908] 2 KB 1 (CA); *Clements v London and Northwestern Railway Co* [1894] 2 QB 482 (CA).

¹⁸⁸ Medical care: *Gillick v West Norfolk and Wisbech Area Health Authority* [1986] AC 112 (HL)

¹⁸⁹ *Edwards v Carter* [1893] AC 360 (HL).

minor's discretion. Hence, the minor can choose to enforce or repudiate the contract upon reaching the age of majority.¹⁹⁰ There are also some contracts that are instead considered completely void if entered into by a minor, such as: mortgage or rent contracts, contracts stipulated for goods and services that are not deemed as necessities.¹⁹¹

Therefore, as opposed to adults with sound mind, the incapacitated party is logically incapable of giving valid consent (so that resultant contracts should be void and of no effect). However, as analysed, such principle encounters several exceptions and related remedies. The age-related restrictions across all EU civil law and common law systems emphasise that contractual capacity exists on a continuum rather than as a binary condition, differing based on legal safeguards for vulnerable individuals such as minors. At the same time, the restrictions upon mentally incapacitated persons underscore the assumption that contractual capability is contingent upon cognitive autonomy and agency, fundamental aspects of legal subjectivity. In both cases, the need for protection for vulnerable individuals against potentially harmful agreements is well balanced by the law by ensuring the integrity of the socio-economic landscape even when contracts are made by individuals lacking contractual capacity.

2.8.3 Non-Human Entities Under the Law: Legal Persons

The second category of subjects of law endowed with legal personhood includes legal persons, also defined as 'artificial persons' or 'juridic persons' as opposed to natural ones. The word 'artificial' comes from the Latin *artificialis*, which denotes something that is real, not imaginary, and created or produced by humans rather than occurring naturally¹⁹²; whereas 'juridic' comes from the Latin *iuridicus*, describing everything that pertains to law.¹⁹³ The etymology of both words describes the essence of non-human persons under the law: something that is created by virtue of man volition and recognised by law. This category

¹⁹⁰ Mindy Chen-Wishart, *Contract Law* (3rd edn, Oxford University Press 2010), 6-16.

¹⁹¹ *Leslie Ltd v Sheill* [1914] 3 KB 607 (CA); *Nash v Inman* [1908] 2 KB 1 (CA); *Edwards v Carter* [1893] AC 360 (HL).

¹⁹² Etymonline <<https://www.etymonline.com/word/artificial>> accessed 18 March 2025.

¹⁹³ *Ibid.*

includes various types of entities such as companies, associations and cooperatives to name a few. Traditionally, the distinction between natural and artificial persons is well-defined: natural persons are born humans, while artificial persons are all other forms of legal entities. Conversely, the legal discussion surrounding the nature of legal persons has been more thorough, encompassing the implications of acknowledging legal personhood for such entities. Indeed, as opposed to natural persons, artificial persons acquire legal personhood by means of a procedural mechanism: the incorporation process.¹⁹⁴ Through incorporation, an entity is legally recognised as a subject of law, with an independent legal personhood, separate from its members' one.¹⁹⁵ The legal recognition of a legal person attributes the collective will and actions of a group of individuals to a single entity, enabling the corresponding legal relations to be allocated to an independent source of reference.¹⁹⁶

There are three main theories that account for the nature of corporate legal personhood: Fiction, Symbolist and the Realist Theories. Fiction theory views the legal personhood of legal entities as a legal construction with no factual foundations.¹⁹⁷ The legal entity is just legal fiction, a mere product of law and, therefore, it can operate only within the scope of its article of association.¹⁹⁸ The core point of such theory is the illusory nature of corporations. In other words, the entity does not have its own will, it is only a means by which natural persons express their will. As stated, a corporation is '[t]hat invisible, intangible, and artificial being, that mere

¹⁹⁴ Arthur W. Machen, Jr. 'Corporate Personhood' (1911) 24 5 Harvard Law Review, 347-365; Also see Companies Act 2014, Part 2 (Incorporation and Registration), No 38 of 2014. Notably, the incorporation procedure follows the same principles with the same outcome across European common law and civil law systems: giving legal life to autonomous systems. See Code de commerce (France), art L210-1 – L210-9; Handelsgesetzbuch (HGB) (Germany), s 6–13a; Bürgerliches Gesetzbuch (BGB), s 21–89 (on associations and legal persons in general); Codice Civile (Italy), Libro V, Titolo V, artt 2325–2335.

¹⁹⁵ Ferrara, *Le Persone Giuridiche* (1938, Editrice Torinese), VII-346.

¹⁹⁶ George Deiser, 'The Juristic Person. I' (1908) 57 (3) University of Pennsylvania Law Review and American Law Register, 131-142.

¹⁹⁷ Ben Allgrove, 'Legal personhood for Artificial Intellecs: Pragmatic Solution or Science Fiction?' (2004) unpublished working paper <<https://ssrn.com/abstract=925723>> accessed 27 March 2025.

¹⁹⁸ Ibid, 60.

legal entity',¹⁹⁹ and again 'being the mere creature of law a corporation possess only those properties which the charter of its creation confers upon it'.²⁰⁰ Because of this standpoint, the Fiction theory did not have an exponential follow. By refusing to acknowledge that juristic persons are real entities, it denies such entities of holding rights and bear duties. In other words, for Fictionalists, corporations are not legal subjects. Corporations exist only in contemplation of law and, therefore, there is no subject in which the right, and duty, can be vested.²⁰¹ Strictly related to the Fiction theory is the Symbolist theory whereby legal personhood of legal entities is a symbol, a mathematical expression of a legal form for doing business.²⁰² Therefore, corporate personhood is an efficient way to describe the relationships between humans and between corporations.²⁰³ Unlike Fiction theory, for the Symbolist theory artificial persons are separate subjects of law.

Notwithstanding the contribution of the Fiction and Symbolist theories to the debate, it is said that it is the Realistic theory that best captures and explains the nature of artificial non-human entities as legal persons.²⁰⁴ For Realists, legal persons are neither fiction nor symbols, they are creatures of law and being artificially created does not imply they do not exist.²⁰⁵ They are real and they exist as much as contracts and artificial lakes are artificial because man-created, but they exist. As such, incorporated legal entities are subjects of law with legal personhood.²⁰⁶ The reality of artificial entities created by law and equipped with legal capacity

¹⁹⁹ *Bank of the US v Deveaux* [1809] USSC Rep 38, 44.

²⁰⁰ *Trustees of Dartmouth College v Woodward* 17 US (4 Wheat) 518 (1819).

²⁰¹ Martin Wolff, 'On the Nature of Legal Persons' (1938) 54 L Q Rev, 494.

²⁰² *County of Santa Clara v Southern Pacific Railroad Co* 18 F 385 (California DCC 1883), 403.

²⁰³ Wesley Newcomb Hohfeld, 'Nature of Stockholders, Individual Liability for Corporation Debts' (1909) 9(4) *Columbia Law Review*, 290; Katsuhito Iwai, 'Persons, Things and Corporations: The Corporate Personhood Controversy and Comparative Corporate Governance' (1999) 47(4) *American Journal of Comparative Law*, 583.

²⁰⁴ Paulius Čerka, Jurgita Grigienė and Gintarė Širbikytė, 'Is It Possible to Grant Legal personhood to Artificial Intelligence Software Systems?' (2017) 33(1) *Computer Law & Security Review*, 685.

²⁰⁵ Gunther Teubner, 'Enterprise Corporatism: New Industrial Policy and the "Essence" of the Legal Person' (1984) 36(1) *American Journal of Comparative Law*, 130.

²⁰⁶ *Ibid*, 137.

and capacity to act is then legitimated. Interestingly, the genesis of legal autonomy of legal persons is completely different to the one of natural persons. For natural persons, it is the degree of autonomy and agency that dictates the level of capacity to act within the legal system. Hence, as previously explored, the legal system reacts with a cluster of safeguards - or limitations- to address the lack of autonomy of the legal subject. For artificial persons instead, their degree of autonomy is not a settling element; it does not mandate a law's response to it, for it is the law that bestows the legal person with (legal) autonomy.²⁰⁷ Therefore, the source of legal autonomy and capacity for natural persons and artificial persons is different: the former is physiological, the latter is functional. In other words, the incorporated artificial entity acquires legal subjectivity that exists within the circumscribed sphere of its activities which are functional to its socio-economic purpose provided for at the incorporation.²⁰⁸ Unlike natural persons, artificial persons' personhood is limited by functional-related aspects within their legal relations rather than safeguard-related constraints.²⁰⁹ The trait of functional-personhood is quite recurring in the legal debate around the nature of artificial persons compared to non-incorporated entities.²¹⁰ To explain the different legal treatment of incorporated and non-incorporated entities the Concession theory is often referred to. According to the Concession theory, legal personhood of artificial entities does not exist unless it is granted by law via incorporation.²¹¹ However, for non-incorporated entities, such as partnerships or trade unions for instance, their members can perform legally relevant acts in the interests of the entity.²¹² As stated, these kinds of entities rather exist and operate with a

²⁰⁷ Shawn Bayern, 'The Implications of Modern Business-Entity Law for the Regulation of Autonomous Systems' (2016) 7(2) *European Journal of Risk Regulation*, 297.

²⁰⁸ George Deiser, 'The Juristic Person. III' (1909) 57(5) *University of Pennsylvania Law Review and American Law Register*, 300-314; Paul Vinogradoff, 'Juridical Persons' (1924) 24 (6) *Columbia Law Review*, 594-604.

²⁰⁹ Max Radib, 'The Endless Problem of Corporate Personhood' (1932) 32 (4) *Columbia Law Review*, 643-667; see also *Ashbury Railway Carriage and Iron Co v Riche* (1875) LR 7 HL 653.

²¹⁰ John Dewy, 'The Historical Background of Corporate Legal personhood' (1926) 35 *Yale Law Journal* 655, 666.

²¹¹ *Ibid.*

²¹² Allgrove (n. 197).

so-called ‘limited legal personhood’.²¹³ In other words, the entity lacks separate legal identity from its members²¹⁴ which remain personally liable for the entity’s obligations.²¹⁵ Hence, those entities cannot sue and be sued in their own name, they cannot own properties nor entering contracts as a single juridical entity.²¹⁶ Some scholars have defined such entities as ‘legal subjects without legal personhood’.²¹⁷ Even though the very existence of a legal personhood that is ‘limited’ can be argued when the act of conferring such personhood is missing, the definition purports that even unincorporated entities can ‘functionally’ be treated as (if) legal subjects. Despite not being artificial persons with legal personhood, unincorporated entities are thus attributed to legal effects, acting through their representatives.²¹⁸ This represents the interesting contrasts between incorporated and unincorporated entities, where the primary element of differentiation lies in the separation of legal identities - and liabilities - between the artificial person and its members. The distinction between the artificial legal subjects with legal personhood and those without is therefore more in how the law treats their members, rather than in the entity’s ability to produce legal effects. In other words, when this identity separation is not present, legal effects still occur, but responsibility does not shift.

The defining trait of legal subjects is indeed the ability to produce legal effects and to be juridical impacted by them. The all-encompassing feature that both natural and artificial persons are required to possess to be recognised as legal subjects is being a party to legal relations.²¹⁹ It is indeed stated that the broad purpose of legal personhood, upon whoever or

²¹³ *Conservative and Unionist Central Office v Burrell* [1981] EWCA Civ 2.

²¹⁴ *Hanchett-Stamford v Attorney-General* [2008] EWHC 330 (Ch).

²¹⁵ *Ibid.*

²¹⁶ *Ibid.*

²¹⁷ Paul Davies and Sarah Worthington, *Gower’s Principles of Modern Company Law* (11th edn, Sweet & Maxwell 2021), Ch 3; Roderick Munday, *Agency: Law and Principles* (2nd edn, OUP 2018), 117–19; Mark Freedland, ‘Government by Contract and Private Law’ (1994) 14 (1) *Oxford Journal of Legal Studies*, 153.

²¹⁸ Mark Freedland, ‘Government by Contract and Private Law’ (1994) 14(1) *Oxford Journal of Legal Studies*, 153; Nicos Stavropoulos, *Objectivity in Law* (OUP 1996), Ch 5.

²¹⁹ Bryant Smith, ‘Legal personhood’ (1928) 37 *Yale Law Journal*, 283.

whatever is conferred, is to facilitate the regulation of conduct and behavior that has legal meaning within the society.²²⁰ While the conceptual foundations and the legal implication of granting legal personhood to artificial beings has been examined in this section, it remains crucial to explore how artificial subjects concretely operate within the legal system as parties to legal relations, in particular throughout the mechanisms of agency and representation which enable them to act and contract.

2.8.4 The Contractual Capacity of Juridical Persons: The Role of Agency Law and Legal Representation in Legal Persons

Unlike natural persons, artificial legal subjects, being limited by physical inexistence, can exercise their contract capacity only through the legal mechanisms of representation and agency.²²¹ In the following section, the doctrinal foundations of agency law and representation will be analysed, laying the groundwork to assess the applicability of these legal theories to decentralised artificial systems. Moreover, the section focuses exclusively on the relationship between incorporated artificial persons with legal personhood and their agents for, as already examined, there is no separation between the legal identity of unincorporated entities and their members. Unincorporated entities, while capable of producing legal effects, are excluded from this investigation due to their legal structure being fundamentally reliant on the personal identity and liability of their members to serve as a social and contractual representative function. In contrast, decentralised artificial agents operate without a member-based governance, rendering the comparison of the operational logic methodologically inadequate.

In European common law traditions, the question of the contract capacity of artificial persons holds a limited significance. As opposed to civil law traditions, it is not indeed an autonomous concept as it is the agency theory that governs the contractual dynamics of a

²²⁰ Ibid, 296; Arthur W. Machen, Jr., 'Corporate Personhood' (1911) 24 (4) Harvard Law Review Association, 253-267.

²²¹ Continental Tyre & Rubber Co (GB) Ltd v Daimler & Co [1915] 1 KB 893 at 916.

corporate entity.²²² Agency law defines the legal framework within which artificial persons exercise their contract capacity. It operates on two levels. Internally, it regulates the authority of the agent within the corporate structure. Externally, it governs the agent's authority towards third parties within contractual relationships by outlining the conditions under which an agent may legally bind his principal to contractual obligations. In this context, two core elements define agency theory: the entity, having legal personhood, exists independently by its agents; the entity's agents must operate within the limit of their authority to legally bind the principal entity to the contracts they stipulate. Agent's authority may arise from actual authority, apparent authority (also defined as ostensible authority) and ratification. Actual authority, which can be expressed or implied, derives from a 'consensual arrangement',²²³ usually a contract between the principal and the agent.²²⁴ When the agent operates within his actual authority, the entity as principal will be legally bound to all contracts entered into by the agent.²²⁵ Ostensible authority, on the other hand, does not derive from a consensual arrangement between the principal and the agent, but from a misrepresentation made by the principal to the third party that the agent has indeed the authority to bind the principal to contract obligations.²²⁶ Apparent authority is often treated as a form of estoppel. Indeed, the principal is prevented to deny the agent's authority towards the third party that stipulated the contract in good faith even if the agent lacked the actual authority in the first place.²²⁷ With ostensible authority, the entity will be bound to the contract even when the agent lacks actual authority whenever the principal, directly or indirectly²²⁸, conveys to the third party the false

²²² Martin Wolff, 'On the Nature of Legal Persons' (1938) 54(4) L Q Rev 494.

²²³ F.M.B. Reynolds, Peter Watts, *Bowstead & Reynolds on Agency* (16th edn, Sweet & Maxwell, 1995).

²²⁴ SMC Electronics Ltd v Akhter Computers Ltd et al [2001] 1 BCLC 433; Thomas Williamson Ltd and Another v Bailieborough Co-operative Agricultural Society Ltd [1986] HC.

²²⁵ Thomas B. Courtney, *The Law of Companies* (4th edn, Bloomsbury, 2016), 394.

²²⁶ *Kett v Shannon & English* [1987] ILRM 364 at 366.

²²⁷ *Freeman & Lockyer v Buckhurst Park Properties (Mangal) Ltd* [1964] 2 QB 480 at 506.

²²⁸ F.M.B. Reynolds, Peter Watts, *Bowstead & Reynolds on Agency* (16th edn, Sweet & Maxwell, 1995), 99. In every case where the principal, by conduct, intentionally or carelessly, caused the belief that the contract was authorised. Also, when the principal, having noticed such belief, did not take any reasonable steps to notify the third party of the facts.

representation that the agent was indeed authorised to stipulate the contract on behalf of the principal.²²⁹ The last example from which the agent may derive his authority is ratification. When an agent stipulates a contract on behalf of the principal without actual authority, the principal can still bind itself to the contract's obligations by ratifying the unauthorised contract.²³⁰ In this case, the act becomes retroactively valid.²³¹ The legal mechanism of agency law is known also in European civil law systems under the name of representation, which operates with some structural differences.²³² Consequently, the mechanism of representation in civil law systems appears more rigid and formal compared to the more flexible agency theory of common law tradition.²³³ The entity legal representatives have the power to enter into contract on behalf of the company, legally binding it to all the agreements they stipulate.²³⁴ Like agency law, the entity representative must act within his authority in order to bind his principal, which is given by the incorporation act.²³⁵ If the agent enters into contracts without authorisation or by exceeding his power, the contract is not binding for the principal unless: the third party was in good faith and the principal ratifies it, making it retroactively valid.²³⁶ Overall, the mechanism of representation in civil law systems is deemed to be more rigid and

²²⁹ Spencer Bower, *Estoppel by Representation* (4th edn, Feltham, Hochberg and Leech, 2004), IX 2.2. n. 3.

²³⁰ *Firth v Staines* [1897] 2 Q.B. 70 at 75.

²³¹ F.M.B. Reynolds, Peter Watts (n. 228), 69-97.

²³² Reinhard Zimmermann, *The Law of Obligations: Roman Foundations of the Civilian Tradition* (OUP 1996) 446–452; Basil S Markesinis and Hannes Unberath, *The German Law of Contract: A Comparative Treatise* (2nd edn, Hart Publishing 2006) 129–141; Christian von Bar, *Non-Contractual Liability Arising out of Damage Caused to Another* (vol 1, Sellier 2009) 510–530.

²³³ See art. 2475-bis del Codice Civile (Italy); Art. 1159 del Code Civil (France); § 26 BGB (Germany).

²³⁴ Konrad Zweigert and Hein Kötz, *An Introduction to Comparative Law* (Tony Weir tr, 3rd edn, OUP 1998) 381–385.

²³⁵ Gian Franco Campobasso, *Diritto Commerciale. 2. Diritto delle Società* (UTET, 7a edn 2021), 143–145.

²³⁶ Macgregor and Busch, 'Unauthorised Agency' (2009) 17(6) *European Review of Private Law*, 967.

formal compared to the more flexible agency theory of common law tradition.²³⁷ There is another relevant aspect that draws a clear divide between civil law and common law systems. While in both systems, the principal must have legal capacity to be bound by contracts²³⁸, the rules for the representative and the agent seem to differ within the two traditions. For civil law traditions, the legal representative must possess not only legal personhood but also capacity to act.²³⁹ Hence, a minor or a person with limited capacity cannot be appointed as a company representative, lacking the contract capacity.²⁴⁰ For agency law instead, what matters is not the agent's capacity but the principal's one.²⁴¹ Therefore, under agency theory, an agent that possesses limited capacity to act on his own account, such as a minor or even an entity without legal personhood, can bind the principal to contract obligations if authorised.²⁴² Thus, what is essential is that the principal possesses legal capacity, and the agent acts within his given authority.

Both legal mechanisms provide a practical explanation of artificial legal subjects' contract capacity. However, they rest on a crucial assumption: the presence of a defined principal as well as a representative or an agent with identifiable, albeit full or limited, legal capacity. The frontier of these existing legal mechanisms begins to falter when confronted with decentralised artificial systems' role within sole-code smart contracts.

²³⁷ Gerard McMeel, *The Construction of Contracts: Interpretation, Implication, and Rectification* (2nd edn, OUP 2011), 320–324.

²³⁸ F.M.B. Reynolds, Peter Watts, *Bowstead and Reynolds on Agency* (21st edn, Sweet & Maxwell 2018) para 1-016.

²³⁹ Gian Franco Campobasso, *Diritto Commerciale. 2. Diritto delle Società* (UTET, 7a edn 2021) 141–144; Mario Cottino, *Diritto Commerciale. Vol. 2: Diritto delle Società* (CEDAM 2005) 138–139.

²⁴⁰ *see* Codice Civile, art 2382 (Italy); Code de commerce, art L223-18 (France).

²⁴¹ F.M.B. Reynolds, Peter Watts (n. 238) para 1-016.

²⁴² Roderick Munday, *Agency: Law and Principles* (2nd edn, OUP 2016), 40–43.

2.9 Reevaluating the Traditional Legal Concepts Within the Context of DsAI Systems

Both legal capacity and capacity to act presuppose the existence of legal relations in which they unfold. In other words, both must have a person – a legal subject- which they necessarily belong to in order to produce legal effects.²⁴³ This is particularly clear in contract relations. Within the discipline of contract law, the term ‘capacity to contract’ is a specific aspect of the broader concept of capacity to act which determines the ability of legal subjects to enter into binding agreements.²⁴⁴

Unlike the contractual element of the intention to contract – which will be analysed in depth in the following chapters - that represents a legal subject’s conscious decision to be bound by an agreement²⁴⁵, contractual capacity is the prerequisite that outlines whether a legal subject is legally permitted to enter into agreements.²⁴⁶ Therefore, a legal subject that does not possess the capacity to act, does not hold capacity to contract as well due to the lack of recognition under the law of the ability to exercise rights and duties within contractual obligations.

Moreover, being a subset of the capacity to act, capacity to contract possesses a social dimension within which it unfolds. In other words, it is within the social framework of contractual relationships that this capacity manifests.²⁴⁷ This is because contract law and the

²⁴³ Angelo Falzea, *Teoria generale del Diritto e di Dogmatica Giuridica* (1st edn, Giuffrè Editore, 1997), 237.

²⁴⁴ Roberto Senigaglia, *Liber amicorum per Paolo Zatti* (2nd edn, Jovene, 2023), 1335.

²⁴⁵ Jill Poole, *Textbook on Contract Law* (9th edn, Oxford University Press, 2008), 190-191; *Balfour v Balfour* [1919] 2 KB 571 (CA).

²⁴⁶ Code civil, art 1145-1149 (France); Bürgerliches Gesetzbuch (BGB) § 104–113 (Germany); Codice Civile, arts 1–2 (Italy); Principles of European Contract Law (PECL), art 4:101.

²⁴⁷ German Civil Code (BGB, §104-113) acknowledges the societal role of contractual capability by governing transactions involving minors and others with incapacities; French Civil Code (Code civil, art 1145-1149) Affirms that the ability to contract is associated with social responsibility, especially in relation to safeguarding minors and vulnerable populations; *National Provincial Bank v Ainsworth*

governance of economic systems do not simply regulate transactions between individuals and/or entities, but shapes opportunities for access to and participation in the economy and society.²⁴⁸ It has been said that such social aspect is proven by the presence of ‘limitations’ imposed by law in the ability to contract for certain categories of legal subjects, such as minors and persons with disabilities.²⁴⁹ As explored in previous sections on persons, these limitations are defenses mechanisms that the law bestows on legal subjects to protect them against agreements that are not beneficial to them and, at the same time, to protect society against contractual effects that are potentially detrimental for the economy.²⁵⁰ In addition, in the contractual discipline of both civil law and common law contracts stipulated in violation of such limitations are usually rendered invalid, as they may be void or voidable. There only few exceptions to these restrictions within the context of the analysis of natural persons as they relate to minors and persons with disabilities.

This is an important aspect in the debate around the role of DsAI systems in smart contract transactions. The current legal frameworks do not recognise DsAI systems as a legal subject holding legal capacity and capacity to act and therefore to contract, as they lack legal

[1965] AC 1175 Emphasises how legal capacity, such as contractual capacity, is embedded within social frameworks; *Imperial Loan Co v Stone* [1892] 1 QB 599 It is affirmed that contractual ability is not solely an individual entitlement but carries social implications, especially for parties engaging with incapacitated individuals.

²⁴⁸ Simon Deakin, 'Capacitas': Contract Law and the Institutional Preconditions of a Market Economy' (2006) 2

ERCL<https://www.researchgate.net/publication/4801090_'Capacitas'_Contract_Law_and_the_Institutional_Preconditions_of_a_Market_Economy> accessed 6 February 2025.

²⁴⁹ William R. Anson, *Principles of the English Law of Contract and of Agency in its relation to Contract* (21st edn, Oxford University Press, 1959), 6-7.

²⁵⁰ Martijn Hesselink, 'Capacity and Capability in European Contract Law' (2005) Amsterdam Center for Law & Economics Working Paper No. 2005-09 <<http://ssrn.com/paper=869246>> accessed 26 February 2025; Ingrid Robeyns, 'The Capability Approach: An Interdisciplinary Introduction' (University of Amsterdam, 9 December 2003) <https://www.researchgate.net/publication/228867656_The_capability_approach_an_interdisciplinary_introduction> accessed 18 February 2025; Simon Deakin (n. 248), 317.

personhood and the ability to consent to be legally bound to an agreement. Despite DsAI systems independently initiating and executing smart contracts that yield legally binding outcomes, the legal and philosophical debate persists regarding whether these systems truly embody intention and consent to contract. However, these considerations highlight why traditional frameworks of capacity, legal personhood, and representation cannot be automatically extended to DsAI systems. Legal capacity, understood as the ability to hold rights and duties, presupposes an identified and legally recognised entity, be it a natural person or a collective body. Legal personhood, in turn, is always the result of a normative act of recognition that attributes rights and obligations to an entity, allowing it to function as a single point of accountability. DsAI systems, on the other hand, have neither a legally recognised identity nor a constitutive act that transforms them into legal persons: they operate as distributed networks of autonomous agents, without a single referent to whom the law can attribute conduct. The same applies to classical theories of representative agency, which presuppose a relationship of mandate or representation between an agent and a principal: the DsAI does not act on behalf of another entity, but as the outcome of internal processes of self-organisation and multi-agent interaction. It follows that its activity, while generating binding legal effects, cannot be traced back to either a contractual capacity in the traditional sense or a represented will. This structural and conceptual fact is at the heart of the legal problem this thesis seeks to address.

Nevertheless, a significant parallel can be drawn with unincorporated associations under civil law and unincorporated partnerships in common law systems. While these entities do not enjoy full legal personhood, they nevertheless possess a limited legal subjectivity that allows them to contract, sue, or assume obligations. In such cases, the law recognises their capacity to act based on social and economic reality rather than a formal act of recognition.²⁵¹ This intermediate model suggests that legal subjectivity is not a binary attribute (all or nothing), but rather a graduated one, varying according to context. It is on this basis that the DsAI analysis

²⁵¹ Pietro Rescigno, *Manuale del diritto privato* (8^a edn, Jovene 2021) 143–147 (sulle associazioni non riconosciute); Guido Alpa, *Le persone giuridiche* (Giappichelli 2017) 59–63; Paul Craig and Gráinne de Búrca, *EU Law: Text, Cases, and Materials* (7th edn, OUP 2020) 103–105; Geoffrey Morse, *Partnership Law* (9th edn, OUP 2021), 15–19.

can establish a useful point of comparison with other legal categories, allowing the legal analysis to progress.

2.10 Seeking Certainty Amidst the Evolving AI Landscape: The European Union Artificial Intelligence Act Regulatory Approach

Currently, the EU AI Act is regarded as the first comprehensive AI legislative framework.²⁵² It seeks to discipline the rules on AI within the European territories in a way that ensures the development of AI technologies while integrating the values and the fundamental rights upheld by European Union.²⁵³ The *human-centric* approach is the very heart of the AI Act.²⁵⁴ This key concept governs the entire framework of AI regulation and has two principles: to ensure that human values are incorporated within the design of algorithms²⁵⁵

²⁵² Beatriz Cabrera, Luiz Luiz and João P Teixeira, 'The Artificial Intelligence Act: Insights regarding its application and implications' (2025) 256 *Procedia Computer Science*, 230-237.

²⁵³ *Ibid*, 233.

²⁵⁴ Jessica Fjeld, Nele Achten, Hannah Hilligoss, Adam Christopher Nagy and Madhulika Srikumar, 'Principled Artificial Intelligence: Mapping Consensus in Ethical and Rights-Based Approaches to Principles for AI' (2020) Berkman Klein Center Research Publication No 2020-1 <<https://cyber.harvard.edu/publication/2020/principled-ai>> accessed 28 April 2025; *see also* OECD, 'Recommendation of the Council on Artificial Intelligence' OECD/LEGAL/0449 <<https://legalinstruments.oecd.org/en/instruments/OECD-LEGAL-0449>> accessed 22 April 2025; OECD, 'Tools for Trustworthy AI: A Framework to Compare Implementation Tools for Trustworthy AI Systems' (2021) OECD Digital Economy Papers No 312 <https://www.oecd-ilibrary.org/science-and-technology/tools-for-trustworthy-ai_008232ec-en> accessed 18 April 2025; UNESCO, 'Recommendation on the Ethics of Artificial Intelligence' SHS/BIO/REC-AIETHICS/2021 <<https://unesdoc.unesco.org/ark:/48223/pf0000380455>> accessed 3 March 2025; High-Level Expert Group on Artificial Intelligence, 'Ethics Guidelines for Trustworthy AI' (2019) European Commission <<https://ec.europa.eu/futurium/en/ai-alliance-consultation>> accessed 3 March 2025.

²⁵⁵ Article 13 of Regulation (EU) 2024/1689 (n. 88). The AI Act, as regards to high-risk AI systems, states that they 'shall be designed and developed in such a way to ensure that their operation is sufficiently transparent to enable users to interpret the system's output and use it appropriately'. To

and that humans retain control over autonomous systems.²⁵⁶ The AI Act represents a milestone in terms of regulation and compliance. The purpose is not only to regulate all the phases that lead to the implementation of the AI systems in the EU market but also to protect users once the AI application has been deployed. It does so through a risk-based approach that aims at classifying and regulating AI applications according to the risk they pose to users' fundamental rights, health and safety, while generating a reliable framework.²⁵⁷ This proportionality principle of regulation based on risks applies regardless the use of AI systems in different fields, rendering the AI Act technology-neutral.²⁵⁸ The purpose is to determine a universal approach that encompasses all different AI systems within a single and scalable regulatory model across all EU countries. The AI-related risks' classification under the AI Act covers

achieve this purpose, the EU High-Level Expert Group on AI and the IEEE developed ethical principles and (moral) values that should guide AI developers during the design phase of AI, such as non-maleficence, fairness, transparency, explainability, and accountability. On this account, *see*: Ibo van de Poel, 'Embedding Values in Artificial Intelligence (AI) Systems' (2020) 30 *Minds and Machines*, 385.

²⁵⁶ David Restrepo Amariles, Pablo Marcello Baquero, 'Promises and Limits of Law for a Human-Centric Artificial Intelligence' (2023) 45 *Computer Law & Security Review*, 105789.

²⁵⁷ Martin Ebers, 'Truly Risk-Based Regulation of Artificial Intelligence: How to Implement the EU's AI Act' (2024) *European Journal of Risk Regulation* <<https://www.cambridge.org/core/journals/european-journal-of-risk-regulation/article/truly-riskbased-regulation-of-artificial-intelligence-how-to-implement-the-eus-ai-act/E526C1D0D7368F9691082220609D60F4>> accessed 28 April 2025.

²⁵⁸ *See* Recitals 5, 13, 26, Regulation (EU) 2024/1689 (n. 88).

limited risks²⁵⁹, high-level risks²⁶⁰, prohibited AI practices²⁶¹ and, as a residual category, minimal risks.²⁶² The risk-based classification brings along all sets of obligations that providers, deployers and users must abide by. The higher the risk posed by an AI system, the higher the regulatory obligations associated with it. In high-risk AI applications such approach

²⁵⁹ Limited risks concern the lack of transparency in the use of AI systems. Therefore, for AI systems that directly interact with people, i.e. chat bots, these are developed in a way that ensures that the person is informed he is interacting with an AI-based system. *See* Article 50, This category includes a wide range of systems that could cause significant harm if they malfunction: biometric identification and facial recognition systems, credit assessment and scoring systems, medical chatbots, autonomous driving systems. The AI Act imposes strict requirements on these systems: mandatory assessments and compliance tests, mandatory safety and risk management measures, transparency on how the system operates, human oversight.

²⁶⁰ This category includes a wide range of systems that could cause significant harm if they malfunction: biometric identification and facial recognition systems, credit assessment and scoring systems, medical chatbots, autonomous driving systems. The AI Act imposes strict requirements on these systems: mandatory assessments and compliance tests, mandatory safety and risk management measures, transparency on how the system operates, human oversight. *See* Article 6 and Annex III Regulation (EU) 2024/1689 (n. 88).

²⁶¹ The AI Act imposes a general and sweeping ban on certain uses of AI that are deemed unacceptable because of the extremely high risks. These include behavioral and cognitive manipulation, untargeted scraping of facial images from the Internet or CCTV footage, emotion recognition in the workplace and educational institutions, social scoring, biometric categorization to infer sensitive data, and certain predictive policing applications, which use AI to predict the likelihood of crime. *See* Article 5 Regulation (EU) 2024/1689 (n. 88). *See also* European Commission, ‘Commission Guidelines on Prohibited Artificial Intelligence (AI) Practices as Defined in the AI Act’ (Digital Strategy, 22 April 2024) <<https://digital-strategy.ec.europa.eu/en/library/commission-publishes-guidelines-prohibited-artificial-intelligence-ai-practices-defined-ai-act>> accessed 16 April 2025.

²⁶² AI systems that do not fall into any of the three previous categories are considered to be low or no risk. As a result, there are no specific compliance obligations for these systems. An example are video games or spam filters. However, any AI system, through its use, development, training, and expansion, can easily fall within another risk category over time. Therefore, proper governance and active monitoring is essential regardless of the initial risk classification of the AI system used.

is also coupled with the concept of ensuring human input and oversight over AI system life-cycle, in line with *human-in-the-loop* (HITL) logic.²⁶³ In the HITL human supervision must be ensured over the entire AI decision-making process to safeguard transparency.²⁶⁴ In contrast, for limited and minimal-risk AI systems, since they should not carry the same harmful impact over users, the HITL oversight is not mandatory.²⁶⁵ Therefore, for these AI systems, the mere information that the user is interacting with an AI system is deemed sufficient and proportionate to safeguard against harmful effects. Although the AI Act does not formally distinguish between *human-in-the-loop* (HITL), *human-on-the-loop* (HOTL) or *human-out-of-the-loop* (HOOTL) models, its functional approach to human oversight in all cases requires a level of human intervention or monitoring appropriate to the level of risk of the system. To be more precise, the HOTL is an operational extension of the HITL. It involves humans providing intervention and feedback to the AI system to improve its performance over time. The HOTL approach is used when the AI system has reached a certain level of performance but still needs human feedback and intervention to continue improving.²⁶⁶ Completely different is the *human-out-of-the-loop* approach. It involves cases of AI autonomous systems which operate independently without human control. There is minimal or no human input during the decision-making process.²⁶⁷ In systems operating under HOTL or HOOTL conditions, compliance with the human oversight obligations under the AI Act depends on ensuring that meaningful human intervention is possible where the risk warrants it. In this sense, whereas HOLT systems still

²⁶³ Recital 47, Regulation (EU) 2024/1689 (n. 88).

²⁶⁴ Eduardo Mosqueira-Rey, Elena Hernández-Pereira, David Alonso-Ríos, José Bobes-Bascarán and Ángel Fernández-Leal, 'Human-in-the-Loop Machine Learning: A State of the Art' (2023) 56 Artificial Intelligence Review, 3005.

²⁶⁵ Melanie Fink, 'Human Oversight under Article 14 of the EU AI Act' (2025) SSRN Electronic Journal <https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5147196> accessed 28 April 2025.

²⁶⁶ Sophia Abraham, Calvin Young, Jason K Moore and Matthew D Johnson-Roberson, 'Adaptive Autonomy in Human-on-the-Loop Vision-Based Robotics Systems' (2021) ArXiv <<https://arxiv.org/abs/2103.15053>> accessed 28 April 2025.

²⁶⁷ Sriraam Natarajan, Saurabh Mathur, Sahil Sidheekh, Wolfgang Stammer e Kristian Kersting, 'Human-in-the-loop or AI-in-the-loop? Automate or Collaborate?' (2024) ArXiv <<https://arxiv.org/abs/2412.14232>> accessed 28 aprile 2025.

grant a degree of human intervention, HOOLT system logic runs the risk of not being considered compliant with the AI Act.

It should be noted that the AI Act regulation is not the first initiative of the European Union to regulate the use of AI systems; rather, it represents the pinnacle of an adoption path that has lasted several years.²⁶⁸ Examples are the AI Strategy, the 2018 Commission Communication on Artificial Intelligence for Europe and the 2019 Commission Communication on increasing trust in human-centred AI.²⁶⁹ These documents have already aimed to encourage the development of AI systems with an ethical vision in European space. Also worth mentioning are the 2019 Ethical Guidelines for Trustworthy AI²⁷⁰ and the White Paper on Artificial Intelligence - A European approach to excellence and trust.²⁷¹ Both initiatives aim to ensure policy approaches that balance the adoption of AI systems with the associated risks to protect not only the user category but the broader spectrum of individuals. The sphere of individual protection in relation to the development, implementation and distribution of AI applications is ensured by informing a legal framework that is inspired by ethics and human dignity. It is important to stress that the ethical underpinning is in line with

²⁶⁸ European Commission, 'Proposal for a Regulation of the European Parliament and of the Council laying down harmonised rules on artificial intelligence (Artificial Intelligence Act) and amending certain Union legislative acts' COM (2021) 206 final.

²⁶⁹ European Commission, 'Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions: Artificial Intelligence for Europe' COM (2018) 237 final <<https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2018%3A237%3AFIN>> accessed 10 March April 2025.

²⁷⁰ European Commission, Directorate-General for Communications Networks, Content and Technology, 'Ethics Guidelines for Trustworthy AI' (Publications Office of the European Union 2019) <<https://doi.org/10.2759/2686>> accessed 8 March 2024.

²⁷¹ European Commission, 'White Paper on Artificial Intelligence – A European Approach to Excellence and Trust' COM (2020) 65 final <<https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0065>> accessed 16 March 2025.

the establishment of the EU digital single market plan, reinforcing this objective.²⁷² The legislative foundation of the AI Act is indeed Article 114 TFEU²⁷³, which permits measures for the establishment and operation of the internal market where fairness and transparency are considered essential elements for fostering a trusted digital market amongst users. Despite the ambition to create a comprehensive and harmonised regulatory approach based on ethical principles, the AI Act still raises numerous doubts about its practical effectiveness, due to the vagueness of key conceptualisations and classifications employed.²⁷⁴ What is indeed of interest in light of this thesis research question is the European Union's regulatory approach for AI systems and the shift in the stance of the EU Institutions in addressing the AI evolving landscape from the initial resolution of the European Parliament in 2017 with Recommendations to the Commission on Civil Law Rules on Robotics.²⁷⁵ In this resolution the European Parliament stated that:

²⁷² European Commission, 'A Digital Single Market Strategy for Europe' COM (2015) 192 final <<https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52015DC0192>> accessed 29 April 2025.

²⁷³ Article 114, Consolidated Version of the Treaty on the Functioning of the European Union [2016] OJ C202/1. This article states that 'Save where otherwise provided in the Treaties, the following provisions shall apply for the achievement of the objectives set out in Article 26. The European Parliament and the Council shall, acting in accordance with the ordinary legislative procedure and after consulting the Economic and Social Committee, adopt the measures for the approximation of the provisions laid down by law, regulation or administrative action in Member States which have as their object the establishment and functioning of the internal market.'

²⁷⁴ DigitalEurope, 'A milestone agreement, but at what cost? Response to the political deal on the EU AI Act' (Press Release, 2023) <<https://www.digitaleurope.org/news/23173/>> accessed 16 April 2025; France Digitale, 'The keys to understanding and applying the law. AI Act Compliance 2024' (2024) <<https://francedigitale.org/en/posts/ai-act-guide-mise-en-conformite>> accessed 16 April 2025; P Davies, 'EU AI Act reaction: Tech experts say the world's first AI law is "historic" but "bittersweet"' Euronews (16 March 2024) <<https://www.euronews.com/next/2024/03/16/eu-ai-act-reaction-tech-experts-say-the-worlds-first-ai-law-is-historic-but-bittersweet>> accessed 16 April 2025.

²⁷⁵ European Parliament, Resolution of 16 February 2017 with Recommendations to the Commission on Civil Law Rules on Robotics (2015/2103(INL)) [2017] OJ C252/239.

‘Creating a specific legal status for robots in the long run, so that at least the most sophisticated autonomous robots could be established as having the status of electronic persons responsible for making good any damage they may cause and possibly applying electronic personhood to cases where robots make autonomous decisions or otherwise interact with third parties independently.’²⁷⁶

That was the first (and only) reference to a possible ‘electronic personhood’ concept that the EU presented. This statement prompted a significant debate, as it was perceived as the recognition of rights (and duties) of robots and, more generally, machines.²⁷⁷ The risk, therefore, is to blur the line between subjects and objects with a collateral downturn for the integrity of the entire legal system. To confer legal status on what is regarded as an object, with the possibility to hold rights and duties, seems a contradiction in terms. Indeed, as stated, this would require a resolution of different legislative issues related to the AI legal capacity and the understanding of how AI acts when performing legal transactions.²⁷⁸ Most importantly, it would require a better comprehension, from a legal stance, of the role of AI which, in turn, might undermine the current general and technologically neutral, risk-based approach. Such an approach would mean to acknowledge the heterogeneity of AI systems, which differ widely in context and functions²⁷⁹ Since AI systems evolve, diversify and increasingly pervade numerous domains of human activity, it is a moving target and a highly unstable regulatory object. Even before the adoption of the AI Act indeed, it has been argued how instead a context-

²⁷⁶ Ibid, paragraph 59.

²⁷⁷ The approach was harshly criticised by many intellectuals in an open letter which can be found at <https://robotics-openletter.eu> accessed 3 April 2025.

²⁷⁸ Expert Group on Liability and New Technologies – New Technologies Formation, ‘Liability for Artificial Intelligence and Other Emerging Digital Technologies’ (2019) <https://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupMeetingDoc&docid=36608> accessed 29 April 2025; Joanna J Bryson and Philip P Kime, ‘Just an Artifact: Why Machines Are Perceived as Moral Agents’ in Toby Walsh (ed), *Proceedings of the 22nd International Joint Conference on Artificial Intelligence (IJCAI)* (AAAI Press 2011) vol 2, 1641.

²⁷⁹ Ibid, 6.

sensitive approach could provide an effective alternative in regulating AI systems. This method recognises that different underlying technologies and applications entail distinctive risks that demand specific regulatory responses.²⁸⁰ As a result, it is stated that a context-based approach with flexible governance mechanisms and targeted sector-related measures would be better suited to respond to the consequences of AI applications.²⁸¹ The reason behind this initial proposed methodology appears simple. Given the rapidly evolving AI landscape, efforts to govern AI using a standardised approach are deemed to compromise the ability of regulation to effectively address the domain-specific challenges. Moreover, the general and all-encompassing risk-based approach might be easily outpaced by the very innovations it aims to regulate as what is currently classified as an AI system might not be the same in the near future.²⁸² After the harsh critics, the proposed electronic personhood for the more sophisticated AI systems was abandoned in favor of the current risk-based approach of the AI Act. It has been debated what the electronic personhood for AI systems would have meant as the concept gives rise to different interpretations. On one hand, it has been contented that the term electronic person is an unknown concept for the Member States' legal systems. Therefore, the first interpretation suggests that this concept is intended to refer to something different from the already existing and widely applied concepts of natural and artificial persons, implying a

²⁸⁰ Sangchul Park, 'Bridging the Global Divide in AI Regulation: A Proposal for a Contextual, Coherent, and Commensurable Framework' (2024) 33 Washington International Law Journal 2, 215.

²⁸¹ Laura Ancona Lee, Benjamin Duraković and Sencer Yeralan, 'AI Ethics: Contextual Frameworks and Domain-Specific Concerns' (2025) 7 Heritage and Sustainable Development 1, 1 <<https://doi.org/10.37868/hsd.v7i1.1224>> accessed 29 April 2025.

²⁸² Andrea Bertolini, 'Artificial Intelligence and Civil Liability' (2020) European Parliament, Policy Department for Citizens' Rights and Constitutional Affairs, PE 621.926 <[https://www.europarl.europa.eu/RegData/etudes/STUD/2020/621926/IPOL_STU\(2020\)621926_EN.pdf](https://www.europarl.europa.eu/RegData/etudes/STUD/2020/621926/IPOL_STU(2020)621926_EN.pdf)> accessed 30 April 2025; Andrea Bertolini and Francesca Episcopo, 'The Expert Group's Report on Liability for Artificial Intelligence and Other Emerging Digital Technologies: a critical assessment' (2021) 12(3) European Journal of Risk Regulation 644 <<https://doi.org/10.1017/err.2021.30>> accessed 30 April 2025.

specific set of AI's rights and duties.²⁸³ A new and different legal subject. On the other hand, a second interpretation suggested that the concept of electronic personhood would not express a new type of subjectivity but rather guarantee a form of legal personhood based on functional considerations. In this sense, machines would not be considered as legal persons with rights and duties, nor as intermediate beings, but rather the use of the legal personhood notion would be comparable to that of a juristic person. This 'functional personhood' would be aimed at purely practical purposes, such as handling liability claims or other legal claims that involve the exploitation of advanced technologies.²⁸⁴ From more of a critical perspective, it can be argued that one of the reasons of the rejection of the concept of electronic personhood as introduced by the EU Parliament and as then interpreted has been the vagueness of the notion. In other words, this new concept has not been sustained by any explanatory context, related, for example, to what kind of AI systems it should have been applied to and why. Moreover, it did not justify the application to sophisticated AIs either from a technical nor legal standpoints as there was no definition of what the term sophisticated entails, which criteria it had to be used to define one and what the concept of electronic subject would have implied. This has opened the field to speculative or even contradictory interpretations, ultimately leading to the inoperativeness of the concept itself. Despite its theoretical potential, the notion of electronic personhood was never further developed, both conceptually and operationally, undermining the viability of its regulatory capacity. The abandonment of this ontological approach in favor

²⁸³ See, amongst others, Lemos, M. C., & de Souza, L. C. 'Robot as Legal Person: Electronic Personhood in Robotics and Artificial Intelligence' (2021) 8 *Frontiers in Robotics and AI*, 789327; Joanna J Bryson, 'The Ethics and Challenges of Legal Personhood for AI' (2022) *The Yale Law Journal Forum* <<https://www.yalelawjournal.org/forum/the-ethics-and-challenges-of-legal-personhood-for-ai>> accessed 29 April 2025; Rafael Dean Brown, 'Property Ownership and the Legal Personhood of Artificial Intelligence' (2021) 30 *Information & Communications Technology Law* 2, 208.

²⁸⁴ Shawn Bayern, 'The Implications of Modern Business–Entity Law for the Regulation of Autonomous Systems' (2016) 7 *European Journal of Risk Regulation* 2, 297; Ugo Pagallo, 'Vital, Sophia, and Co.—The Quest for the Legal Personhood of Robots' (2018) 9 *Information* 9, 230; Rafael Dean Brown, 'Property Ownership and the Legal Personhood of Artificial Intelligence' (2021) 30 *Information & Communications Technology Law* 2, 208; Claudio Novelli, 'Legal Personhood for the Integration of AI Systems in the Social Context: A Study Hypothesis' (2022) 38 4 *AI & Society*, 1-13.

of the risk-based methodology of the AI Act has however prompted other questions of whether the regulation can successfully address the challenges of DsAI systems. Therefore, the following paragraph analysis how the AI Act captures some aspects of DsAI systems while others remain unsolved and outside of its regulatory scope.

2.11 The Applicability of the AI Act to DsAI Systems

The applicability of the AI Act to the DsAI systems is challenging. The main difficulties arise in relation to the regulatory approach. The general all-encompassing methodology is not calibrated on the actual role that AI systems assume during their autonomous operations but rather on the AI systems' lifecycle-oriented perspective.²⁸⁵ The latter focuses on the identifiable stages of pre-deployment - or building phase - and the post-deployment - or use phase- of AI systems.²⁸⁶ The risk-based approach is indeed directed at containing AI applications within certain perimeters of regulation and primarily addressing identifiable developers, providers and users. This approach presupposes that AI systems are developed, deployed and operated within centralised and controllable environments. In other words, the technology-neutral framework of the AI Act conveys aspects of incompatibility with the ontological element of decentralisation. This in turn causes fundamental frictions when applied to decentralised, open source and distributed AI systems. At the same time, it is extremely important to acknowledge the merit instead of the definition of AI as developed within the AI Act:

‘AI system’ means a machine-based system that is designed to operate with varying levels of autonomy and that may exhibit adaptiveness after deployment, and that, for explicit or implicit objectives, infers, from the input it receives, how to generate outputs such as

²⁸⁵ OECD, Explanatory Memorandum on the Updated OECD Definition of an AI System (OECD Artificial Intelligence Papers No 8, OECD Publishing 2024) <<https://doi.org/10.1787/623da898-en>> accessed 5 May 2025.

²⁸⁶ Ibid, 7-12.

predictions, content, recommendations, or decisions that can influence physical or virtual environments.’²⁸⁷

This definition is flexible enough to encompass DsAI systems on a general level.²⁸⁸ Despite the inclusion within the definitory aspect, the AI Act framework shows profound

²⁸⁷ Article 3 (1) Regulation (EU) 2024/1689 of the European Parliament and of the Council of 13 June 2024 laying down harmonised rules on artificial intelligence (Artificial Intelligence Act) and amending Regulations (EC) No 300/2008, (EU) 2018/858, (EU) 2018/1139 and (EU) 2019/2144 and Directives 2014/90/EU, (EU) 2016/797 and (EU) 2020/1828 [2024] OJ L168/1; *see also* Recital 12, Regulation (EU) 2024/1689 of the European Parliament and of the Council of 13 June 2024 (Artificial Intelligence Act) [2024] OJ L168/1; European Commission, Guidelines on the Definition of an AI System under the AI Act (6 February 2025) <https://eimin.lrv.lt/public/canonical/1739857334/5400/Guidelines_on_the_definition_of_AI%20system.pdf> accessed 5 May 2025. The AI Act definition of AI systems is inspired by the OECD, Explanatory Memorandum on the Updated OECD Definition of an AI System (OECD Artificial Intelligence Papers No 8, OECD Publishing 2024) <<https://doi.org/10.1787/623da898-en>> accessed 5 May 2025, 6. The AI Act definition of AI systems successfully operates without any contradiction to the more technical definition of AI as stated in the ISO/IEC 22989:2022, as follows: ‘engineered system that generates outputs such as content, forecasts, recommendations or decisions for a given set of human-defined objectives’ ISO/IEC, Information Technology — Artificial Intelligence — Artificial Intelligence Concepts and Terminology (ISO/IEC 22989:2022) <<https://www.iso.org/standard/74296.html>> accessed 5 May 2025.

²⁸⁸ The DsAI system falls within the seven definitory elements set out in the AI Act and identified by the EU Commission: 1) a machine-based system, 2) with different levels of autonomy, 3) exhibiting adaptiveness, 4) able to infer with an input-output logic, 5) which has explicit or implicit objectives, 6) capable of generating predictions, content, recommendations and decision, 7) influencing physical or virtual environments. For a more specific and detailed description of each of these seven elements, see European Commission, Guidelines on the Definition of an AI System under the AI Act (6 February 2025)

https://eimin.lrv.lt/public/canonical/1739857334/5400/Guidelines_on_the_definition_of_AI%20system.pdf accessed 3 May 2025.

limitations and regulatory gaps in successfully governing DsAI systems' operational logic.²⁸⁹ The mismatch creates indeed a paradox: legal recognition without effectiveness. The AI Act has *horizontal-oriented* and centralised regulatory compliance obligations for the AI lifecycle clearly distributed amongst providers, deployers, distributors and users.²⁹⁰ In the decentralised environment instead, *interdependent* dynamics govern real-time interactions. This latter aspect, coupled with a geographically distributed and cross-border nature of decentralised AI lifecycle operations, creates an overlapping and opaque architecture that prevents the identification (and distribution) of roles and of related risks across the chain of actors. In other words, in an open-source distributed and decentralised fashion the definitory perimeter of identifiable providers, deployers and users becomes vague, especially when all of them can assume multiple roles at once yet remaining anonymous. This translates into a difficulty to apply a centralised risk governance to a decentralised environment. Furthermore, DsAI systems are mainly classified as HOOTL which are not regulated under the AI Act. Therefore, there is an incompatibility with the obligation of human supervision and with the principle of transparency which in turn makes *ex ante* risk management not applicable.²⁹¹ Although in the definition of AI, pursuant to Article 3, the autonomy of the artificial intelligence system is taken into consideration from an ontological point of view, it is not then expressed in the regulation.²⁹² Despite the overall inapplicability to DsAI systems, the AI Act may still find spaces for indirect application in specific cases. An example is when a centralised platform integrates a back-end DsAI system, acting as a contractual intermediary²⁹³, or when a user

²⁸⁹ Philipp Hacker, 'AI Regulation in Europe: From the AI Act to Future Regulatory Challenges' (arXiv, 9 October 2023) <<https://doi.org/10.48550/arXiv.2310.04072>> accessed 1 April 2025.

²⁹⁰ Dave Lewis, Marta Lasek-Markey, Delaram Golpayegani and Harshvardhan J Pandit, 'Mapping the Regulatory Learning Space for the EU AI Act' (2024) ArXiv preprint <<https://arxiv.org/abs/2503.05787>> accessed 21 May 2025.

²⁹¹ AI Act, article 14 and Article 52.

²⁹² AI Act, Article 3.

²⁹³ An example is Uniswap. Uniswap is a decentralised exchange platform where the frontend is managed by a centralised entity whereas the backend uses DsAI bots to optimise trading prices and strategies. In this case, the platform might need to comply with the AI Act as an AI deployer. See <<https://app.uniswap.org>> accessed 20 May 2025.

interface directly connects users to the DsAI where the operator could be qualified as a distributor of the DsAI system.²⁹⁴ There are few examples that should be analysed on a case-by-case basis as all of them might entail specific technical and legal complexities. Consequently, the AI Act, although embracing DsAI within its conceptual and definitional parameters, lacks a systematic and consistent regulatory framework for governing DsAI. The legislative framework of the AI Act relies on assumptions of traceability, centralised oversight, and identifiable responsibility, features that DsAI lacks. This approach reveals a significant regulatory gap: currently, there are no technical or regulatory mechanisms to acknowledge and assess the impact and the role of autonomous and decentralised systems in producing legally relevant effects.

Consequently, although the AI Act includes DsAI in its conceptual and definitional parameters, it lacks a systematic and coherent regulatory framework for its governance. The AI Act's regulatory framework is based on assumptions of traceability, centralised control, and identifiable responsibility, characteristics that DsAI lacks. This leaves a significant regulatory gap: currently, no technical or regulatory mechanisms exist to adequately recognise and evaluate the role of autonomous and decentralised systems in producing legally relevant effects. From an ontological perspective, AI systems continue to be considered objects and

²⁹⁴ This example includes agentic platforms, sometimes known as AI agents. These projects are relatively new additions to the decentralised AI environment. They merge AI agents and blockchain technology, enabling new use cases such as AI agents creating and trading tokens while working semi- or entirely autonomously. ElizaOS and Virtuals Protocol are two prominent examples of agentic platforms.

Virtuals Protocol is a blockchain-based platform for creating and exchanging AI agents. Each agent is backed by a liquidity pool and employs ERC-6551 compliant wallets to provide dynamic pricing. The platform allows anyone to create their own tokenised AI bots, with token holders having access to specified functionality. ElizaOS is a multi-agent simulation framework written in TypeScript that allows for the design and management of autonomous AI agents. It is intended to retain consistent agent personalities and expertise across several platforms. See <<https://app.virtuals.io>> and <<https://www.elizaos.ai>> accessed 18 May 2025.

products; however, DsAI challenges this classification, acting in ways that blur the traditional distinction between subject and object.

2.12 Conclusions

This chapter has demonstrated that the distinctive technical traits of Decentralised Artificial Intelligence (DsAI) cognitive systems—autonomy, adaptive learning, internal models, cooperation and negotiation among multiple agents, and self-organisation—are not marginal characteristics, but systemic properties that enable these systems to operate effectively in decentralised environments. Their integration into sole-code smart contracts demonstrates how DsAI does not simply passively execute predefined rules, but actively contributes to the creation, configuration, and execution of contracts. In this way, DsAI generates observable, repeatable, and binding effects, such as the transfer of resources or the creation of obligations. This dynamic appears to somehow distance DsAI from the traditional classification as a mere tool.

At the same time, this technical analysis confirms the concern raised at the beginning of the chapter. Legal relationships presuppose the identification of a centre of interests to which rights and duties are assigned. DsAI blurs this allocation by directly intervening in contractual dynamics. For the first time, a technological system emerges as an actor of legally relevant situations, without a clear legal category to frame it.

In conclusion, the chapter has shown how neither current regulatory frameworks nor classical doctrinal theories offer adequate instruments to explain this phenomenon. Regulatory responses, such as the European AI Act, remain anchored to an anthropocentric paradigm based on traceability, risk, centralised control, and identifiable responsibility, characteristics incompatible with the DsAI architecture. Likewise, traditional theories of legal subjectivity, personhood, and representative agency fail to fully capture the systemic and distributed nature of DsAI decisions. This results in a conceptual and normative void: DsAI produces concrete and binding effects within legal and social relationships, but existing categories do not offer a coherent framework for their attribution.

This unresolved tension, between technical autonomy and legal recognition, constitutes the central paradox addressed in this thesis. Addressing this issue means shifting the analysis from general categories to the specific legal context in which the role of DsAI is most clearly manifested: sole-code smart contracts. For this reason, the next chapter will analyse the legal nature of smart contracts, assessing whether and to what extent they can be classified as contracts. This step is essential before addressing the specific analysis of the legal role of DsAI in contractual dynamics within the subsequent chapters.

CHAPTER 3

Enter: Smart Contracts

Exploring the Technical and Legal Nature of Blockchain-based Transactions

3.1 Introduction

The fascinating complexity of Artificial Intelligence systems is not only bound to their technical insights. It can be further appreciated also from the legal perspective. As AI is gaining ground in ensuring a fast, safe, and successful decision-making process in the current fast-paced human interactions, it appears fundamental to understand the role the former systems are taking in these legal relationships. In such a scenario, Decentralised AI deployed on blockchain platforms entails several challenges for law in this context. They descend from a simple conundrum. On the legal side, it is possible to ascertain two main intertwined issues, regarding blockchain-based transactions and smart contracts, when it comes to analysing the deployment of DsAI systems on blockchain. The first one leans upon the qualification of blockchain transactions and smart contracts and the question whether, and to what extent, they can be considered as contracts from a legal point of view. Otherwise, the second is linked to the identification of the role that the DsAI system may potentially assume with respect to the counterparties of blockchain-based transactions. In other words, to comprehend what happens from a legal standpoint when DsAI systems create and perform blockchain-based smart contract transactions, it is necessary to analyse both the technical and legal dynamics. These dynamics operate within the blockchain environment and interact to produce legal effects. This is because it is just by detecting the legal elements inside the technical ones that it might be

thereby possible to explain if the role of DsAI systems, by means of their autonomous behaviour, is able to affect such transactions producing legal effects.

Therefore, a prior analysis of the nature of blockchain-based transactions and smart contracts is the essential playground of further legal discussions. The scope is to narrow down the risk over the legal uncertainty that stems from the cross application of both AI and blockchain technologies. It is a question of deciding whether the role of decentralised multi-agent systems is determining in legal relations that can be set in the blockchain environment amongst parties involved. From a legal standpoint, the decision upon the former shall inevitably affect the latter.

To tackle such key arguments and advance the central research question, this chapter will focus on the analysis related to the nature of blockchain smart contract transactions and their qualification under the legal standpoint. In doing so, the thesis progresses the analysis amid three pivotal points which form the three main chapter's sections. The first one shall focus on the analysis of the technical side of blockchain transactions' systems. The investigation narrows the path from the general technical context of blockchain transactions to this thesis selected one: smart contracts and sole-code smart contracts. The analysis will, in fact, highlight the operational similarities and related differences between blockchain simple transactions and sole-code smart contracts. The purpose is to present the (legal) aftermaths stemming from these different decentralised applications and their correlation to the central research question. The second section of this chapter will indeed set the legal scene by introducing the overall discussion upon the concept of juristic transactions and their pivotal function in the legal systems. Then, the discussion will progress to the analysis of contract law principles in the light of the harmonisation efforts from the European standpoint, without under mentioning the importance of some fundamental rules existing at the domestic level, in both European civil law and common law traditions. The purpose is to have under the magnifying glass the rationale of shared contract law principles, essential to sharpen the discussion upon the legal qualification of blockchain-based transactions. Finally, in the latest section, the research shall

put forward the debate upon the possible adaptation and application of the contract law principles to the blockchain sole-code smart contracts, offering its considerations and perspectives. The ultimate scope is to identify the nature of sole-code smart contracts under the contract law principles to define an overall legal framework in which the role of Decentralised AI systems will be further analysed in subsequent chapters.

3.2 Blockchain Technology: Unveiling a New Framework for Legal Relations

Before delving into the legal aspects, it is necessary to set the technical scene by deepening the discussion around the blockchain technology and the nature of its most relevant application: smart contracts.

3.2.1 The Blockchain Realm: Architecture and Operations

As discussed in chapter one, the overall blockchain infrastructure operates as a layer placed on top of the Internet.¹ This means that the blockchain protocol is supported by the Internet network which allows the peer-to-peer exchange of data between a chain of computers, so-called blocks.²

¹ Daniel Bennet, Lily Maria, Yulia Putri Ayu Sanjaya and Achani Rahmania Az Zahra, ‘Blockchain Technology: Revolutionizing Transactions in the Digital Age’ (2024) 5(2) ADI Journal of Recent Innovation, 192; Giulia Rafaiani, Paolo Santini, Marco Baldi and Franco Chiaraluce, “Implementation of Ethereum Accounts and Transactions on Embedded IoT Devices” (2022) ArXiv <<https://arxiv.org/abs/2206.14782>> accessed 3 July 2023; Hong-Ning Dai, Zheng, Zhang, ‘Blockchain for Internet of Things: A Survey’ (2020) Arxiv <<https://arxiv.org/pdf/1906.00245.pdf>> accessed 7 March 2021.

² Patel, ‘Blocs’ (2024) <<https://ethereum.org/en/developers/docs/blocks/>> accessed May 2024; Daniele Marletta, Alessandro Midolo & Emiliano Tramontana, ‘A Blockchain-Based Strategy for Certifying Timestamps in a Distributed Healthcare Emergency Response Systems’ (2025) 17 Future, 210.

3.2.1 a) Technical Anatomy of The Blockchain

The blockchain blocks can be imagined as boxes, in which all the operations and transactions that run on the platform are cryptographically secured and stored. Such blocks are linked to form a time-stamped sequence of all transactions occurring among peer nodes.³ Blocks can therefore be understood as batches of transactions.⁴ As noted, '[B]lockchain transactions are cryptographically signed instructions from accounts'.⁵ Indeed, each participant of the decentralised platform holds an account by means of that it is possible to initiate a transaction that, as a result, will determine an update to the state of the entire blockchain network.⁶ Therefore, the state of the blockchain is a continuous and synchronised record of all transactions' data. Again, this is possible because each node of this distributed chain holds a copy of such block-operations, whose origin and destination are verified through the use of cryptographic public and private keys mechanism which is allocated to each account member of blockchain network once first entered the system.⁷ Furthermore, to recognise each

³ Andrey L Bulgakov et al, 'Scalability and Security in Blockchain Networks: Evaluation of Sharding Algorithms and Prospects for Decentralized Data Storage' (2024) 12 Mathematics, 3860; Primavera De Filippi and Aaron Wright, *Blockchain and the Law, The Rule of Code*, (Harvard University Press, 2019), 17.

⁴ Patel, (n. 2).

⁵ Richards, 'Ethereum Accounts' (2021), <<https://ethereum.org/en/developers/docs/accounts/>> accessed April 2021.

⁶ Hang Feng, Yufeng Hu, Yinghan Kou, Runhuai Li, Jianfeng Zhu, Lei Wu and Yajin Zhou, 'A Lightweight Architecture for Ethereum Archive Nodes' in 2024 USENIX Annual Technical Conference (USENIX ATC 24) (USENIX Association 2024), 623–639.

⁷ Shi Dong, Khushnood Abbas, Meixi Li and Joarder Kamruzzaman, 'Blockchain Technology and Application: An Overview' (2023) 9 PeerJ Computer Science, e1705; Gousia Habib, Sparsh Sharma, Sara Ibrahim, Imtiaz Ahmad, Shaima Qureshi and Malik Ishfaq, 'Blockchain Technology: Benefits, Challenges, Applications, and Integration of Blockchain Technology with Cloud Computing' (2022) 14(11) Future Internet, 341.

transaction occurred, each block of the chain contains a ‘header’, used to organise the shared ledger.⁸ In fact, the header usually contains three elements, the ‘hash’ function of all transactions recorded in that block, the timestamp, and the hash of the previous block.⁹ This way, creating a sequentially organised time-stamped chain.¹⁰ The blockchain is therefore connected through all these data contained in each header. Consequently, the presence of the hash of the previous block allows reconstructing the path of each operation performed chronologically.¹¹

3.2.1 b) Public vs Private and Permissioned vs Permissionless Blockchain Infrastructure

Thus, from a technical point of view, the blockchain transactions run and update at the same time on all the nodes forming the peer-to-peer computer networking. Such a concept is of great importance since it explains both who can access the data and information stored in the blockchain or who can enact itself as a node in the chain.¹² Therefore, from the data access viewpoint, the blockchain can be private or public. In the first case, only the authorised

⁸ Jack Davies, ‘What Makes a Block? A Meta-Analysis of Blockchain Block Header Fields’ (2024) 7 *Frontiers in Blockchain*, 1387362; Gautami Tripathi, Mohd Abdul Ahad and Gabriella Casalino, ‘A Comprehensive Review of Blockchain Technology’ (2023) 9 *Decision Analytics Journal*, 100344.

⁹ Ziad Hussein, May A Salama and Sahar A El-Rahman, ‘Evolution of Blockchain Consensus Algorithms: A Review on the Latest Milestones of Blockchain Consensus Algorithms’ (2023) 6 *Cybersecurity*, 23.

¹⁰ *Ibid.*

¹¹ Joseph Lee and Vere Marie Khan, ‘Blockchain and smart contract for peer-to-peer energy trading platform: legal obstacles and regulatory solutions’ (2020) 19 *UIC Review on Intellectual Property Law*, 285.

¹² Ahmed M. Tawfik, Ayman Al-Ahwal, Adly S. Tag Eldien, Hala H. Zayed et al, “Blockchain-based access control and privacy preservation in healthcare: a comprehensive survey” (2025) *Cluster Computing* 28, article 529; Lorenzo Piatti, ‘Blockchain e smart contracts’ (lecture in Coding for lawyers, University of Milan, 4 March 2021).

accounts can get access to the information stored.¹³ It is open only to a group of individuals or organisations which share the system among them as peers.¹⁴ As opposed, in the public blockchain system, all people and entities worldwide can access the data stored in the ledger.¹⁵ The private one can turn public if necessary or whenever a specific operation needs to be conducted on a public mode.¹⁶ At the same time, from the nodes standpoint, a blockchain can be permissioned or permissionless. This data is particularly relevant since Decentralised Artificial Intelligence systems operate predominantly on public and permissionless blockchains, contexts in which the absence of prior authorisations amplifies both the technical autonomy and the legal implications.¹⁷ In the first case, the nodes of the blockchain are directly controlled and who want to enact as such, must have the authorisation from whoever manage the blockchain platform.¹⁸ Unlike the permissioned, the permissionless system, is open and accessible to anyone with an internet connection can enact as a node in the chain.¹⁹ By combining these concepts together, a blockchain network can thus be private and permissioned

¹³ Christine V. Helliar, Louise Crawford, Laura Rocca, Claudio Teodori and Monica Veneziani, 'Permissionless and permissioned blockchain diffusion' (2020) 54 *International Journal of Information Management*, 102136.

¹⁴ Chris Gilbert and Mercy Abiola Gilbert, 'Unraveling Blockchain Technology: A Comprehensive Conceptual Review' (2024) 1(4) *Journal of Emerging Technologies*, 45.

¹⁵ Nazanin Moosavi, Hamed Taherdoost, Nachaat Mohamed, Mitra Madanchian, Yousef Farhaoui and Inam Ullah Khan, 'Blockchain Technology, Structure, and Applications: A Survey' (2024) 237 *Procedia Computer Science*, 645.

¹⁶ Rishabh Dhillon et al, 'Exploring dimensions of governance for different types of blockchain networks' (2025) *The British Accounting Review*, 101588.

¹⁷ Philipp Hacker, 'Regulating Smart Contracts: Legal Theory, Law, and Regulation of Disruptive Technologies' (2019) 21 *German Law Journal*, 1341.

¹⁸ Ibid; European Parliament, Policy Department for Economic, Scientific and Quality of Life Policies, 'Cryptocurrencies and Blockchain, Legal context and implications for financial crime, money laundering and tax evasion', PE 619.024, July 2018 <<https://www.europarl.europa.eu/cmsdata/150761/TAX3%20Study%20on%20cryptocurrencies%20and%20blockchain.pdf>> accessed September 2020.

¹⁹ Ibid, 15.

as well as public and permissioned.²⁰ At the same time, the blockchain can be either public and permissioned or public and permissionless, like Bitcoin²¹ and Ethereum.²² As a consequence, in the latter, anyone can access, participate, manage, and operate on the public environment as a peer node.²³

3.2.2 Core Features of Blockchain Systems

In order to understand how all these steps are effectively determined in the network, it is necessary to outline the blockchain key-features, which are disintermediation, resilience, transparency, pseudonymity, and consensus mechanism.²⁴ While complex, these are the technical characteristics that bring about all the conundrums under the legal sphere. Therefore, once these features have been explored, the leading legal quandaries will be identified. The aim is to define the legal conundrums that exhibit a crucial correlation concerning the role of DsAI systems.

3.2.2 a) Disintermediation and Decentralisation

It has been stated that the more distributed the blockchain is, the more is hard to manage.²⁵ Consequently, to facilitate the management of the overall infrastructure, the

²⁰ An example is Exonum. See <<https://exonum.com/index>> accessed 8 March 2023.

²¹ To access a blockchain platform: <<https://www.blockchain.com/explorer>> 7 February 2024.

²² Ethereum blockchain: <<https://ethereum.org/en/>> 6 May 2024.

²³ Johannes Sedlmeir, Jonathan Lautenschlager, Gilbert Fridgen, Nils Urbach and others, “The transparency challenge of blockchain in organizations” (2022) 32 Electronic Markets, 1779-1794.

²⁴ Parma Bains, ‘Blockchain Consensus Mechanism’ (IMF, 2022).

²⁵ Imran Bashir, *Mastering Blockchain* (4th edn, Packt Publishing, 2023); De Filippi and Wright (n. 3), 29.

majority of these systems are open-source software.²⁶ This means that blockchain-based algorithms can be potentially enhanced and implemented by everyone in the world, operating outside from the original formal structure. Therefore, a plethora of software developers can be responsible for the blockchain large-scale platform maintenance and transaction performances.²⁷ Moreover, it is both the disintermediation and the distribution mechanism which allows, as argued, ‘anyone with an Internet connection can retrieve information stored on a blockchain simply by downloading freely available open-source software’.²⁸

3.2.2 b) Resilience and Tamper-Resistance

Furthermore, blockchain systems are equipped with not only such a global and cross-border nature, but also with the tamper resistance protocol.²⁹ As previously mentioned, once data and information are recorded on the network of nodes, it becomes tough to modify the former, given the timestamp feature of the chain.³⁰ Once a transaction code is deployed on the

²⁶ Kevin Werbach, *The Blockchain and the New Architecture of Trust* (MIT Press 2018), 67–72; Satoshi Nakamoto, ‘Bitcoin: A Peer-to-Peer Electronic Cash System’ (2008) <<https://bitcoin.org/bitcoin.pdf>> accessed 16 September 2024.

²⁷ Christian Catalini and Joshua S Gans, ‘Some Simple Economics of the Blockchain’ (2019) 29 *Communications of the ACM*, 95; Muhammad Muzammal, Qiang Qu and Bulat Nasrulin, ‘Renovating blockchain with distributed databases: An open-source system’ (2019) 90 *Future Generation Computer System*, 1234–678.

²⁸ Melanie Swan, *Blockchain: Blueprint for a New Economy* (O’Reilly Media 2015) 9–14.

²⁹ Adishesu Hari and T. V. Lakshman, ‘The Internet Blockchain: A Distributed, Tamper-Resistant Transaction Framework for the Internet’ (2016) 204-216 *The 15th ACM Workshop* <<https://dl.acm.org/doi/10.1145/3005745.3005771>> accessed 15 March 2020.

³⁰ Roger Wattenhofer, *The Science of the Blockchain* (Inverted Forest Publishing 2016) 17–19; Lu Yang, ‘The blockchain: State-of-the-art and research challenges’ (2019) 15 *Journal of Industrial Information Integration*, 80.

system, no single party can alter or change it. This is the resilience feature of Blockchain systems.³¹

3.2.2 c) Transparency and Traceability

Along with such characteristics mentioned above, this technology also embodied a great tool of transparency.³² All the activities that occurred on the platform are recorded and tracked on this peer-to-peer network.³³ Thus, all the data triggered on the distributed ledger are open, non-repudiable and readable to everyone on the chain. As it has been affirmed:

‘Because blockchain relies on public-private key encryption and digital signatures, once a transaction occurs on a blockchain-based network, parties subject to that transaction will have a hard time denying involvement. Before engaging in a transaction with a smart contract or another member of the blockchain-based network, a party must sign the transaction with their private key. The digital signature serves as evidence that an account initiated a transaction, narrowing the ability of the holder of a blockchain-based account to refute the fact that a transaction occurred unless a party can prove that the private key associated with the account was somehow compromised.’³⁴

³¹ Lawrence Lessig, *Code and Other Laws of Cyberspace* (Basic Books 1999, updated edn 2006), 132–135; Vitalik Buterin, ‘Ethereum: A Next-Generation Smart Contract and Decentralized Application Platform’ (2014) <<https://ethereum.org/en/whitepaper/>> accessed 16 September 2024.

³² Philipp Hacker, Ioannis Lianos, Georgios Dimitropoulos and Stefan Eich (eds), *Regulating Blockchain: Techno-Social and Legal Challenges* (OUP 2019) 41–45; Primavera De Filippi, ‘Blockchain Technology and Decentralized Governance: The Pitfalls of a Trustless Dream’ (2019) 9 *Decentralized Cooperation Review*, 5.

³³ Ibid.

³⁴ De Filippi and Wright (n. 3), 37.

3.2.2 d) Pseudonymity and Trust by Design

The blockchain technology is further typified by pseudonymity trait.³⁵ As a consequence of the encryption mechanism, people and even digital agents can engage in transactions without revealing their nature or real identity.³⁶ As a result, in the decentralised environment, the trust among peers is at its high standards.³⁷ However, none of such blockchain features would be fully operating without the last and the most significant trait, which reveals the inner nature of this technology. It is called the consensus mechanism.³⁸ At this point, this section will focus on the core nature of consensus in the blockchain systems, underlying some of the aftermaths it determines, while leaving to following chapters further discussions around the effects stemmed by such a trait on the legal ground.

3.2.3 The Consensus Mechanism: The Backbone of Blockchain Systems

The consensus mechanism governs how information can be added and thus flow on the blockchain platform.³⁹ In other words, it is the blockchain systems' validation process. Without any doubt, it is the backbone of the blockchain-based network since it provides the

³⁵ Arvind Narayanan, Joseph Bonneau, Edward Felten, Andrew Miller and Steven Goldfeder, *Bitcoin and Cryptocurrency Technologies: A Comprehensive Introduction* (Princeton University Press 2016) 137–141.

³⁶ Bashir (n. 24), 102.

³⁷ Elli Androulaki et al, 'Hyperledger Fabric: A Distributed Operating System for Permissioned Blockchains' (2018) 37 EuroSys Conference Proceedings 1–15; Nikolaos Alexopoulos, Emmanouil Vasilomanolakis, Atália Réka Ivánkó and Max Mühlhäuser, 'Towards Blockchain-Based Collaborative Intrusion Detection Systems', in Gregorio D'Agostino and Antonio Scala (eds), *Critical Information Infrastructures Security* (CRITIS 2017), 107-118.

³⁸ Imran Bashir (n 134), 37; Garrick Hileman and Michel Rauchs, *Global Blockchain Benchmarking Study* (Cambridge Centre for Alternative Finance 2017), 24–28.

³⁹ Arvind Narayanan, Joseph Bonneau, Edward Felten, Andrew Miller and Steven Goldfeder, *Bitcoin and Cryptocurrency Technologies: A Comprehensive Introduction* (Princeton University Press 2016) 156–160.

decentralisation of control over data exchanged.⁴⁰ It is necessary to highlight that the consensus process can change based on the type of blockchain system in use; that is, the same consensus mechanism is not suitable for all types of blockchain and vice versa.⁴¹

Thus, the different types of networks can affect the choice upon a specific consensus process for not all the blockchain systems can technically perform it at the same level.⁴² The core nature of the consensus mechanism is strictly connected to the concept of decentralised control, as previously mentioned. That is, since into the blockchain-based network there is no room for a third trusted authority, the validation over information and data shared for all the operations and transactions must be reached amongst the participants. The consensus process aims at gaining this trust by helping achieve validation agreement among the blockchain's peer nodes.⁴³ As it has been argued:

‘To achieve consensus, different algorithms are used. It is easy to reach an agreement between two nodes (in client-server systems, for example), but when multiple nodes are participating in a distributed system and they need to agree on a single value, it becomes quite a challenge to achieve consensus. This process of attaining agreement common state or value among multiple nodes despite the failure of some nodes is known as distributed consensus’.⁴⁴

⁴⁰ Shermin Voshmgir, *Token Economy: How the Web3 Reinvents the Internet* (2nd edn, Token Kitchen 2020), 83–87; Elli Androulaki et al, ‘Hyperledger Fabric: A Distributed Operating System for Permissioned Blockchains’ (2018) 37 EuroSys Conference Proceedings, 1–15.

⁴¹ Maria Bampa, Aggelos Kiayias and Dionysis Zindros, ‘Proof-of-Stake Protocols: A Survey’ (2020) 35 ACM Computing Surveys, 1–33; Don Tapscott and Alex Tapscott, *Blockchain Revolution* (Portfolio 2016) 74–79.

⁴² Roger Wattenhofer, *The Science of the Blockchain* (Inverted Forest Publishing 2016) 25–29; Joseph Bonneau, Andrew Miller, Jeremy Clark, Arvind Narayanan, Joshua Kroll and Edward Felten, ‘SoK: Research Perspectives and Challenges for Bitcoin and Cryptocurrencies’ (2015) IEEE Symposium on Security and Privacy, 104–121.

⁴³ Christian Catalini and Joshua S Gans, ‘Some Simple Economics of the Blockchain’ (2019) 29 Communications of the ACM, 95–105.

⁴⁴ Imran Bashir (n 134), 36.

Thus, it can be said that consensus allows all or the majority of blockchain network members to agree on a proposed state of the latter in the following two circumstances: when a specific transaction must be validated either whenever a new node needs to be added to the blockchain network.⁴⁵ In addition to this, all the consensus algorithms are designed to deal with potential faults, allowing the distributed system to reach the final state of agreement.⁴⁶

3.2.3 a) Main Consensus Models and the Phenomenon of Transaction Failure

Currently, there are numerous types of consensus processes in the existing blockchain systems.⁴⁷ However, four remain the major ones: proof of work (PoW), proof of stake (PoS), practical byzantine fault tolerance (PBFT) and delegated proof of stake (DPoS).⁴⁸ Each of these kind of consensus algorithms have their own specific technical traits to ensure the reliability and consistency of data and transactions deployed.⁴⁹ The purpose is that by means of consensus, all operations occurring in the blockchain are verified, so that the state of the entire

⁴⁵Ibid, 37; Arvind Narayanan, Joseph Bonneau, Edward Felten, Andrew Miller and Steven Goldfeder, *Bitcoin and Cryptocurrency Technologies: A Comprehensive Introduction* (Princeton University Press 2016) 163–167.

⁴⁶ Leslie Lamport, Robert Shostak and Marshall Pease, ‘The Byzantine Generals Problem’ (1982) 4(3) *ACM Transactions on Programming Languages and Systems* 382; Wenbo Wang, Dinh Thai Hoang, Peizhao Hu, Zehui Xiong, Dusit Niyato, Ping Wang, Yonggang Wen, Dong In Kim, ‘A Survey on Consensus Mechanisms and Mining Strategy Management in Blockchain Networks’ (2019) 7 *IEEE Access*, 22328.

⁴⁷ Ibid, 22333.

⁴⁸ Maria Bampa, Aggelos Kiayias and Dionysis Zindros, ‘Proof-of-Stake Protocols: A Survey’ (2020) 35 *ACM Computing Surveys* 1–33; Li, Jiang, Chen, Luo, Wen, ‘A survey on the security of blockchain systems’ (2020) 107 *Future Generation Computer Systems*, 841-853.

⁴⁹ Shermin Voshmgir, *Token Economy: How the Web3 Reinvents the Internet* (2nd edn, Token Kitchen 2020) 95–101; Joseph Bonneau, Andrew Miller, Jeremy Clark, Arvind Narayanan, Joshua Kroll and Edward Felten, ‘SoK: Research Perspectives and Challenges for Bitcoin and Cryptocurrencies’ (2015) *IEEE Symposium on Security and Privacy*, 104–121.

ledger is constantly and synchronically updated over all the blockchain nodes.⁵⁰ Therefore, the essence of consensus can be envisioned as a group decision-making process which authorises the general agreement over transactions among peer blocks.⁵¹ That is, the total control over information and exchanges is utterly decentralised and entrusted to participants. Consequently, it can be argued that in the case in which the consensus over information and data deployed in the network is not reached, the transaction request cannot be determined. This is often called ‘transaction failure’.⁵²

3.2.4 From Technical Traits to Legal Challenges

From such an overview of the blockchain features analysed so far, some points of discussion can be gathered under the legal debate.⁵³ Above all, it must be considered that blockchain-based technology oversteps the mere technical side. Hence, they produce effects on reality, causing paramount frictions on several legal frameworks. For instance, the decentralisation trait, along with the open source blockchain protocols’ structure can cause regulation concerns.⁵⁴ In fact, just as Internet, since the blockchain aims at operating worldwide, anyone can modify its protocols as well as determining transactions structuring both social and economic activities. In such cases, the question about what kind of regulation is possible to apply to govern such cross-border exchanges is pivotal for two main reasons. The first one is strictly related to the possibility of qualifying blockchain-based transactions as

⁵⁰ Christian Catalini and Joshua S Gans, ‘Some Simple Economics of the Blockchain’ (2019) 29 Communications of the ACM, 95–105.

⁵¹ Don Tapscott and Alex Tapscott, *Blockchain Revolution* (Portfolio 2016) 82–87.

⁵² Cook, Painter, Peterson, Dechev, ‘Read-Uncommitted Transactions for Smart Contract Performance’ (2019) IEEE 39th International Conference on Distributed Computing Systems (ICDCS), 1960.

⁵³ Michèle Finck, *Blockchain Regulation and Governance in Europe* (Cambridge University Press 2019) 17–22.

⁵⁴ Chris Brummer (ed), *Cryptoassets: Legal, Regulatory, and Monetary Perspectives* (Oxford University Press 2019) 35–39; Ugo Pagallo, *The Laws of Robots: Crimes, Contracts, and Torts* (Springer 2013) 102–106.

having legal nature. It must be investigated to what extent they are legally relevant and if so, how much they can share with traditional contracts' regulation.⁵⁵

The second one regards the role of exchanges' parties. Since the pseudonymity or even anonymity is involved, blockchain transactions may raise legal accountability issues, since these features can strengthen risks of unlawful actions conducted by the parties, such as money-laundering, terrorism financing, frauds, intellectual property infringements or tax evasion, due to the blurred lines of blockchain digital identity.⁵⁶ Consequently, such cases boost further problems of control over peer-to-peer trade-offs as well as upon protection of parties' rights and about legal enforcement procedures in such a closed and, at the same time, too open context.⁵⁷

Furthermore, the ability to deploy autonomous software in the decentralised blockchain environment, without the control of third entities or centralised servers, determines the difficulty to retain the power of stopping the code from executing operations which are not desired or even no longer wanted. In particular, in the public permissionless systems, once the code is deployed and the transaction authorised, is difficult to reverse the process. The only way is indeed having a 'Fork'.⁵⁸ The fork occurs when the nodes agreed that the original software is splatted into two versions that run on the same blockchain network.⁵⁹ Indeed, with

⁵⁵ Gunther Teubner, *Constitutional Fragments: Societal Constitutionalism and Globalization* (Oxford University Press 2012) 115–120.

⁵⁶ Dirk Zetsche, Ross Buckley and Douglas Arner, 'The Distributed Liability of Distributed Ledgers: Legal Risks of Blockchain' (2018) 19 *University of Illinois Law Review*, 1361.

⁵⁷ Nydia Remolina, 'Blockchain, Smart Contracts, and the Law' (2019) 14 *Capital Markets Law Journal*, 38; Chris Brummer, *Fintech Law in a Nutshell* (West Academic 2019) 121–126.

⁵⁸ Miles Carlsten, Harry Kalodner, S Matthew Weinberg and Arvind Narayanan, 'On the Instability of Bitcoin Without the Block Reward' (2016) 23 *ACM Conference on Computer and Communications Security*, 154; Ittay Eyal and Emin Gün Sirer, 'Majority is Not Enough: Bitcoin Mining is Vulnerable' (2014) 18 *Financial Cryptography and Data Security*, 436.

⁵⁹ Walch, 'In Code(rs) We Trust', in Philipp Hacker, Ioannis Lianos, Georgios Dimitropoulos and Stefen Eich (eds), *Regulating Blockchain, Techno-social and Legal Challenges* (Oxford University Press, 2019), 62.

the fork, the protocol breaks into two version, in order to get an upgraded or modified version of the original network.⁶⁰ After the fork, the two chains, the original and the new one, have different rules.⁶¹ Moreover, the respective transactions will no longer be compatible, whilst the blockchain will keep the history of the transactions that took place up to the moment of the Fork.⁶² In addition, the fork can be ‘soft’ or ‘hard’.⁶³ The former happens when it is necessary to proceed to gain an upgraded version of the original software, whereas the latter occurs in order to correct a disfunction recorded in the ledger, a bug, or a breach.⁶⁴ The Fork event demonstrates the power of the decentralisation that runs the blockchain open-source protocol as the consensus to operate the split on the software is extremely complex to determine.

Thus, as it has been quoted ‘By relying on a peer-to-peer network and a consensus mechanism, they facilitate the execution of computer code in a way that is entirely independent of any one party.’⁶⁵ Such an automatic, as well as autonomous execution, creates a highly deterministic system. On a legal point of view, this determines further questions on how to

⁶⁰ Garrick Hileman and Michel Rauchs, *Global Cryptocurrency Benchmarking Study* (Cambridge Centre for Alternative Finance, 2017) 46–49; Peter Rizun, ‘A Transaction Fee Market Exists Without a Block Size Limit’ (2015) *Ledger Journal* 1.

⁶¹ Walch, ‘Open-Source Operational Risk: Should Public Blockchains Serve as Financial Market Infrastructures?’ in David Lee Kuo Chuen and Robert Deng (eds), *Handbook of Blockchain, Digital Finance, and Inclusion* (Elsevier, 2017), 259-266.

⁶² Islama, Mäntymäki, Turunen, ‘Why do blockchains split? An actor-network perspective on Bitcoin splits’ (2019) 148 *Technological Forecasting and Social Change*, 119743; Andrew Miller et al, ‘The Honey Badger of BFT Protocols’ (2016) ACM SIGSAC Conference on Computer and Communications Security, 31.

⁶³ EC-Council, ‘HARD FORKS VS. SOFT FORKS (AND HOW THEY WORK WITH BLOCKCHAIN)’ (2021) <<https://blog.eccouncil.org/hard-forks-vs-soft-forks-and-how-they-work-with-blockchain/>> accessed April 2021; Joseph Bonneau, ‘Why Buy When You Can Rent? Bribery Attacks on Bitcoin-Style Consensus’ (2016) International Conference on Financial Cryptography and Data Security, 19–24.

⁶⁴ Bryan Ford, ‘On the Scale and Decentralization of Blockchain-Based Systems’ (2019) 19 IEEE Symposium on Security and Privacy, 51–65.

⁶⁵ De Filippi and Wright (n. 3), 44.

secure the return of any unwanted exchange of value or asset due to the blockchain tamper-resistant nature. No less, the autonomy and functionality of blockchain exchanges' procedures rely on the consistency and effectiveness of consensus mechanism.⁶⁶ This way, legal issues increase over the necessity to understand the critical role of such a process concerning individual transactions and the legal effects it causes in case the group consensus is not reached.⁶⁷ This aspect is particularly relevant if it is assumed that blockchain proceedings have some contractual value. That is, what occurs when the consent of the individual parties is not sufficient to determine the successful conclusion of a blockchain-based transaction. Furthermore, what happens in the event of failure to form consensus mechanisms with respect to the obligations of the transaction counterparties.⁶⁸

All such problematic aspects about decentralised systems' regulation, control and governance will then be addressed over the thesis discussion in the context of the DsAI and its role in blockchain procedures. At this stage, it is necessary to highlight that, for the purpose of this thesis, all debate round the central research question will focus exclusively on the public permissionless blockchain-based systems. Compared to the private one, in fact, the public blockchain environment sharpens the above-mentioned legal issues, especially in the light of DsAI systems which can be therein deployed.

In order to further analyse the blockchain architectures, in the next section the thesis shall examine one of the most compelling decentralised applications: smart contracts. The scope is

⁶⁶ Dirk Zetsche and Ross Buckley, 'Decentralized Finance (DeFi)' (2021) 22 European Banking Institute Working Paper, 1; Philipp Hacker, 'Corporate Governance for Complex Cryptoeconomies' (2019) 10 European Business Organization Law Review, 259.

⁶⁷ Maxwell Short, 'The Blockchain Governance Crisis from the Perspective of Corporate Theory' (10 March 2024) SSRN Electronic Journal <<https://ssrn.com/abstract=4787807>> accessed 16 September 2024.

⁶⁸ Christopher Markou and Simon Deakin, 'From Rule of Law to Legal Singularity? Reimagining Rights in the Age of AI' in Simon Deakin and Christopher Markou (eds), *Is Law Computable?* (Hart 2020), ch 3.

to define such features under the light of both technical and legal perspectives directly linked to the investigation of central research question.

3.3 Smart Contracts: The Evolution of Contracts

3.3.1 Defining Smart Contracts in the Blockchain Environment

Smart contracts are the rising sun of new-generation interactions. They represent the linkage between the concrete effectiveness of the blockchain decentralised environment and its operational purpose. Above all, since smart contracts constitute a feature that can be run on distributed ledger systems they can be implemented as key-applications of blockchain network.⁶⁹ From a technical perspective, as anticipated in chapter one, smart contracts are self-executing protocols that allow blockchain transactions based on a complex program logic.⁷⁰ That is to say, in the coding semantics, that smart contract algorithm reacts to a conditional logic expressed by the paradigm ‘if/then’ or ‘if this, then that’ (‘this’ is the condition that triggers the ‘that’, namely the transaction to be performed).⁷¹ In other words, smart contracts are blockchain software features used to determine and automatically carry decentralised

⁶⁹ Fabian Schär, ‘Decentralized Finance: On Blockchain- and Smart Contract-Based Financial Markets’ (2021) 103 Federal Reserve Bank of St. Louis Review, 153; Loi Luu, Duc-Hiep Chu, Hrishi Olickel, Prateek Saxena and Aquinas Hobor, ‘Making Smart Contracts Smarter’ in Proceedings of the 2016 ACM SIGSAC Conference on Computer and Communications Security (CCS ’16) (ACM 2016), 254.

⁷⁰ Das, Ekey, Frassetto, David Gens, Hostáková, Jauernig, Faust, Sadeghi, ‘FASTKITTEN: Practical Smart Contracts on Bitcoin’ (2019) IACR Cryptol. ePrint Arch., 1 <<https://eprint.iacr.org/2019/154.pdf>> accessed October 2020.

⁷¹ Nick Szabo, ‘Formalizing and Securing Relationships on Public Networks’ (1997) First Monday 2 (9) <<https://doi.org/10.5210/fm.v2i9.548>> accessed 6 Aprile 2023; Christopher D Clack, Vikram A Bakshi and Lee Braine, ‘Smart Contract Templates: foundations, design landscape and research directions’ (2016) <arXiv:1608.00771> accessed 8 July 2022; Clifford Chance, ‘Smart Contracts: legal framework and proposed guidelines for lawmakers’ (2018), 6 <<https://www.ebrd.com/documents/legal-reform/pdf-smart-contracts-legal-framework-and-proposed-guidelines-for-lawmakers.pdf>> accessed 4 July 2020.

transactions between chain nodes.⁷² This technical paradigm is crucial in relation to DsAI systems, since their autonomous operation is based precisely on the execution of conditional logics without human supervision.

Despite their important application, not all blockchain platforms support smart contract functions. To be clearer, whereas all blockchain systems allow simple exchange transactions, which do not present the same features of smart contract protocols, not all blockchain networks uphold complex smart contract transactions. The most effective examples are, indeed, Bitcoin and Ethereum.⁷³ Unlike the former, the Ethereum system, the most prominent public permissionless blockchain, embeds and enables complex smart contract protocols to run.⁷⁴

3.3.2 Technical Functions and Operational Features

Being aware of such approaches in blockchain platforms, this section shall examine the smart contract technical functions, in order to draw a comparison with the other blockchain-based simple transactions, namely the exchange ones, for the scope of the legal analysis.⁷⁵ Moreover, it is essential to highlight that, currently, there is no existing shared notion of smart contract, just as there are no unconditional stances relating to its legal nature.⁷⁶ Nonetheless, for the scope of this thesis' research question, both simple decentralised transactions and more

⁷² Andreas M Antonopoulos and Gavin Wood, *Mastering Ethereum: Building Smart Contracts and DApps* (O'Reilly Media 2018).

⁷³ Andreas M Antonopoulos, *Mastering Bitcoin: Programming the Open Blockchain* (2nd edn, O'Reilly Media 2017); Nicola Atzei, Massimo Bartoletti and Tiziana Cimoli, 'A Survey of Attacks on Ethereum Smart Contracts (SoK)' in *Principles of Security and Trust — POST 2017, LNCS 10204* (Springer 2017), 164.

⁷⁴ Kevin Delmolino, Mitchell Arnett, Ahmed Kosba, Andrew Miller and Elaine Shi, 'Step by Step Towards Creating a Safe Smart Contract: Lessons and Insights from a Cryptocurrency Lab' in *Financial Cryptography and Data Security 2016 Workshops* (Springer 2016), 79.

⁷⁵ Law Commission of England and Wales, *Smart Legal Contracts: Advice to Government* (November 2021).

⁷⁶ Max Raskin, 'The Law and Legality of Smart Contracts' (2017) 35 GEO. L. TECH. REV, 305.

complex smart contracts deserve to be investigated from a legal perspective, since they represent the pivot on which the debate around the legal role of the DsAI revolves.

It has been the advancement of chain-based technology that led many to state how smart contracts display a great potential to affect legal outlooks.⁷⁷ From a practical perspective, however, the opposite statement may be more accurate. It is worth remembering that the smart contracts' concept was initially conceived to accomplish legal purposes in a technological rationale.⁷⁸ In fact, the smart contract notion roots itself in a more legal than technological conception. Conceived and introduced by Nick Szabo in the early 1990s, the definition proposed was as follow:

‘A smart contract is a computerized transaction protocol that executes the terms of a contract. The general objectives of smart contract design are to satisfy common contractual conditions (such as payment terms, liens, confidentiality, and even enforcement), minimize exceptions both malicious and accidental, and minimize the need for trusted intermediaries. Related economic goals include lowering fraud loss, arbitration and enforcement costs, and other transaction costs’.⁷⁹

As it has been argued, such a description has two main effects; it implies the legal dimension of smart contracts while highlighting how their digital feature is the condition

⁷⁷ Jianying Jlang, ‘The Normative Role of Smart Contracts’ (2018) 15 3, US-China Law Review, 139-149.

⁷⁸ Kevin Werbach and Nicolas Cornell, ‘Contracts Ex Machina’ (2017) 67 Duke Law Journal 313, 319–327; Max Raskin, ‘The Law and Legality of Smart Contracts’ (2017) 1 Georgetown Law Technology Review 305, 307–312; Alexander Savelyev, ‘Contract Law 2.0: “Smart” Contracts as the Beginning of the End of Classic Contract Law’ (2017) 26 (2) Information & Communications Technology Law, 116; Harry Surden, ‘Computable Contracts’ (2012) 46 UC Davis Law Review, 629.

⁷⁹Szabo, ‘Smart Contracts’ (1994) <https://www.fon.hum.uva.nl/rob/Courses/InformationInSpeech/CDROM/Literature/LOTwinterschool2006/szabo.best.vwh.net/smart_contracts_2.html> accessed August 2020.

failing which it would be impossible to achieve the purpose of a smart contract.⁸⁰ As a result, it has been the development of blockchain systems, still unknown in the 1990s, to give the right momentum to this technology, offering the most rewarding chance for its implementation. The game changer event has been, indeed, the development of the blockchain consensus validation mechanism. In fact, once the transaction conditions defined in the smart contract code are met and the consensus upon it is reached, the smart contract shall automatically perform the transaction. This is the main reason why smart contract codes must be so accurate and reliable; they have to perform and conclude logic transactions with a steady input-output architecture.⁸¹

3.3.2 a) Automation and Self-Execution

The deterministic trait is the main parameter by which all the other most important features of smart contracts originate, such as automatic and self-executing performance, security, and irreversibility.⁸² Smart contracts are highly performant programs since, as already mentioned, once the transaction conditions written in the code are unfolded, they will be carried out automatically. Consequently, the transaction execution will not be stopped since the code will be read and performed within the entire structure of the decentralised system.⁸³

⁸⁰ Sai Agnikhotram and Antonios Kouroutakis, 'Doctrinal Challenges for the Legality of Smart Contracts: Lex Cryptographia or a New, 'Smart' Way to Contract?' (2019) 19 J High Tech L, 300; Jeremy M Sklaroff, 'Smart Contracts and the Cost of Inflexibility' (2017) 166 University of Pennsylvania Law Review, 263.

⁸¹ Gavin Wood, 'Ethereum: A Secure Decentralised Generalised Transaction Ledger (Yellow Paper)' (2014, rev) <<https://ethereum.github.io/yellowpaper/paper.pdf>> accessed 16 September 2025.

⁸² Sai Agnikhotram and Antonios Kouroutakis, 'Doctrinal Challenges for The Legality of Smart Contracts: Lex Criptographia or a new 'Smart' way to contract?' (2019) 19 J High Tech L, 300.

⁸³ Sklaroff (n. 79) 262-303; Zibin Zheng, Shaoan Xie, Hong-Ning Dai, Xiangping Chen and Huaimin Wang, 'An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends' in *2017 IEEE International Congress on Big Data* (IEEE 2017), 557.

Thus, the software running will be no longer under the control of the transaction's original parties. In other words, it will be self-executing.⁸⁴

3.3.2 b) Security, Determinism and Irreversibility

Furthermore, the autonomous trait at the run time as well as the self-enforceable one makes smart contracts so reliable since there is the certainty of determining the outcome. In fact, once the conditions have been ascertained by the distributed consensus, it is the entire blockchain architecture that will carry out the conduct.⁸⁵ This also implies the outer element of irreversibility.⁸⁶ Given the concept of the determinism of the distributed environment, the result of the transaction, being duplicated on all nodes of the system, can no longer be modified.⁸⁷ Consequently, parties are prevented from backtracking on the original situation. The result of the transaction will be irreversible.⁸⁸ This completes the circle of the characteristics of the smart contract system. That is, the need to preserve the stability and consistency of the entire operational structure of the blockchain. If this were not the case, the very rationale of distributed and decentralised systems would disappear.

From the analysis of the overall features of smart contract applications, it is possible to state that the blockchain evolution has shaped their functioning. This is particularly true considering that while the original definition of Szabo's smart contracts still defines the

⁸⁴ Agnikhotram and Kouroutakis (n. 80), 309.

⁸⁵ Imran Bashir, *Mastering Blockchain: Distributed Ledger Technology, Decentralization, and Smart Contracts Explained* (2nd, Packt Publishing, 2018), 265.

⁸⁶ Mingxiao Li, Zhenbang Jiang, Xiaohui Chen, Xiaodong Luo and Qiaoyan Wen, 'A Survey on the Security of Blockchain Systems' (2018) 57 *Future Generation Computer Systems*, 671; Lauri Yli-Huomo, Deokyeon Ko, Sujin Choi, Sooyong Park and Kari Smolander, 'Where Is Current Research on Blockchain? — A Systematic Review' (2016) 11(10) *PLOS ONE*, e0163477.

⁸⁷ Erika J. Nash, 'Blockchain & Smart Contract Technology: Alternative Incentives for Legal Contract Innovation' (2019) 38 *BYU Law Review*, 800-33.

⁸⁸ *Ibid*, 821.

distinctive core of these features, blockchain technology currently implements smart contracts in different ways.

There are blockchain systems that do not empower smart contract transactions. In other words, the operations that occur on the network are not carried by smart contracts but by means of the blockchain system itself since they are not considered ‘complex’.⁸⁹ The example is again Bitcoin platform. Bitcoin just allows the value exchange of its cryptocurrency, called Bitcoin, amongst its nodes. This type of transaction is considered a simple one since it is computationally not complex to determine and perform. Unlike Bitcoin, there are other blockchain platforms which allow, at the same time, both the cryptocurrencies’ exchange and the smart contract transactions. The Ethereum context is the most appropriate example to follow. On the Ethereum blockchain, indeed, these two functions are provided to the chain members by allowing them to choose between two types of accounts: the externally owned account (EOA) and the contract account.⁹⁰ The first type is created by and for human users. Similar to Bitcoin, it allows to send and receive transactions of ETH, which is Ethereum’s cryptocurrency, between two or more externally owned accounts. Conversely, the contract account allows blockchain members to create a smart contract, deploying it on the network. Once done, this type of account is no longer controlled by humans but by code.⁹¹ In other words, it will be the code instructions to run all the functions of the smart contract. Additionally, both accounts enable the interaction with other smart contracts that run on the blockchain network as well as send and receive ETH transactions. In particular, both the externally owned account and the contract account can trigger a transaction towards another

⁸⁹ Jimmy Song, *Programming Bitcoin: Learn How to Program Bitcoin from Scratch* (O’Reilly Media 2019) 1; Henning Diedrich, *Ethereum: Blockchains, Digital Assets, Smart Contracts* (Wiley 2016), 45.

⁹⁰ Roberto Infante, *Building Ethereum DApps* (Manning 2019), 13; Maher Alharby and Aad van Moorsel, ‘Blockchain-Based Smart Contracts: A Systematic Mapping Study’ (2017) <arXiv:1710.06372> accessed 4 March 2023.

⁹¹ Katarina Pistor, *The Code of Capital: How the Law Creates Wealth and Inequality* (Princeton University Press 2019), 1; European Securities and Markets Authority (ESMA), ‘Advice: Initial Coin Offerings and Crypto-Assets’ (9 January 2019) 13–26 <<https://www.esma.europa.eu> accessed> 16 September 2023.

contract account, by ‘calling’ the relative smart contract function, whenever they need it to be performed. Notwithstanding such possibilities, only the contract account can determine and deploy complex smart contract transactions. Thus, what does it mean complex transaction? Why are they executed by smart contracts? The decentralised environment of blockchains like Ethereum enables the use, storage, and interaction of complex data contents. These options can generate several consequences. In fact, by means of smart contracts it is possible to execute many different actions. For instance, it is possible to create, manage and transfer digital assets. In particular, as regards to digital assets, in the blockchain realm, the real-life assets (e.g., money, securities, real estate assets, etc.) are digitally embedded into features called ‘tokens’.⁹² In other words, real-life assets have their corresponding digital version in the blockchain-based system. Without entering in the discussion around all the different type of tokens that already exists, it is enough to say that tokens can be the subject of a smart contract transaction between parties.⁹³ Most notably, token are digital instruments that can thus embed rights and privileges that parties on blockchain platforms can transfer each other.⁹⁴ Furthermore, a smart contract code is even able, in turn, to determine a new contract, as well as interacting with another smart contract or whatever is expected from the instructions it contains.⁹⁵

By means of these examples, it is possible to understand the slight difference between a simple blockchain transaction and the smart contract one. Whereas all smart contracts might enable all type of blockchain transactions, including the simple exchange ones, not all

⁹² Chen, ‘Blockchain tokens and the potential democratization of entrepreneurship and innovation’ (2018) 61 4 Business Horizon, 567-575.

⁹³ EPRS | Servizio Ricerca del Parlamento europeo, ‘Come la Blockchain può cambiarci la vita’ PE 581.948 (2017), 8
[https://www.europarl.europa.eu/RegData/etudes/IDAN/2017/581948/EPRS_IDA\(2017\)581948_IT.pdf](https://www.europarl.europa.eu/RegData/etudes/IDAN/2017/581948/EPRS_IDA(2017)581948_IT.pdf) accessed November 2020.

⁹⁴ Ibid, 9.

⁹⁵ These kinds of smart contracts are the ERC-20 and the ERC-121. Lorenzo Piatti, ‘Blockchain e smart contracts’ (lecture in Coding for lawyers, University of Milan, 4 March 2021); Chris Dannen, *Introducing Ethereum and Solidity* (Apress 2017), 119.

blockchain-based simple transactions are performed by means of smart contracts. Therefore, it follows that the smart contract protocol does not just implement transaction automation, rather it represents a codified activity that can potentially produce legal effects amongst the blockchain participants. This distinction is crucial to the thesis's argument: while simple exchanges remain dependent on the parties' operational act, smart contracts shift the locus of contract formation and execution onto the system itself, raising the question of how this codified activity can qualify as a legal agreement.

3.4 The Lifecycle of Blockchain Transactions

3.4.1 Lifecycle of a Simple Transaction

At this point, it is important to highlight the technical difference that stands between a simple transaction and a smart contract one. The technical aftermath will serve for the legal analysis. The scope is to be questioning if it is possible that simple exchange transactions between nodes can fit under the most broader contract definition of European PECL models, even without the employment of smart contract protocols.

THE LIFE-CYCLE OF A BLOCKCHAIN TRANSACTION

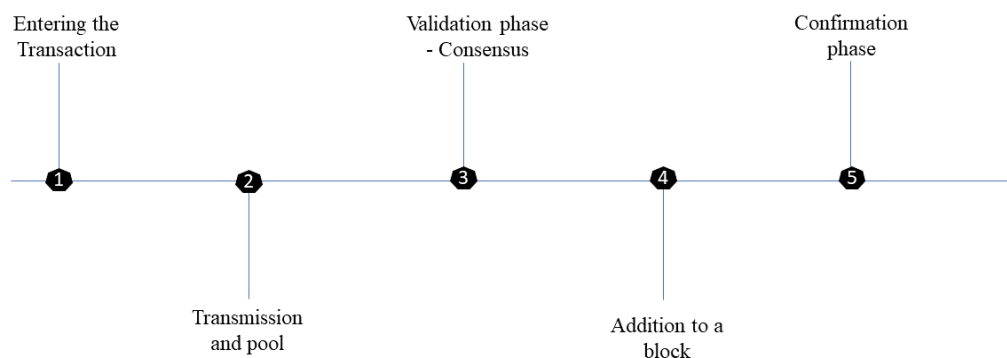


Fig. 3.A - The Lifecycle of a Blockchain Transaction

A blockchain transaction undergoes five essential phases to determine the effects that parties want to accomplish (Fig. 3.A). The first phase is the initial step, when one party's intention is to determine the transaction towards a counterpart, called 'entering phase'. For example, Alice wants to send a total amount of ETH to Bob. During this phase, the blockchain system creates the transaction data content with the cryptographically framework already analysed in the previous section. Once done, the transaction is sent to the 'pool'. The blockchain pool is like a box full of transactions that must be chosen by the nodes to get added to a block that constitutes the blockchain. The choice usually falls on the transactions that have the highest fees a party is willing to pay to get the transaction validated.⁹⁶ Indeed, the consensus upon a certain transaction is also strictly related to the fees that the validation nodes, often called miners, received. More fees equal more chances to get the transaction validated.⁹⁷ The third phase opens when Alice's transaction is picked by miners. During this phase, miners must control that transaction's data comply with the platform technical and logical rules.⁹⁸ Once validated, the transaction is added to a block.⁹⁹ The last phase is the confirmation one. Once the block has been inserted in the chain it expects that at least five or six blocks are attached to it for confirmation. In fact, if to a block does not follow others, it means that that block has no

⁹⁶ Christian Decker and Roger Wattenhofer, 'Information Propagation in the Bitcoin Network' in IEEE P2P 2013 Proceedings (IEEE 2013), 1; Kyle Croman, Christian Decker, Ittay Eyal and others, 'On Scaling Decentralized Blockchains' in Financial Cryptography and Data Security 2016 Workshops (Springer 2016), 106.

⁹⁷ Michael J Freedman Easley, Maureen O'Hara and Soumya Basu, 'From Mining to Markets: The Evolution of Bitcoin Transaction Fees' (2019) 134 Journal of Financial Economics, 91; Malte Möser and Rainer Böhme, 'Trends, Tips, Tolls: A Longitudinal Study of Bitcoin Transaction Fees and Spam' in *Financial Cryptography and Data Security 2015 Workshops* (Springer 2015), 19.

⁹⁸ Watanabe, Fujimura, Nakadaira, Miyazaki, Akutsu, 'Blockchain Contract: A complete Consensus using Blockchain' (2015) 2015 IEEE 4th Global Conference on Consumer Electronics (GCCE).

⁹⁹ Arthur Gervais, Ghassan O Karame, Karl Wüst, Vasileios Glykantzis, Hubert Ritzdorf and Srdjan Capkun, 'On the Security and Performance of Proof of Work Blockchains' in *Proceedings of the 2016 ACM SIGSAC Conference on Computer and Communications Security (CCS '16)* (ACM 2016), 3–16.

future in the chain, and the transaction will not be confirmed.¹⁰⁰ Conversely, if confirmation occurs it means that the block is valid and will be part of the blockchain system. Thus, the transaction is completed, and Bob gets the ETH.

This is what usually happens when a simple exchange transaction is performed on blockchain networks. Additionally, there are some blockchains, like Ethereum, where it is possible to a transaction parties to add, in the data contents during the first phase, also some conditions or even more complex contents and terms by means of messages that will be encrypted in the data field of the transaction.¹⁰¹ This way, only the counterparties can read such terms by means of their public-private keys. An example is needed. It is possible that Alice and Bob, in the data field of their transaction, indicate some terms whereby the exchange serves as a mutual transfer of money or other property. The content parties will add to the transaction data field will be converted into an encrypted message that is part of the transaction itself. Once they receive their transaction, they will be able to read the terms by means of its paired key that decrypts the content.

3.4.2 Lifecycle of Smart Contract Transactions

Different from the simple transaction lifecycle is the smart contract one (Fig. 3.B). Here the logic complexity of the protocol is self-evident. From this perspective, DsAI systems can

¹⁰⁰ Nicolas T Courtois, Marek Grajek and Rahul Naik, ‘The Unreasonable Fundamental Incertitudes Behind Bitcoin Mining’ (2014) 3 (2) <arXiv:1310.7935v2> accessed 5 March 2021; Nicolas T Karame, Elli Androulaki and Srdjan Capkun, ‘Double-Spending Fast Payments in Bitcoin’ in *Proceedings of the 2012 ACM Conference on Computer and Communications Security (CCS ’12)* (ACM 2012), 906–917.

¹⁰¹ Ahmed Kosba, Andrew Miller, Elaine Shi, Zikai Wen and Charalampos Papamanthou, ‘Hawk: The Blockchain Model of Cryptography and Privacy-Preserving Smart Contracts’ in 2016 IEEE Symposium on Security and Privacy (S&P) (IEEE 2016), 839; Eli Ben-Sasson, Alessandro Chiesa, Christina Garman, Matthew Green, Ian Miers, Eran Tromer and Madars Virza, ‘Zerocash: Decentralized Anonymous Payments from Bitcoin’ in 2014 IEEE Symposium on Security and Privacy (S&P) (IEEE 2014), 459.

interact directly with sole-code contracts, taking an active role in validating and executing transactions without human mediation.¹⁰²

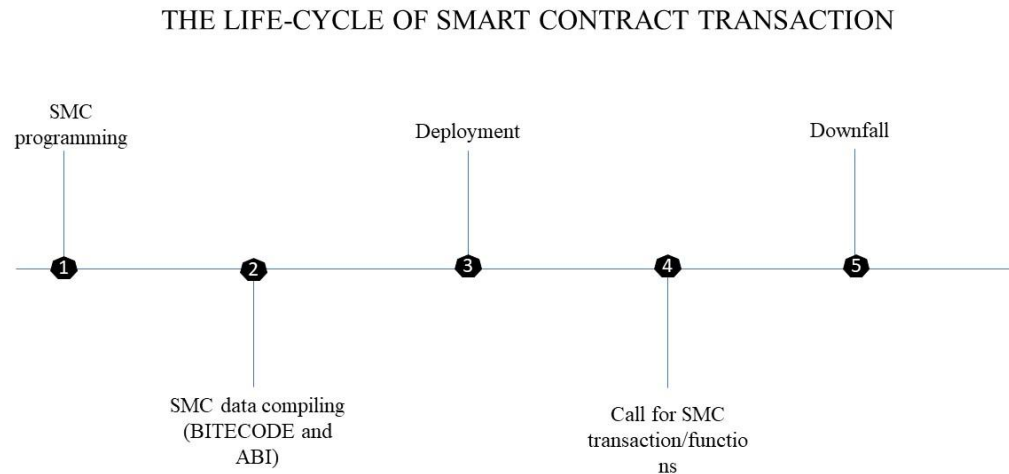


Fig. 3.B - The lifecycle of Smart Contract Transactions

As a premise, it must be said that the smart contract, being essentially a piece of code, it can be also used for the blockchain governance.¹⁰³ In such a case, it is said that the smart contract is ‘in’ the blockchain system, as it is embedded in the original protocol of a certain platform to grant its functioning.¹⁰⁴ Vice versa, the smart contract concept that falls under this thesis analysis are the smart contracts that are created and deployed ‘on’ blockchain by blockchain members; humans, entities, or other software. Nonetheless, it is enough to bear in

¹⁰² Niels Vandezande, ‘Smart Contracts: The End of Contract Law as We Know It?’ (2017) 33 Computer Law & Security Review, 153.

¹⁰³ Larry A DiMatteo, Michel Cannarsa and Cristina Poncibò (eds), *The Cambridge Handbook of Smart Contracts, Blockchain Technology and Digital Platforms* (Cambridge University Press 2019), chs 3–5; Wessel Reijers, Iris O’Brolcháin and Paul Haynes, ‘Governance in Blockchain Technologies & Social Contract Theories’ (2016) 1(1) Ledger, 134.

¹⁰⁴ The example is the Ethereum Virtual Machine (EVM).

mind that when the infrastructure is governed by a smart contract protocol, all the transactions and the operations that occurs ‘on’ the network have to interact, in turn, also with the smart contract ‘in’ the blockchain. That is because by means of this interaction the entire blockchain state is maintained and constantly updated.

For the purpose of this research, only the lifecycle of smart contracts on blockchain systems will be investigated (Fig. 3.B). As already analysed, these smart contracts run when predetermined conditions are met.¹⁰⁵ The first phase of smart contract lifecycle is programming. This is the step in which the content and the purpose of the smart contract is defined and translated into code. Once the code is ready, the compiling phase follows. Compiling is a complex operation that allows generating two things: 1) a bytecode code which is then used for the deploying of the contract and 2) the ABI code, a non-human readable code, that allows the smart contract to interact with other smart contracts and applications, as in the case of machine-to-machine contracts. Both these two codes translate the same smart contract content. At the compiling phase follows the deployment on the blockchain system. As a consequence of this publication function, the smart contract can be then ‘called’ by blockchain accounts or by other smart contracts, in cases called machine-to-machine contracts¹⁰⁶, to perform its scope once the conditions defined are met. During the fourth phase (see Fig. 3.B, n. 4), the smart contract stands ‘silent’ as long as it receives calls for performance. In other words, it remains passive until conditions are met, or its function is requested. When the smart contract is called for a transaction, the validation and confirmation phase already seen for the simple transaction (see Fig. 3.A, n. 3-5) must be accomplished. In such a case, the smart contract transaction is completed, and the effects parties wanted to fulfil are achieved, as a

¹⁰⁵ Grigore Rosu, Everett Hildenbrandt, Manasvi Saxena, Yi Zhang and others, ‘KEVM: A Complete Formal Semantics of the Ethereum Virtual Machine’ in 2018 IEEE 31st Computer Security Foundations Symposium (CSF) (IEEE 2018), 204; Yoichi Hirai, ‘Ethereum Formal Verification: A Survey’ in Principles of Security and Trust — POST 2017, LNCS 10204 (Springer 2017), 151.

¹⁰⁶ Guadamuz, ‘All watched over by machines of loving grace: A critical look at smart contracts’ (2019) 35 105338 Computer Law & Security Review, 1.

consequence of the self-execution trait.¹⁰⁷ However, it is possible that the parties decided to add instructions within the contract that make it unusable if certain conditions are determined. In such a case displayed in the fifth phase called ‘downfall’, the smart contract will remain inactive in the blockchain system forever, given the immutability trait of the latter. In a certain sense, the contract terminates, staying dormant in the blockchain.¹⁰⁸ The fifth phase is thus an option parties can decide and does not happen every time. In the smart contract lifecycle as explained, it must be highlighted that once it is deployed, it departs from parties’ control. As it has been stated ‘This means that the actual performance of a smart contract does not depend on the subjective expectation of the parties, based on their interpretation of the source code, but merely on the operations dictated by the compiled bytecode deployed to the blockchain’.¹⁰⁹

From the differences just examined between the lifecycles of both simple transactions and smart contract transactions, it is possible to draw some conclusions. There is no doubt that, by means of the former complex terms and conditions in transactions are allowed to determine most complex relationships between blockchain parties. As assessed, these are exactly the purpose of smart contracts, both in technical and legal sense. At the same time, However, from a technical point of view, simple transactions must be performed by parties. Since they are not

¹⁰⁷ Ilya Sergey, Amrit Kumar and Aquinas Hobor, ‘A Concurrent Perspective on Smart Contracts’ in *Financial Cryptography and Data Security 2018 Workshops* (Springer 2018), 478; Fan Zhang, Ethan Cecchetti, Kyle Croman, Ari Juels and Elaine Shi, ‘Town Crier: An Authenticated Data Feed for Smart Contracts’ in *Proceedings of the 2016 ACM SIGSAC Conference on Computer and Communications Security (CCS ’16)* (ACM 2016), 270.

¹⁰⁸ Ivica Nikolić, Aashish Kolluri, Ilya Sergey, Prateek Saxena and Aquinas Hobor, ‘Finding The Greedy, Prodigal, and Suicidal Contracts at Scale’ in *Proceedings of the 25th Annual Network and Distributed System Security Symposium (NDSS 2018)* (Internet Society, 2018), 1; Neville Grech, Lexi Brent, Bernhard Scholz, Paolo Giarrusso and Yannis Smaragdakis, ‘MadMax: Surviving Out-of-Gas Conditions in Ethereum Smart Contracts’ in *Proceedings of the ACM on Programming Languages, OOPSLA* (ACM 2018), 1.

¹⁰⁹ De Filippi, Wray, Sileno, ‘Smart contracts’ (2021) 10 (2) Internet Policy Review, 5; Dominique Devriese, Frank Piessens and others, ‘Foundations of the Ethereum Gas Mechanism’ (2017) *Proceedings of the 2017 ACM Workshop on Programming Languages and Analysis for Security (PLAS ’17)*, 51.

self-executing, parties must operate the transmission. Once done, the blockchain validation system confirms the state of the requested transaction and its effects are determined. In this sense, parties do not lose control over the transaction. This means that the process of the exchange transaction is automated but not automatically performed. Vice versa, all the process of transaction in smart contracts is automatically determined and parties do lose control over it once deployed on the blockchain. In other words, the smart contract lives on blockchain and can perform its purpose in self-execution even multiple times, whenever blockchain actors call or re-call it.

3.4.3 From Automation to Legal Qualification?

Such technical differences have their own consequences also on legal perspectives. The challenge is then to practically recognise when blockchain smart contract transactions can determine the rise of a contract transaction and to what extent contract law principles can be applied or adapted to it. Differences in blockchain-based transactions are not limited between simple transactions and smart contracts, but also between different type of smart contracts. Before delving into such differences, it is necessary, however, to first set the scene under which the legal analysis will be conducted in relation to the nature of smart contracts and, in particular, of sole-code smart contracts. The following section will indeed make a shift towards the concepts of juristic acts and contracts, deepening the analysis of contract law principles within the European legal tradition as well as within the EU common law and civil law systems.

3.5 Legal Transactions and Juristic Acts: Foundations

3.5.1 Legal Relations: Sources, Effects and Structure

That the law considers legal transactions as one of the keystones of relations amongst natural and legal persons is a principle as old as the legal systems.¹¹⁰ Not only they are means of conjunction, but also signs of society's progress, for they can change and adapt their outline

¹¹⁰ Emilio Betti, *Teoria generale del negozio giuridico* (Edizioni Scientifiche Italiane 1994).

at every evolutionary thrust, retaining their nature at the same time. Consequently, over time, the law has experienced many situations which have been then qualified as legal transactions, broadening such legal category with more examples.¹¹¹ Hence, it appears necessary to the scope of this thesis to explore the spectrum where such transactions unveil their rationale.

Whenever legal subjects enter into a legal relation with each other, they can expand, reduce either alter their respective legal entitlements.¹¹² Legal relations are indeed functional connections between legal sources in which each legal subject involved has the capacity to alter the legal position of the other. Thus, it is from this linkage that the overall legal categories of facts, events, and acts derive, aimed at regulating the dynamics of legal relations.¹¹³ Into one of these categories there are the so-called legal transactions.

3.5.2 Facts, Events and Acts: The Taxonomy of Legal Change

In the world of etymology, transaction means ‘driving across’.¹¹⁴ In the legal world, the meaning of transactions does not differ so much, for a transaction is defined as a voluntary act whereby a person creates or transfers, in favour to another one, legal advantages such as rights, duties or privileges.¹¹⁵ In other words, with a transaction, a person makes a voluntary action by which he can drive such legal entitlements, stemming from his own legal unit, across to

¹¹¹ Angelo Falzea, ‘Efficacia giuridica’ in *Enciclopedia del diritto*, vol. XIV (Giuffrè 1965).

¹¹² Kramer, ‘On the Nature of Legal Rights’ (2000) 59 3, *The Cambridge Law Journal*, 473; Ferson, ‘Nature of Legal Transaction and Juristic Acts Analysis of Common Factors and Variations’ (1945-46), 31 2, *Cornell Law Quarterly*, 105.

¹¹³ Wesley Newcomb Hohfeld, ‘Some Fundamental Legal Conceptions as Applied in Judicial Reasoning’ (1913) 23 *Yale Law Journal* 16; Holland, *Elements of Jurisprudence*, (12th ed, Oxford University Press, 1917), 92; Jack Beatson, Andrew Burrows and John Cartwright, *Anson’s Law of Contract* (31st edn, OUP 2020), ch 1.

¹¹⁴ *Oxford Latin Dictionary* (OUP 1982) s.v. *transactio*; Webster’s New International Dictionary (2nd ed. 1942).

¹¹⁵ Meoli, ‘Diritto Civile’ Lecture in Civil law, University of Salerno, February 2019.

another person, thus transforming their relations.¹¹⁶ Transactions may then be considered as bridges, aiming at overcoming distances between legal subjects, creating new sources of rights and duties.¹¹⁷ At the same time, the scope of legal transactions in legal system finds, in turn, its frame into the grater realm of another legal category, the juristic acts.¹¹⁸ Before entering into the discussion around juristic acts, a brief premise relating to the other legal categories of facts, events and acts is useful to understand the common factors and variations that will be the object of following paragraphs' discussion.

Both in common law and civil law traditions the creation, transfer or extinction of rights and duties are due to facts, which can be either events or acts.¹¹⁹ In the former case, rights and duties are created, transferred, or extinguished as consequences of certain events, legally predetermined by law (i.e. birth or death).¹²⁰ Along with the events, there is an important class called acts. An act is an event deems as under human control.¹²¹ As Markby stated 'an act is a determination of will, producing an effect in the sensible world'.¹²² Therefore, as opposed to events, to have acts in the eyes of the law there must be will and a manifestation of the will, without which there is no act at all. An example of acts can be the tacit acceptance of an inheritance.

¹¹⁶ J.C. Haage, 'What is a legal transaction?' in M. del Mar, & Z. Bankowski (Eds.), *Law as Institutional Normative Order* (Ashgate, 2009), 103.

¹¹⁷ Pasquale Stanzone, *Commercio elettronico, contratto e categorie civilistiche* (Giuffrè 2001) 1–20.

¹¹⁸ Cesare Massimo Bianca, *Diritto civile. Vol. 3: Il contratto* (Giuffrè 2000) §§ introd.

¹¹⁹ Holland (n. 113), 91; Angelo Falzea, *Capacità, efficacia giuridica, fatto giuridico, manifestazione*. Voci estratte dall'Enciclopedia del diritto (Giuffrè 1999).

¹²⁰ Markby, *Elements of Law*, (4th edn, Clarendon Press), 113; Cesare Massimo Bianca, *Diritto civile. Vol. 1: Il diritto* (Giuffrè, varie ed).

¹²¹ Thomas Erskine Holland, *The Elements of Jurisprudence* (1st edn, Clarendon Press, 1880) ch 4; William Markby, *Elements of Law Considered with Reference to Principles of General Jurisprudence* (Clarendon Press 1871).

¹²² Markby (n. 121), 112.

3.5.3 Juristic Acts and the Centrality of Intention

Amongst the class of acts, the law recognises a subset called juristic acts or acts in the law.¹²³ As it has been said ‘when the doer of an act adverts to a consequence of his act and desires it to follow, he is said to intend that consequence’.¹²⁴ Thus, a juristic act is an act in which legal effects, or results, are both contemplated and desired by the legal subject as a consequence of that act. This is the realm of intention and its manifestation. Whereas the juristic acts share with the class of acts the presence of the will, it is only in the category of juristic acts that the manifestation of intention is essential, as direct to the production of legal effects.¹²⁵ Examples of acts in the law are exchanges, contracts, sales, mortgages etc. So that, the crucial connection between juristic acts and legal relations amongst legal subjects is that the purpose of the former is to define or alter the latter intentionally. Indeed, as affirmed, in juristic acts ‘the intention of the parties must refer to legal relations’.¹²⁶

3.5.4 Legal Transactions as Bridges Between Legal Positions

To this point, it is possible to trace the link between legal transactions and juristic acts in the light of legal relations amongst legal subjects. Legal transactions can be defined as voluntary acts made by legal subjects that ‘define and effect a change in the legal relations of the parties’.¹²⁷ Therefore, legal transactions belong to the broader category of juristic acts as the subject’s intention is to be bound to the related legal consequences.¹²⁸ Even if there are many types of legal transactions with different features, the core nature of them is essentially

¹²³ Ibid, 122.

¹²⁴ Ibid.

¹²⁵ Pasquale Stanzone (a cura di), *Il soggetto. II. Capacità, legittimazione, status* (Trattato di diritto privato, Giuffrè 2017).

¹²⁶ Jack Beatson FBA and Andrew Burrows FBA, QC (Hon) and John Cartwright, *Anson's Law of Contract* (31st edn, OUP 2020).

¹²⁷ Merton Ferson, ‘Operative Acts: Juristic and Non-Juristic’ (1959) 11 1 Hastings Law Journal, 1.

¹²⁸ Violeta Slavu, ‘Effects of Civil Juristic Act’ (2015) 4 Journal of Law and Administrative Science, 1.

alike. For instance, a form of legal transactions are gifts¹²⁹, whereby a person voluntary and intentionally transfers to another the property right upon something without any exchange.¹³⁰ Conversely, another type of legal transaction where parties are adversely affected is the mutual exchange¹³¹, like cash sales or barter, where subjects make cross transfers of rights or privileges.¹³² All these kinds of transactions are juristic acts where the final intention of the parties consummates the transaction itself.¹³³

3.5.5 Why Contracts Are Paradigmatic Legal Transactions

Certainly, the most important class of legal transactions and, thus, juristic acts are then contracts. It is important to highlight that, unlike civil law systems, in common law systems gifts and exchanges are not contracts.¹³⁴ In fact, for common systems, whereas exchanges require consent or mutual assent between parties, they are not able to create obligations like contracts do.¹³⁵ In fact, as Ferson argued, ‘an exchange is executed by both of the parties at the moment it is made; no contract duty is created’.¹³⁶ The difference is pivotal and must be taken into account. However, in both cases of exchanges and contracts, the essential nature of legal

¹²⁹ John Sprankling, Coletta Raymond, *Property: A Contemporary Approach* (4 ed, West Academic Publishing, 2018), 209–225.

¹³⁰ *Ibid*, 217.

¹³¹ Lon Fuller, ‘Consideration and Form’ (1941) 41 5 Columbia Law Review, 799.

¹³² *Ibid*, 818.

¹³³ Ferson (n. 127), 3.

¹³⁴ ‘The word contract was used in the time of the Year Books in a much narrower sense than that of today. It was applied only to those transactions where the duty arose from the receipt of a *quid pro quo*, e.g., sales or loan. In other words, contract meant what we now mean by ‘real contract’. James, ‘Parols Contracts Prior to Assumpsit’ (1894) 8 5 Harvard Law Review, 253.

¹³⁵ Edwin Patterson, ‘The Restatement of the Law of Contracts’ (1933) 33 3 Columbia Law Review, 397-427.

¹³⁶ Merton Ferson, ‘Nature of legal Transactions and Juristic Acts Analysis of Common Factors and Variations’ (1945-46) 31 Cornell Law Quarterly, 105-180.

transactions as directed to intentionally alter legal relations between parties is granted in both domestic legal systems.

Having so described an overall framework of legal transactions and their rationale in legal systems, in the next section the thesis shall focus on the most significant one: contracts. Indeed, it is essential for the purpose of answering the central research question, to examine contracts and their regulation. The aim is to define a legal perimeter for further discussions around the blockchain-based transactions and smart contracts. This thesis will indeed use the lens of juristic acts to evaluate the behaviour encoded in public and permissionless blockchains. The question is to understand when algorithmic behaviour (deployment, interaction (call), and automatic execution) sufficiently manifests intent and agreement to qualify as a contract, and when it simply represents a different type of legal transaction. To this purpose, the next section will outline the principles of contract law under the Principles of European Contract Law and the European e-commerce regulatory framework with particular attention to the concept of intent, agreement by conduct, and electronic formation.

3.6 Contracts as Legal Transactions: Comparative Principles and Digital Challenges

3.6.1 Scope, Method and the Role of PECL

As argued, one of the most important kinds of legal transactions is contract. Contracts are further qualified as juristic acts for they embed all the characteristics law requires to give rise to effects able to create either affect relations existing between legal subjects. In the following analysis of contracts and their regulation, the thesis will focus its investigation on legal principles governing the former, as defined in the Principles of European Contract Law (PECL)¹³⁷ law models. Such a choice, has explained in chapter 1, has a main purpose. Conducting the analysis within the PECL principles will narrow down the differences existing

¹³⁷ Lando and Beale, *Principles of European Contract Law*, Pts I and II (2000), Pt III (2003) (The Hague, Kluwer Law International). These Principles are also conveyed within the UNIDROIT Principles of International Commercial Contracts 2016 (PICC)¹³⁷ law models.

in contract law between common and civil law systems, demonstrating that a common perspective is possible. So that, it seems appropriate to adopt an overall legal framework that is suitable to be applied in both legal systems within the European legal tradition. Even if the PECL principles are not legally binding, for they are conceived to be incorporated into contracts by the parties¹³⁸, they can serve to this thesis' purpose as guidelines to appreciate how some notions are broadly accepted. Moreover, the debate shall take into account only the contract principles that are strictly related to the purpose of answering the central research question. Notably, the thesis will proceed to the investigation about what a contract is, its fundamental elements as well as formation, and execution process. From this section's debate the specific analysis of the negotiation phase as well as non-binding agreements is excluded, for they are out of this sections' scope. Therefore, the choice to analyse contracts as defined in European contract principles responds to the necessity to take into account also the cross-border nature of blockchain systems. Notably, by studying the contract law realm on these standpoints, it should be possible to establish in so far as such principles are able to be adapted to the current state-of-the-art of smart contracts and blockchain transactions. Furthermore, anytime that a comparison between common law and civil law systems appears beneficial to the analysis it will be done.

3.6.2 What Is a Contract? Definitions and Core Principles

Contracts are part of social life. Consequently, they represent the largest portion of legal interactions between legal subjects. Therefore, in endeavouring to draw a line between what is and what is not a contract, it is important to define what a contract is meant to be. As stated in the previous section, contracts give rise to rights or duties when parties themselves have successfully manifested such an intention to be legally bound to the effects of a contract.¹³⁹ Unlike civil law systems, in which the notion of contract can be easily found in civil codes¹⁴⁰,

¹³⁸ Art. 1:101, PECL.

¹³⁹ Marky, *Elements of Law*, (4th edn, Oxford University Press, 1889), 299.

¹⁴⁰ Italy, *see* Art. 1321 Codice Civile, Regio Decreto 16 marzo 1942, n. 262; France, *see* Art. 1101 Code Civil, Ordonnance 2016, n. 131.

in common law systems there is not an agreed definition of what a contract is.¹⁴¹ However, the basic elements of contracts are set out with a huge degree of certainty in both legal systems so that they serve as guiding lights to explain why law regards some statements or behaviours as legally binding and others not. Such basic elements are considered cornerstones in both domestic civil and law and common law traditions as well as in PECL. Such basic elements are defined as contract law general principles.

In order to harmonise contract relations, the PECL regime offer a certain degree of flexibility about the concept of what a contract is. Such principles are flexible enough to take account of the continuously mutable circumstances brought about by the technological developments affecting cross-border economic and commercial practice. At the heart of PECL principles there is the rule whereby contracts arise where parties intent to be legally bound and reach a sufficient agreement.¹⁴² These principles represent, in turn, the further explanation of the broader rule of freedom of contract whereby parties are free to both enter into contract and to determine its content.¹⁴³

3.6.3 Intention and Agreement: Subjective vs Objective Theories

At all legal systems' levels, the debate around the intention of legal subjects to be legally bound to a mutual agreement assumes a crucial role. In civil law systems, the existence of a contract depends on the coincidence between the parties' internal will and its external expression.¹⁴⁴ The requirement of intention is therefore substantial, since only when internal will corresponds to external expression can a contract produce legal effects.¹⁴⁵ A similar centrality of intention appears in common law, where the intention to create legal relationships

¹⁴¹ McKendrick, *Contract law*, (7th edn, Oxford University Press, 2016), 4.

¹⁴² Art. 1:301, art. 2:101, art. 2:10 PECL.

¹⁴³ Art. 1:102 PECL; Art. 1.1., PICC.

¹⁴⁴ Art. 1362 Codice Civile (Italy); Massimo Bianca, *Diritto Civile, III: Il contratto* (3rd edn, Giuffrè 2000), 410–430; Pietro Perlingieri, *Il diritto civile nella legalità costituzionale* (2nd edn, ESI 2006), 285.

¹⁴⁵ Pasquale Stanzone, *Manuale di diritto privato* (4th edn, Jovene 2017), 433.

distinguishes legal agreements from mere social or domestic arrangements.¹⁴⁶ In PECL models, there is a contract if both parties have manifested such an intention by reaching a sufficient agreement.¹⁴⁷ At the same time, an agreement is deemed sufficient reached when parties have agreed upon the contract terms, which are necessary to respectively determine their rights and obligations so that the agreement can be enforced or thus defined under such principles.¹⁴⁸ Therefore, the sufficient agreement represents the demanded minimum content whereby a contract can be considered as such. The issue takes on further relevance when applied to DsAI systems, as it is necessary to understand whether their autonomous algorithmic behaviour can be equated with legally relevant behaviour for the purpose of contract formation. At this point there is a significant difference between civil and common law systems. Whereas in the former, lack of agreed terms can be directly integrated by legal rules¹⁴⁹, in the latter, matters left to be agreed can undermine the conclusion of contract, unless there are clear indications that parties wanted to be bound, nonetheless.¹⁵⁰ Thus, it is possible to state that, much more than in domestic systems, at European (and in particular at international) level the principle of *pacta sunt servanda*,¹⁵¹ by means of which the existence of contractual agreements amongst parties must be kept, acquire its strongest definition.¹⁵² Moreover, otherwise agreed by parties themselves, no further requirements of form are contemplated in PECL¹⁵³ models,

¹⁴⁶ The case law illustrates the point: the landmark case *Balfour v Balfour* [1919] 2 KB 571 (CA) denied contractual force in domestic promises; *Jones v Padavatton* [1968] 1 WLR 776 (CA); *Merritt v Merritt* [1970] 1 WLR 1211 (CA) confirmed enforceability when parties objectively intended to create legal effects.

¹⁴⁷ Art. 2:101 PECL.

¹⁴⁸ Art. 2:103 PECL.

¹⁴⁹ Perlingieri (n. 144), 270.

¹⁵⁰ John Cartwright, *Contract Law*, (3rd ed, Hart, 2016), 208.

¹⁵¹ From Latin, ‘agreements must be kept’, Black’s Law Dictionary (8th, 2008). See more on <<https://www.britannica.com/topic/pacta-sunt-servanda>> accessed 5 February 2021.

¹⁵² Article 1.3. PICC.

¹⁵³ Art. 2:101 (2) PECL.

in accordance with the freedom principle, given the possibility to prove the existence of contracts by any means.

Therefore, with their intention to be bound, contract parties manifest their will to create or alter their legal relations by reaching a sufficient agreement able to produce binding legal effects, as they intended to be determined. That is the essential core of contracts as juristic acts. But when and how is it possible to ascertain individual intention and in so far as can it grant the existence of a contract? The common ground is granted by the necessity that parties must manifest their own intention to be legally bound to contract effects, by means of statements or conduct. What is different is the importance legal systems grant to the coincidence between internal intention or will and its external manifestation for the contract to be valid.¹⁵⁴ Indeed, in some continental civil law systems there is agreement only when the parties subjectively intend to enter into contract with each other at the same terms.¹⁵⁵ In such systems the parties' will to enter into agreement must be formed without any vice of consent.¹⁵⁶ In fact, there can be contracts if both parties' subjective intentions and their external manifestation are aligned. This is called subjective theory approach and it is very common in civil law systems.¹⁵⁷ Unlike the former, common law ascertains the existence of a contract based on an objective approach.¹⁵⁸ This means that it is the declared intention, expressed or implied by conduct,

¹⁵⁴ Wayne Barnes, 'The Objective Theory of Contracts' (2008) 76 *University of Cincinnati Law Review* 1119; Alex drina-Augusta Bora, 'Analysis of the Mechanisms of the Legal Will – an Argument for an Interdisciplinary Scientific Framework' (2022) 9 *European Journal of Law and Public Administration* 154.

¹⁵⁵ Cartwright (n. 150), 69.

¹⁵⁶ Ibid.

¹⁵⁷ Stephen Waddams, 'The Draft Common Frame of Reference in relation to English contract law', in Devenney and Kenny (eds), *The Transformation of European Private Law* (Cambridge University Press, 2013), 9.

¹⁵⁸ Gregory Klass, 'Intent to Contract' (2009) 95 6 *Virginia Law Review*, 1437; Daniel O'Gorman, 'Learned Hand and the Objective Theory of Contract Interpretation' (2019) 18 1 *University of New Hampshire Law Review*, 63.

rather than its subjective mental disposition, that grant the existence of a contract.¹⁵⁹ In other words, it is only the external manifestation of parties' intentions to be legally bound to the agreement's legal effects that matters for ascertain the existence of the contract, even if there is no alignment with an internal, subjective intention. In common law systems, consequently, there is less space for consent's vice, like mistakes.¹⁶⁰ Above all, it can be said that it is the expression or manifestation of assent the pivotal element of contractual obligations. The underlying consequence of such an approach is that what matters is the protection of parties' mutual expectations upon the execution of agreed terms, as they are reasonably understood by the counterparty, based on the external manifestation of his intention.¹⁶¹ At the same time, the subjective intention of parties reaches a subsidiary role compared to the external manifestation of it.¹⁶²

The explanation of both these theories is useful to highlight the fact that from the European point of view of PECL, the ascertain of the existence of a mutual agreement follows the objective theory rather than the subjective once.¹⁶³ In other words, to decide if there are mutual obligations derived from a contract, the external manifestation of the intention to produce that specific legal effects on each other legal sphere must be scrutinised. In this sense, PECL models offer a broader range to detect these contract elements, opening up the possibility to link the intention of being legally bound to the context in which the agreement itself is determined. Therefore, they bring back under the contract law both circumstances in which the

¹⁵⁹ *Smith v Hughes* (1871) LR 6 QB 597 (QB); *Brogden v Metropolitan Railway Company* (1877) 2 App Cas 666 (HL); *Carlill v Carbolic Smoke Ball Co* [1893] 1 QB 256 (CA).

¹⁶⁰ *Cartwright* (n. 148), 96-97.

¹⁶¹ Art. 6:101 and 6:102 PECL.

¹⁶² Perillo, 'The Origins of the Objective Theory of Contract Formation and Interpretation' (2000) 69 2 *Fordham Law Review*, 427-477.

¹⁶³ Indeed, PECL models state at the Article 2:102 that the intention of the parties of being legally bound by contract 'must be determine by the party's statements or conduct as they were reasonably understood by the other party.'

contract is formed as well as situations whereby parties' conducts can be considered as a manifestation of the former.¹⁶⁴

3.6.4 Consideration and Cause: Divergences and PECL's Neutrality

The PECL contract models are interesting also from another point of view. They do not require either 'consideration' nor the 'cause' elements for an agreement to be considered as a contract.¹⁶⁵ Consideration and cause are other essential elements of contracts, respectively in common law and civil law systems. The doctrine of consideration is a long-standing feature of contract law rooted into common law systems and it is the line that distinguishes enforceable from not enforceable promises.¹⁶⁶ Since a contract, under the common law, is considered as a bargain, an exchange of mutual promises between parties which give rise to mutual obligations or duties, the consideration has the effect to exclude gratuitous transactions or promises of gifts, which do not provide nothing in return, from the scope of contract law.¹⁶⁷ Consideration is the quid-pro-quo element of contract transactions. It defines the element of economic value in the promises exchanged between parties in a contract. Thus, a promise can be part of contract

¹⁶⁴ Lando and Beale (n. 137), 93.

¹⁶⁵ Ole Lando and Hugh Beale (eds), *Principles of European Contract Law, Parts I and II (Combined and Revised)* (Kluwer Law International 2000) arts 1:101–1:107, 2:101 and Comments; Christian von Bar and Eric Clive (eds), *Principles, Definitions and Model Rules of European Private Law: Draft Common Frame of Reference (DCFR)* (Sellier 2009) I.–1:101, II.–1:101; Codice civile (Italy), art. 1325;

Cesare Massimo Bianca, *Diritto civile. Vol. 3: Il contratto* (Giuffrè 2000).

¹⁶⁶ Edwin Peel, *Treitel: The Law of Contract* (15th edn, Sweet & Maxwell 2020) chs 3–4 (consideration as requirement; gratuitous promises generally unenforceable absent deed); Ewan McKendrick, *Contract Law: Text, Cases, and Materials* (Oxford University Press 2020), 109–152; Richard Brown, 'The English Doctrine of Consideration in Contract' (Introductory lecture, St. Mungo's College, Glasgow, 1891), 4-5.

¹⁶⁷ Cartwright (n 49), 132; Robert Lee Henry, 'Cause in the Civil Law and Consideration in the Common: Much Ado about Nothing' (1941) 29 4 Kentucky Law Journal, 369.

and thus being enforceable only if something of value is provided in return.¹⁶⁸ This is the essence of mutual exchange that determines contract obligations. Because gratuitous transactions are not supported by consideration and, thus, by an economic value exchange between parties, they are not contracts.¹⁶⁹ Consequently, they are unenforceable under the contract law of common law systems. Thus, in Common Law, what distinguishes contracts from gifts is consideration, whereas what distinguishes contracts from exchange is that in the latter, unlike the former, no duty or obligation is created, since it is executed at the moment it is made.

Such differences are particularly crucial if one considers that in some civil law systems both gratuitous gifts and exchanges can be contracts.¹⁷⁰ Moreover, some scholars have assumed that the counter element of consideration is the ‘contract cause’ under some civil law traditions.¹⁷¹ Even if the discussion about this item is out of the scope of this thesis, it must be pointed out that the concept of cause is much wider than consideration, as it defines the socio-economic purpose of juristic acts and not only contracts.¹⁷² Moreover, the cause is not limited to the purpose parties want to achieve by means of their agreements, but it involves the entire legal scope of a contract at a social level.¹⁷³ Therefore, it is not possible to consider the cause in contracts as having some regards to the common law consideration.

Hence, what is of particular interest is the absence, in the PECL models, of both consideration and cause for the existence of an agreement between parties. Eliminating these elements from the contract equation, the core essence of the latter is still safe to be considered

¹⁶⁸ *Currie v Misa* (1875) LR 10 Ex 153 (Ex Ch).

¹⁶⁹ *Thomas v Thomas* (1842) 2 QB 851, 114 ER 330 (QB); *Williams v Roffey Bros & Nicholls (Contractors) Ltd* [1991] 1 QB 1.

¹⁷⁰ Calleros, ‘Introducing Civil law Students to Common Law Legal Method Through Contract Law’ (2011) 60 40 *Journal of Legal Education*, 641-663.

¹⁷¹ Lorenzen, ‘Causa and Consideration in the Law of Contracts’ (1919) 28 9 *Yale Law Journal*, 621-646.

¹⁷² Franceschetti, ‘La causa del contratto’ (2016) *Altalex*, <<https://www.altalex.com/documents/altalexpedia/2016/02/29/causa>> accessed 6 March 202.

¹⁷³ *Ibid.*

as having legal effects between legal subjects.¹⁷⁴ Consequently, the notion of contract within PECL models seems to be broader than the domestic ones, able to include a variety of legal transactions.¹⁷⁵ The reference is, indeed, to another types of juristic acts that can be considered contracts under some civil law systems, but not under the common law framework, such as gifts and exchanges.¹⁷⁶ Indeed, the purpose is the necessity to accommodate the variety of transactions that can be determined at the cross-border level, ensuring space of legal certainty when the parties come from different legal systems.¹⁷⁷

3.6.5 The Dynamics of Offer and Acceptance: Rule and Exceptions

Alongside of the meeting of mutual intentions to enter into agreement, namely consent, the formation of a contract is not deemed concluded without the encounter of the offer and acceptance.¹⁷⁸ Indeed, are such elements that traditionally define a contract as an agreement. That is because the offer represents the expression of willingness of one party, the offeror, to enter into contract, whereas the acceptance represents the counterparty, the offeree, unequivocal assent to do so as well.¹⁷⁹ Traditionally, once the latter meets the former, the

¹⁷⁴ Hein Kötz, *European Contract Law* (2nd edn, Oxford University Press 2017), 44–49.

¹⁷⁵ Martijn W Hesselink, *The New European Private Law: Essays on the Future of Private Law in Europe* (Kluwer Law International 2002), 141; Jan M Smits, *Contract Law: A Comparative Introduction* (3rd edn, Edward Elgar 2021) 41.

¹⁷⁶ *Eastwood v Kenyon* (1840) 11 Ad & E 438; *Central London Property Trust Ltd v High Trees House Ltd* [1947] KB 130.

¹⁷⁷ Stefan Vogenauer and Stephen Weatherill (eds), *The Harmonisation of European Contract Law: Implications for European Private Laws, Business and Legal Practice* (Hart Publishing 2006) 1–24

¹⁷⁸ Robert Merkin and Séverine Saintier, *Poole's Textbook on Contract Law* (16th edn, Oxford University Press 2023) 1; Mindy Chen-Wishart, *Contract Law* (7th edn, Oxford University Press 2020) chs 3–4; Andrew Stewart, Warren Swain and Karen Fairweather, *Contract Law* (Cambridge University Press, 2019), 83–88.

¹⁷⁹ Artt. 2:201–2:205 PECL; Stewart (n. 178).

contract is made.¹⁸⁰ As said, the offer and acceptance doctrine actually encompass a set of principles which are used to determine not only whether parties have accomplished an agreement, but also at what point, where and when it occurred.¹⁸¹ So that, leaving aside all the possible declination of such instances and events in the lifecycle of a contract formation¹⁸², two are the main points which are of importance to the scope of this chapter. These are, principally, the way in which the offer and acceptance become effective for law¹⁸³ and the further analysis of some circumstances whereby the offer-acceptance model to make a contract departs from the traditional scheme.¹⁸⁴

3.6.5 a) The Mirror-Image Rule and Its Limits

The general rule of contract law, both at domestic and EU level, assumes that a contract is formed when the proposal to enter into an agreement, as made by the offeror, is unequivocally accepted by the offeree.¹⁸⁵ To be considered as an offer, the proposal must be communicated to one or more specific person or to the public, show the intention to be bound and contain terms sufficiently defined.¹⁸⁶ At the same time, to be qualified as an acceptance, the offeree's communication must not modify or alter the material terms of the offer, otherwise

¹⁸⁰ *Hyde v Wrench* (1840) 3 Beav 334, 49 ER 132; *Stevenson, Jacques & Co v McLean* (1880) 5 QBD 346.

¹⁸¹ *Entores Ltd v Miles Far East Corporation* [1955] 2 QB 327 (CA); *Brinkibon Ltd v Stahag Stahl* [1983] 2 AC 34 (HL).

¹⁸² Such as preliminary negotiations, expression of interest, invitation to treat, the rule of silence, termination of offer, counteroffer etc.

¹⁸³ *Codice civile* (Italy), art 1326.

¹⁸⁴ *Brogden v Metropolitan Railway Co* (1877) 2 App Cas 666 (HL); *RTS Flexible Systems Ltd v Molkerei Alois Müller GmbH & Co KG* [2010] UKSC 14, [2010] 1 WLR 753; *Carlill v Carbolic Smoke Ball Co* [1893] 1 QB 256 (CA); *Butler Machine Tool Co Ltd v Ex-Cell-O Corporation* [1979] 1 WLR 401 (CA).

¹⁸⁵ Ewan McKendrick, *Contract Law: Text, Cases and Materials* (5th edn, Oxford University Press 2012), 81.

¹⁸⁶ *Ibid* 54-56.

it is then qualified as a rejection and as a following counteroffer, which can be subsequently accepted or rejected by the offeror.¹⁸⁷ Such a process encompasses the core of the traditional ‘mirror-image’ doctrine which states that acceptance must follow the form of the initial offer.¹⁸⁸

3.6.5 b) Contracts by Conduct and Implied Agreements

Additionally, like the other declaration of intentions, the acceptance can be made by statements or by conduct as long as it indicates assent to the offer. The purpose of the latter concept is to support and implement the *favor contractus* principle which, as stated demands a contract be concluded as much as possible in cases where some manifestations of consent are found.¹⁸⁹ For instance, in both domestic and international model law, the acceptance of a contract offer made by conduct, often by means of direct performance acts made by the offeree,¹⁹⁰ represents an exception to the mirror-image doctrine. As it has been considered, in fact, the offer-acceptance model ‘has not always functioned in practice’,¹⁹¹ since the traditional process does not take into account the variety of other models for the conclusion of contracts. Departures from the traditional model are not limited to acceptance by conduct. They also include circumstances where the entire contract formation process is determined by the parties’ conduct. In more complex cases, it may be impossible to reduce the agreement process to a simple offer and acceptance scheme.¹⁹² These kinds of exceptions find room in the EU and international realm where the needs of prompt and efficient transactions, in the trade and transfers of value, are at stake. Consequently, the cross-border transactions are, thus, the places in which the *favor contractus* principle enjoys the maximum protections. The example is given

¹⁸⁷ Ibid.

¹⁸⁸ Nenad Gvrlivic, ‘European Contract law and the Problem of Modified Acceptance: Is there Room for a unified Approach?’ (2020) 11 1 Iustinianus Primus Law Review, 1.

¹⁸⁹ Ibid, 2.

¹⁹⁰ Ibid, 3.

¹⁹¹ Guenter H. Treitel, *The law of Contract* (11th ed, Sweet & Maxwell, 2003), 19.

¹⁹² Lando and Beale (n. 137), 169.

by article 2:211 PECL which rules cases in which contracts are not concluded by means of offer and acceptance traditional models. Amongst a variety of situations, the PECL norm takes into account circumstances in which the entire contract formation process is made by conduct alone.¹⁹³ For instance, it is possible to think about contracts made by a person and a machine, such as vendor machines or even car park machine and travel insurance purchased from a slot machine.¹⁹⁴ A contract can be considered as such whenever parties acted in the way in which their conduct is sufficient to reveal a mutual agreement. As it has been stated:

‘In commercial practice contracts, particularly when related to complex transactions, are often concluded after prolonged negotiations without an identifiable sequence of offer and acceptance. In such cases it may be difficult to determine if and when a contractual agreement has been reached. According to this Article a contract may be held to be concluded even though the moment of its formation cannot be determined, provided that the conduct of the parties is sufficient to show agreement’.¹⁹⁵

It must be highlighted that in contracts made by conduct, the interpretation of parties’ behaviours play a significant role under both subjective and objective theories, as discussed. Thus, the conduct must show a leading direction towards the purpose of enter into agreement, displaying parties’ intentions. In common law systems, case law has consolidated the approach according to which a contract can be concluded through implicit conduct or automated interactions.¹⁹⁶ In civil law systems, codifications recognise the sufficiency of conclusive

¹⁹³ Lando and Beale (n. 137), 187.

¹⁹⁴ Ibid.

¹⁹⁵ Lando and Beale (n. 137), 159.

¹⁹⁶ *Thornton v Shoe Lane Parking Ltd* [1971] 2 QB 163 (CA); *Carlill v Carbolic Smoke Ball Co* [1893] 1 QB 256 (CA).

conduct for the valid formation of a contract.¹⁹⁷ In both models, the general rule is freedom of form, with written form requirements only for specific types of contracts.¹⁹⁸

3.6.6 Electronic Contracts: Point-and-Click and Multi-Step Digital Formation

Exceptions to the traditional offer-acceptance model are also the internet-based electronic contracts. These kinds of agreements, expressed by means of data messages, may be brought under the umbrella of more complex contract formation processes.¹⁹⁹ Despite the regulation of electronic commerce is mostly entrusted to domestic laws, the European space has several legal sources which are pivotal in the regulation of Digital market and the related aspects of electronic commerce.²⁰⁰ Even if the analysis of electronic commerce regulation landscape is far from the scope of this chapter, the thesis wants to share two main interesting points of reflection directly linked to the debate around the analysis of contract transactions. In the electronic commerce, the legal relation between legal subjects is explicitly directed towards the realisation of contract transactions, as an exchange of products and services between a buyer and a seller. However, this relation is undertaken with a series of electronic activities, a combination of systems and methodologies designed to support the exchange of information necessary to the transaction.²⁰¹ This is the reason why it is possible to state that it

¹⁹⁷ Codice civile (Italia) artt 1321–1326; Bürgerliches Gesetzbuch (BGB) §§ 145–151. Vedi anche Massimo Bianca, *Diritto Civile, III: Il contratto* (3rd edn, Giuffrè 2000) 45–52.

¹⁹⁸ Pietro Perlingieri, *Il diritto civile nella legalità costituzionale* (2nd edn, ESI 2006) 287–290.

¹⁹⁹ Pasquale Stanzone, *Commercio elettronico, contratto e categorie civilistiche* (Giuffrè 2001), 35–62; *Specht v Netscape Communications Corp* 306 F3d 17 (2d Cir 2002).

²⁰⁰ Directive 2000/31/EC of the European Parliament and of the Council of 8 June 2000 on certain legal aspects of information society services, in particular electronic commerce, in the Internal Market ('Directive on electronic commerce') [2000] OJ 178/1, art 9.

²⁰¹ 'e-commerce therefore represents the set of systems, activities and methodologies relating to the use of technologies specifically designed and implemented to support (in whole or in part) the information exchange necessary for the transaction. This may imply that, where possible, electronic commerce will also support its effective execution (i.e. the transfer of goods or services, or payment), but we can speak of electronic commerce even in cases where this does not happen. Indeed, a transaction is not a single

is in the electronic contract formation context that the legal transaction is not limited to a single act but rather it can be considered as a process which implies many steps and phases.²⁰² The offer-acceptance model is often broken down to get adapted to the Internet infrastructure. The example is given by the point-and-click model where a computer user agrees to the terms of an electronically displayed agreement by pointing the cursor on the screen and thereby clicking.²⁰³ The traditional mirror-image scheme is essentially shifted. In fact, since the Internet cancels the temporal space between the interlocutors, data transmission occurs practically in real time. That is because the most relevant distinctive elements of the world wide web are generally identified in the intangible and global nature of the network. However, what happen is that the scheme of legal transactions acquires more steps than a traditional one for it can be qualified as a more complex process, even if all automated.

3.6.7 Performance Architecture: Independent/Dependent Obligations and Conditions

Once all the contract elements have been determined by parties and the agreement reached, the next phase is the performance of contractual obligations. The time, the place and methods of each party obligation performance can vary depending on the type of terms they agreed upon. Such circumstances are recognised both on domestical and international viewpoint. In the performance framework, there also can be dependant or independent obligations.²⁰⁴ Difference lies on the fact that obligations are independent from one another

activity but rather a process that involves various stages. In other words, we can speak of electronic commerce when the use of the Internet concerns at least part of the transaction (provided of course it is significant enough for the purposes of the transaction itself).’ On translation. Zamboni, ‘Applicazioni di Commercio Elettronico: Classi e tipologie’ (2019) <<http://docplayer.it/47812856-Applicazioni-di-commercio-elettronico-classi-e-tipologie.html>> accessed 5 February 2020.

²⁰² Ibid.

²⁰³ Harrison, ‘Just Click Here: Article 2B's Failure to Guarantee Adequate Manifestation of Assent in Click-Wrap Contracts’ (1997-1998) 8 Fordham Intell. Prop. Media & Ent. L.J., 907.

²⁰⁴ Stewart, Swain and Fairweather (n. 178), 231.

and parties can perform them independently from one another.²⁰⁵ At the same time, an obligation is dependant from the counterparty's one when its performance is conditioned to the other party's one.²⁰⁶ The conditions that can be defined in the contract process can intervene also when an obligation is conditional upon the occurrence of a certain future event.²⁰⁷ In this case the obligation produces its effect only if the event occurs or comes to an end if the event occurs.²⁰⁸ The former case identifies the suspensive condition, the latter the so-called resolutive condition. It must be taken into account that these kinds of conditions are different from the dependant-based obligations. In fact, unlike the latter, the former is based on uncertainty, that stems from external events which parties may not have any control upon.²⁰⁹

3.7 From Juristic Acts to Code: Evolution of Transactions

At this point, it possible to affirm how and why contracts are considered the most complex legal transactions, compared to other types of juristic acts.²¹⁰ The element of intention for legal subjects involved into agreements leads to the manifestation of consent (encounter of minds) by means of the elements of contracts formation. In particular, it is in the exception cases of the mirror-image doctrine that is possible to recognise that evolutionary thrust in the outline of legal transactions and contracts.²¹¹ The development of technology has caused, indeed, the necessity to qualify new kind of transactions, adapting and broadening the relative

²⁰⁵ Ibid.

²⁰⁶ Ibid.

²⁰⁷ Art.16:101 PECL; Angelo Falzea, 'Condizione (dir. civ.)' in *Enciclopedia del diritto*, vol VIII (Giuffrè 1961); Luigi Mengoni, *Obbligazioni condizionali e termine* (Giuffrè 1954).

²⁰⁸ Cesare Massimo Bianca, *Diritto civile*. Vol. 3: Il contratto (n 1).

²⁰⁹ Lando and Beale (n. 137), 230.

²¹⁰ Angelo Falzea, 'Negozio giuridico' in *Enciclopedia del diritto*, vol XXVIII (Giuffrè 1978).

²¹¹ *Butler Machine Tool Co Ltd v Ex-Cell-O Corporation (England) Ltd* [1979] 1 WLR 401 (CA); *GHSP Inc v AB Electronic Ltd* [2010] EWHC 1828 (TCC); Mindy Chen-Wishart, *Contract Law* (7th edn, Oxford University Press 2020), 102.

legal category and regulation accordingly.²¹² The modality and the velocity whereby juristic acts can link and affect mutually the legal sphere of legal subjects' rights and duties is pivoting at a fast pace. This seems particularly true for blockchain technology and its most important applications: smart contracts.²¹³ Therefore, the next section will focus on the analysis of the technical and legal nature of smart contracts and under what circumstances they might be considered legal contracts. This passage is crucial for the analysis of the thesis, since it allows to question how the autonomous conduct of the DsAI, recorded on-chain, can constitute a manifestation of contractual intention.

3.8 Sole-Code Smart Contracts 'on' Chain: Are They Contracts Made by Conduct?

In the legal realm, there is a general scholars' preference in outlining a clear difference between smart contracts and smart legal contracts.²¹⁴ In particular, the former notion defines the mere computer code stored on a distributed ledger, concerned with the mere execution of tasks where a pre-defined set of conditions are met.²¹⁵ Conversely, the latter should identify both the code and a legal agreement, namely a digital contract. As it has been affirmed:

²¹² Roger Brownsword, *Contract Law: Themes for the Twenty-First Century* (3rd edn, Oxford University Press 2023), 45; Larry A DiMatteo, Michel Cannarsa and Cristina Poncibò (eds), *The Cambridge Handbook of Smart Contracts, Blockchain Technology and Digital Platforms* (Cambridge University Press 2019), ch 1.

²¹³ Horatia Muir Watt, 'Party Autonomy in International Contracts: From the Makings of a Myth to the Requirements of Global Governance' (2010) 10 *European Review of Contract Law*, 250; Max Raskin, 'The Law and Legality of Smart Contracts' (2017) 1 *Georgetown Law Technology Review* 305.

²¹⁴ Law Commission of England and Wales, *Smart Legal Contracts: Advice to Government* (Law Com No 401, November 2021), 2.9–2.19; Richard Susskind, *Tomorrow's Lawyers: An Introduction to Your Future* (3rd edn, Oxford University Press 2023), 141.

²¹⁵ Karen Levy, 'Book-Smart, Not Street-Smart: Blockchain-Based Smart Contracts and the Social Workings of Law' (2017) 3 *Engaging Science, Technology, and Society*, 1; evin Werbach, *Blockchain and the New Architecture of Trust* (MIT Press 2018), 77.

‘Smart legal contracts - digital contracts (designed either to complement or entirely substitute natural language agreements) with the potential of creating legally enforceable rights that are executed by software embedded with smart contract code. In other words, a smart legal contract always contains at least one piece of smart contract code, but not all pieces of smart contract code equate to a smart legal contract.’²¹⁶

Despite the mentioned differences, this thesis embraces the original rationale of smart contract protocol, with no divergence between its technological and legal dimension.²¹⁷ That is for two reasons. First, such a distinction does not exist in the technical side. Secondly, also from a legal perspective, this distinction cannot be supported as even smart legal contracts contain smart contract code.²¹⁸ In other words, this thesis shall consider smart contracts as a single paradigm, embracing the original Szabos’ intention and definition upon the discussion around the central research question.

Notwithstanding, it is pivotal to take into account that the conundrum around the necessity to differentiate two meanings lies in the question whether all type of smart contracts can be considered as legally binding contracts and, consequently, if they can be legally enforceable.²¹⁹ As already discussed in the previous section, the idea of expressing a contractual relationship in electronic form is not new. In fact, the reliance on software for making and executing agreements has always been strongly coveted. For instance, it is enough to reflect on the broader implementation of data-oriented, computable, and Ricardian

²¹⁶ Erika Nash, ‘Blockchain & Smart Technology: Alternative Incentives for Legal Contract Innovation’ (2019) 3 8, *BYU Law Review*, 800-833.

²¹⁷ Allen Gruner and Florian Möslin, ‘Contracting with Algorithms: Smart Contracts and the Limits of Code’ (2020) 21 *German Law Journal*, 1337.

²¹⁸ Mik, ‘Smart contracts: terminology, technical limitations and real-world complexity’ (2017) 9 (2) *Law, Innovation and Technology*, 269.

²¹⁹ Christophe Busch and Roger Brownsword (eds), *Research Handbook on Law and Technology* (Edward Elgar 2022), 205; Aurore Catherine Bossu, ‘Smart Contracts: Is the Law Ready?’ (2020) 27 *Maastricht Journal of European and Comparative Law*, 729.

contracts.²²⁰ Without engaging in too much detail, risking shifting the discussion towards appraisals not useful to the current debate, a brief description of the main characteristics of such digital deals deserves to be undertaken. Namely, in data-oriented contracts, parties can express part of contractual arrangements into computer-processable data to make an assessment of *prima facie* compliance and performance.²²¹ Conversely, in a computable contract, as it has been affirmed, the software has to have even ‘the ability to engage in some sort of automated comparison between the terms of the contract and relevant information concerning compliance’.²²² That is, as stated, ‘computer systems can be instructed how to assess contract terms in a way that mirrors parties’ intentions’.²²³ As for Ricardian contracts, instead, these are kind of contracts more focused on transposing legal terms into machine-readable agreements, increasing the prose of a digital document.²²⁴ Therefore, taking into account these functional descriptions is possible to corroborate that the core purpose of all digital agreements is to convey as steadily as possible the contractual semantics into an algorithmic key, paving the way to increasingly sophisticated automated transactions. Accordingly, the thesis argues that smart contracts can display this function, elevating blockchain-based transactions as legal ones and, in particular, as legal contracts whenever they comply with the general contract principles.²²⁵

In particular, smart contracts can represent a further class of digital relationships. Indeed, these kinds of blockchain-based transactions are able to affect the legal relationship between

²²⁰ Giovanni Rinaldi, ‘Smart Contract: Meccanizzazione del Contratto nel Paradigma Blockchain’, in Guido Alpa (eds), *Diritto e Intelligenza Artificiale* (Pacini Giuridica, 2020), 355; Harry Surden, ‘Computable Contracts’ (2012) 46 UC Davis Law Review, 629.

²²¹ Harry Surden, ‘Computable Contracts’ (2012) 46, UC Davis Law Review, 629-674.

²²² Ibid, 660.

²²³ Ibid, 658.

²²⁴ Philipp Hacker, *Digitale Verträge: Smart Contracts und das Privatrecht* (Mohr Siebeck 2021), 31; Mark Fenwick, Wulf A Kaal and Erik P M Vermeulen, ‘Legal Education in the Blockchain Revolution’ (2018) 20 Vanderbilt Journal of Entertainment and Technology Law, 351; Ian Grigg, ‘The Ricardian Contract’ (2004) <http://iang.org/papers/ricardian_contract.html accessed> 19 September 2024.

²²⁵ Guido Alpa and Mads Andenas (eds), *Smart Contracts: Comparative Perspectives* (Routledge 2022).

parties involved for, as it happens with real life transactions, by means of blockchain technology, parties can expand, reduce either alter their respective legal entitlements. At the same time, smart contracts, every time that display contractual elements, can be qualified as legal contracts subject to the contract principles' regulation as well.

To underpin such a concept, it is necessary to understand if the elements of juristic acts and, distinctively, contracts can be seen in smart contracts as well. As studied in the previous section, to have juristic acts it is necessary that a legal subject express, by means of this act, not only his will to undertake it but also his intention to determine its effects. Without doubt, this is true both for simple exchange and smart contract transactions. The simple blockchain exchange transactions resemble the real-life mutual exchanges which are considered juristic acts. In such a case, parties express both will and intention to determine the exchange and its legal effects between them by means of a digital transaction.

Vice versa, smart contracts paradigm can exhibit the elements of a contract and be able to produce legal effects between the legal subjects involved. Taking into account the already analysed contract principles, it has been affirmed that, similar to traditional contracts, also blockchain-based smart contracts can express consent, a state of mutual agreement.²²⁶ That is to say that a cybernetic blockchain-based algorithm can be the means of development and convergence of parties' bounding intentions. Indeed, blockchain members can enter into a binding relationship using smart contracts either entirely or partially embedded into a code.²²⁷ In fact, as it is for real life contracts, smart contract parties can create or transfer rights and duties by means of this digital paradigm. It already happens, for smart contracts can create or transfer digital assets and their respective rights, namely tokens.²²⁸ However, to think about smart contract as a legal contract, it is pivotal being able to identify objectively parties' intention to be legally bound to it as well as mutual obligations and offer-acceptance minimal

²²⁶ Agata Ferreira, 'Regulating smart contracts: legal revolution or simply evolution?' (2021) 45 102081 Telecommunication Policy, 1-16.

²²⁷ Ibid, 7.

²²⁸ Guadamuz, 'All watched over by machines of loving grace: A critical look at smart contracts' (2019) 35 (105338) Computer Law & Security Review, 5.

framework which led to the conclusion of a legal contract. This thesis suggests that such elements can be shown only in smart contracts which are entirely created 'on' chain. To further clarify the concept, it must be said that smart contracts can be used in both 'on' and 'off' blockchain agreements.

3.8.1 Models of Smart Contracts: Integrated, Non-Integrated and Sole-Code

These divergent circumstances give, indeed, rise to different types of smart contract models. Such models are designed to cover a range of several situations in which a contract may or not be totally drafted in computer programme language and as argued, in the case where 'the software may have various roles in concluding, performing and/or enforcing (part of) a contract itself'.²²⁹ Currently, smart contract models are as follows: Integrated and Non-Integrated models, Concluding and Performance models.²³⁰ The first one occurs when a contract is utterly or partially written in code. In such a case, the smart contract is used to automate the agreement's clauses that parties have already agreed upon in a real-life negotiation, off-chain.²³¹ Conversely, a Non-Integrated model defines a case where parties draft an agreement in natural language and then include an additional agreement in which they decide to use smart contracts to perform and/or enforce the contract.²³² Both the Integrated and

²²⁹ Clifford Chance, 'Smart Contracts: legal framework and proposed guidelines for lawmakers' (2018), 6 <<https://www.ebrd.com/documents/legal-reform/pdf-smart-contracts-legal-framework-and-proposed-guidelines-for-lawmakers.pdf>> accessed 4 July 2020; Smaranda Nistor and Aurelia Manea, 'Smart Contracts and Their Applicability in Civil Law' (2020) 68 Annals of the University of Oradea: Economic Science, 224.

²³⁰ The World Bank Group, 'smart Contract Technology and Financial Inclusion' (2020) <<https://openknowledge.worldbank.org/bitstream/handle/10986/33723/Smart-Contract-Technology-and-Financial-Inclusion.pdf?sequence=1&isAllowed=y>> accessed November 2020; Florian Möslin, 'Conflicts of Laws and Codes: Defining the Boundaries of Digital Jurisdictions' (2019) 27 European Review of Private Law, 783; Sofia Ranchordás, 'Digital Agoras: Democratic Legitimacy, Online Dispute Resolution, and Blockchain Contracts' (2019) 36 Computer Law & Security Review, 105374.

²³¹ The World Bank Group (n. 230), 6-7.

²³² Clifford Chance (n. 229), 13.

the Non-integrated models define smart contracts as part of a legal contract which has been concluded off-chain.²³³ Thus, in such cases, contract elements like the meeting of minds, mutual exchange and the offer-acceptance model have been determined elsewhere, based on the type of contract concluded off chain. However, the obligations' performance will be fulfilled on chain, as a consequence of the self-execution trait of smart contracts.²³⁴

Conversely, more issues are caused whenever a legal contract is entirely formed on chain by means of sole-code smart contract.²³⁵ This is the case of the Concluding either Performance models, which are usually used in conjunction and represent the most used variety of sole-code smart protocols.²³⁶ With the former model, a contract can be concluded directly and autonomously by the software itself, regardless of a parties' prior or even separate agreement.²³⁷ At the same time, with the performance model, the smart contracts execute the assets' transfer on the shared ledger between two or more nodes.²³⁸ That is, as argued, 'the software may form or create legally binding obligations between the parties'.²³⁹ As illustrated, it is possible to state that these are the most interesting models since it utterly implements the

²³³ Giusella Finocchiaro and Cristina Amato (eds), *Smart Contracts e Blockchain: Profili giuridici e tecnologici* (Giappichelli 2020), 81; Axel Metzger, 'Contract Law 2.0? Smart Contracts as the Beginning of a New Era' in Alberto De Franceschi (ed), *European Contract Law and the Digital Single Market* (Intersentia 2016), 35.

²³⁴ Ibid, 12.

²³⁵ Michael Fritsch, 'Solely Code? Smart Contracts and the Quest for Autonomy' (2021) 39 Computer Law & Security Review, 105500.

²³⁶ Clifford Chance (n. 229), 15.

²³⁷ Ibid, 14.

²³⁸ Andrea Bertolini, 'Smart Contracts as a Challenge for Contract Law' (2019) 26 European Review of Private Law, 753; Christoph Busch, 'The Future of Pre-Contractual Information Duties: From Behavioural Insights to Big Data' (2019) 7 Journal of European Consumer and Market Law, 50.

²³⁹ Clifford Chance (n. 229), 14.

autonomy trait of smart contracts, conveying in a single moment the contract elements. Therefore, these models can be referred as one.²⁴⁰

3.8.2 Contract Formation in Sole-Code: Offer, Acceptance and Conduct

As regards to the contract elements, in such a case, it is possible to identify them completely on chain. Above all, the offer and acceptance model definitely fall under the exception of the mirror-image doctrine, like it happens for electronic contracts.²⁴¹ From a legal perspective, the relevant behaviour is therefore on-chain behaviour: a timestamped interaction capable of demonstrating acceptance of the rights and obligations embedded in the code.²⁴² In fact, as analysed in the life cycle of smart contracts, it is possible to consider the deployment phase as the moment in which the offer is made towards all the blockchain members or between two or more blockchain parties.²⁴³ Consequently, the acceptance to enter into that binding agreement, considering the pre-settled conditions of a smart contract, will follow whenever another account member ‘calls’ for that smart contract performance.²⁴⁴ In this case, as it occurs for internet-based contracts in the point and click situation, the acceptance is fulfilled by the ‘calling’ feature. This way, reciprocal duties are formed and performed all at ones. The example is made by the case in which, by means of a smart contract, a blockchain party promise

²⁴⁰ Guido Alpa and Mads Andenas (eds), *Smart Contracts: Comparative Perspectives* (Routledge 2022) 61.

²⁴¹ Hugh Beale (ed), *Chitty on Contracts*, vol 1: *General Principles* (34th edn, Sweet & Maxwell 2021).

²⁴² Oliver Wendell Holmes, *The Common Law* (Little, Brown 1881), 242; Cesare Massimo Bianca, *Diritto civile. Vol. 3: Il contratto* (Giuffrè 2000), 121.

²⁴³ Giusella Finocchiaro, Chantal Bompreszi, ‘A legal analysis of the use of blockchain technology for the formation of smart legal contracts’ (2020) *Media Laws* <<https://www.dimt.it/wp-content/uploads/2020/06/finocchiaro-bompreszi.pdf>> accessed 10 March 2021.

²⁴⁴ Fabrizio Bassan, ‘From Smart Legal Contracts to Contracts on Blockchain’ (2024) 42 *Computer Law & Security Review*, 105862; Niels Vandezande, ‘Smart Contracts: The End of Contract Law as We Know It?’ (2017) 33 *Computer Law & Security Review*, 148; Daniela Bavasso, ‘Contracts and Code: Smart Contracts as the Expression of Autonomous Will’ (2022) 18 *European Review of Contract Law*, 187.

to operate a service in exchange of money or of another certain service. Such conditions are embedded into the smart contract when it is deployed. Once a counterparty calls for that service, paying or providing a service required, the contract is concluded, and it will automatically perform the agreed obligations. This translates in practice the famous statement ‘when conditions are met’.²⁴⁵

Therefore, the parties’ intention to produce legal effects and to be legally bound is manifested each time the smart contract performs its purpose.²⁴⁶ At the same time, the economic mutual exchange required to qualify a transaction as a contract in domestic systems can be ascertained from the smart contract’s conditions. Since the smart contract is self-executing, in such cases the process of contract formation happens all at once. As a consequence, smart contracts might be fall under both provisions of PECL, when respectively assess that a contract may be concluded either by the offer-acceptance frame or by conduct of the parties that is sufficient to show agreement.²⁴⁷

The central difficulty with sole-code formation is that unlike classical contracts by conduct, sole-code arrangements lack natural-language expressions of consent at the point of formation. Therefore, agreement arises exclusively from algorithmic behaviour: the

²⁴⁵ Sangharatna Godbole, P Radha Krishna, Sunkara Sri Harika and Pooja Varnam, ‘Validation Framework for E-Contract and Smart Contract’ (2025) *arXiv* <<https://arxiv.org/abs/2504.19137>> accessed 19 September 2025.

²⁴⁶ Pietro Perlingieri, *Profili applicativi della legalità costituzionale* (Edizioni Scientifiche Italiane, 2007), 221; Frederick Pollock and Frederic W Maitland, *The History of English Law before the Time of Edward I*, vol 2 (2nd edn, Cambridge University Press 1968 [1898]), 211.

²⁴⁷ Art 2:211 PECL and art. 2.1.1. PICC; Chanuka Wijayakoon, Hai Dong, H M N Dilum Bandara, Zahir Tari and Anurag Soin, ‘Legal Compliance Evaluation of Smart Contracts Generated By Large Language Models’ (2025) *arXiv* <<https://arxiv.org/abs/2506.00943>> accessed 19 September 2025; Ole Lando and Hugh Beale (eds), *Principles of European Contract Law: Parts I and II* (Kluwer Law International 2000), 146; Mauro Bussani and Ugo Mattei, *The Common Core of European Private Law: The Making of European Contract Law* (Giappichelli 2002), 55.

transaction itself is the manifestation of consent.²⁴⁸ This raises the doctrinal question whether coded conduct alone suffices to establish a contract. Under PECL art 2:204, the answer turns on whether an external observer can infer a sufficient agreement from behaviour; in a sole-code setting, that behaviour is the sequence of on-chain interactions culminating in consensus. Where the protocol publicly exposes offer-like terms at deployment and acceptance-like calls under those terms, the legal threshold for conduct-based formation can be met.²⁴⁹ Moreover, what is very interesting is that in sole-code smart contracts, the consensus mechanism and the collapse of formation elements at the moment of performance are very much polarised.

3.8.3 Collapsing Formation and Performance: Legal Effects of Sole-Code Smart Contracts

In sole-code smart contracts, network consensus often collapses formation and performance into a single coded event: when conditions are met and the transaction attains finality, the system both records agreement by conduct and executes performance.²⁵⁰ This functional unity strengthens the case for contractual qualification, while also reallocating risk and complicating remedies ex post given immutability. However, following PECL models, it can be possible for sole-code smart contracts to be qualified within the variety of contracts made by conduct, because on-chain technical interaction can constitute conclusive conduct by manifesting consent to pre-set terms at the moment of formation/performance. At the same time, their validity depends on the interpretability of that codified conduct: whether a reasonable external observer can identify offer (at deployment/configuration) and acceptance (via the call/interaction) in the transaction sequence. This can be proven consistent with both

²⁴⁸Roger Brownsword, *Law, Technology and Society: Re-Imagining the Regulatory Environment* (Routledge 2019) 97; Karen Yeung and Martin Lodge (eds), *Algorithmic Regulation* (Oxford University Press 2019), 210.

²⁴⁹Kalonji Kalala, 'Logical Foundations of Smart Contracts' (2025) *arXiv* <<https://arxiv.org/abs/2502.09232>> accessed 19 September 2025.

²⁵⁰Christoph Busch, 'The Future of Pre-Contractual Information Duties: From Behavioural Insights to Big Data' (2019) 7 *Journal of European Consumer and Market Law*, 50.

the civil law (as conclusive conduct) and common law (objective intention) approaches, as well as with PECL models, art. 2:204, on formation by conduct.

Therefore, it is the decentralised and distributed blockchain traits that enable the most innovative virtue of smart contracts that is the chance to merge the agreement and the execution phase. In fact, as stated, ‘smart contract both is agreement and executes it’.²⁵¹ Therefore, smart contracts can remove the distinction between these two traditional contract phases. The ambitious outcomes that mirror the Szabo’s idea of smart contracts are to make it virtually impossible for parties not to fulfil the transaction. Consequently, the non-compliance risk is extinguished at its root.²⁵² This is the self-enforcement trait of sole-code smart contract conditions. A smart contract remains dormant until it is called, and its conditions are met. If the conditions are not fulfilled, no transaction occurs. Once consensus is reached, however, the transaction is released from any human control.²⁵³ This represents the highest level of automation: the ability to codify parties’ intention and execute obligations without further intervention. Consequently, it can be said that smart contracts further narrow the distances between all stages of contractual phases. In fact, whether in other electronic contracts, like the Internet based ones, it is possible to distinguish the development stages of contract elements, in sole-code smart contracts the automation is so exasperated that it makes challenging to identify the precise moment of the completion of mutual consent and execution.²⁵⁴ It happens all in one step. As it has been stated,

‘In general, legal value is granted to blockchain technology and smart contracts in conducting electronic transactions, recognising the ownership rights upon information guaranteed by the blockchain system. Thus, the legal effect,

²⁵¹ Henning Diedrich, *Ethereum: Blockchains, Digital Assets, Smart Contracts, Decentralised Autonomous Organisations*, (CreateSpace Independent Publishing Platform, 2016), 3.

²⁵² Giovanni Rinaldi (n. 220), 354.

²⁵³ *Ibid.*

²⁵⁴ *Ibid.*, 360.

validity and exclusivity of a transaction cannot be denied only because it took place through such technologies'.²⁵⁵

Hence, it is possible to recognise smart contracts as legally binding contracts. Most important, as it has been argued, '[s]mart [c]ontracts represent [a] new challenge to legal regulation. Systems creating such contracts live by their own rules, beyond the boundaries of law'.²⁵⁶ Hence, smart contracts might be a cross point to contract law. As the technology behind evolves and expands, with time, it will be difficult to consider smart contracts as an isolated category rather than components of the contractual legal system, potentially subject to the same framework of rules. This, in turn, will maximise not only their legal impact but also their commercial value. Ultimately, the legal relevance of sole-code smart contracts is amplified by the fact that DsAI systems are increasingly deployed to interact with them, making it urgent to evaluate whether their algorithmic conduct can integrate the contractual formation requirements.

3.9 Conclusions

To conclude, the thesis shall offer some considerations. Blockchain systems are suitable to be qualified as technical environment where legal subjects can give rise to the two-fold relationship. In fact, by means of blockchain, legal subjects realise a direct relationship with legal objects, in this case digital assets like cryptocurrencies or tokens. This way, demonstrating to hold a relevant interest, an advantage that law must protect. At the same time, there is a correlation between rights and duties amongst blockchain members, as legal subjects, where they can affect each other juristic sphere by means of blockchain-based transactions. In fact, even within the decentralised environment is possible to create new sources of rights and duties. Therefore, it can be stated that blockchain transactions like smart contracts can be

²⁵⁵ Massimo Giuliano, 'La Blockchain e gli Smart Contracts nell'Innovazione del Diritto nel Terzo Millennio' (2018) II 6 Diritto dell'Informazione e dell'Informatica, 989.

²⁵⁶ Kevin Werbach and Nicolas Cornell, 'Contracts *Ex Machina*' (2017) Duke Law Journal, 314-382.

classified as juristic acts, whereby blockchain members can define or alter their legal relations intentionally.

At the same time, smart contracts can be potentially considered as new form of legal transaction. In fact, acknowledging their legal relevance can determine a positive impact on the overall commercial value that run in blockchain systems. The inner nature of such decentralised transactions can convey, indeed, pivotal traits of juristic acts and contracts. It is possible to say that whatever smart contract model parties want to apply, each of them can produce significant legal effects amid participants, transcending the sole cyberspace. Whether fully constituting a contract, accompanying one or even being used only in the execution phase, smart contracts can contribute to the entire chain of production of binding legal effects between parties. However, the existing differences between the indicated models of smart contracts can affect their qualification as legal contracts.

From a legal perspective, sole-code smart contracts represent the most suitable ones to be entirely classified as agreements completely formed and performed on chain. Consequently, they can show a sufficient agreement, objectively ascertainable, between blockchain members even when entirely created 'on' chain. Therefore, these are certainly the case whereby EU contract law principles can be applied to smart contract protocols, given the cross-border traits of the blockchain environment. The reason lies also in the definition of what a contract is, as identified in PECL models, much broader than the domestic ones. In fact, they can carry out digital encoded rights, duties or obligations, producing legal effects.²⁵⁷

Without any doubts, amongst the different scenarios highlighted, the formation of smart contract process that occur entirely on chain is the most interesting one from a legal viewpoint. In fact, these types of models demonstrate to depart from the traditional mirror image doctrine of the offer-acceptance contract process, potentially falling under the provisions of contracts concluded by conduct, as defined in article 2.11 PECL. In particular, the acceptance of pre-set terms, in such cases, encounter the offer made with the deployment phase by the calling phase that run out the execution stage at the same time. This way, it is possible to further

²⁵⁷ Philip Boucher, 'How Blockchain technology could change our lives', (2017) EPRS| European Parliamentary Research Service PE 581.948, 8.

confirm that blockchain parties' conduct demonstrate a leading direction towards the mutual intention to enter into agreement. This kind of contract formation resembles for certain aspects the internet-based contract, the point-and-click one. However, as opposed to the latter, where the transaction can be envisaged as a process, in smart contract formation there is not a transaction process but a 'transaction moment'.

All in all, juristic acts, and contract in particular, are more than mere performative tools; they are social mechanisms. Therefore, it cannot be withheld that blockchain-based smart contract transactions can show contract nature. Indeed, they retain a social value, as they can affect the involved legal subjects' mutual legal relations, benefiting commercial as well as human relationships. Accordingly, it can be undoubtedly said that blockchain smart contract transactions can be legally relevant.

CHAPTER 4

Decoding the Role of Decentralised AI Systems in Sole-Code Smart Contract Transactions: The Integrated Agency Approach

4.1 Introduction

The emergence of Decentralised Artificial Intelligence as autonomous actors in blockchain-based environments necessitates a fresh examination of AI's role within contractual interactions. Traditionally focused on legal capacity and intention of the parties to be legally bound¹, contract law is now facing circumstances in which the process of contract formation is autonomously performed by cognitive AI systems.² The increasing complexity of DsAI systems gives, indeed, rise to unprecedented legal and, to some extent, philosophical questions around contract capacity and intention to be bound. Such concepts then inevitably intersect with the notions of autonomy³ and agency of artificial agents. Notions that while in the legal

¹ Ewan McKendrick, *Contract Law* (14th edn, Macmillan 2021), 7–12.

² Simon Deakin and Christopher Markou (eds), *Is Law Computable? Critical Perspectives on Law and Artificial Intelligence* (Hart 2020).

³ See the updated definition of AI provided by the OECD.AI: ‘An AI system is a machine-based system that, for explicit or implicit objectives, infers, from the input it receives, how to generate outputs such as predictions, content, recommendations, or decisions that can influence physical or virtual environments. Different AI systems vary in their levels of autonomy and adaptiveness after deployment’. OECD, *Explanatory Memorandum on the Updated OECD Definition of an AI System* (OECD Artificial Intelligence Papers, March 2024) 5 <https://www.oecd.org/content/dam/oecd/en/publications/reports/2024/03/explanatory-memorandum-on-the-updated-oecd-definition-of-an-ai-system_3c815e51/623da898-en.pdf> accessed 6 April 2025.

sphere are implicitly assumed for natural and legal persons, in the AI cognitive field are still evolving. This circumstance is especially exacerbated in the domain of sole-code smart contracts, which provide an unprecedented setting where DsAI-driven decisions directly initiate and form legally binding obligations. Significantly, this context prompts crucial interrogations concerning the role of DsAI entities in contract formation and the extent to which their actions are legally relevant. In this regard, the core friction lies in what traditionally qualifies as a contract party. From a legal perspective, a party is the centre, or source, of interests from which, or towards which, the legal effects of the contract flow.⁴ This legal recognition is traditionally reserved for natural or legal persons, capable of holding rights and obligations. The challenge, therefore, is understanding whether a DsAI system, formally lacking both legal personhood and legal capacity, can nonetheless functionally operate as an autonomous legal source of interests, a contract party. In such a case, the legal system may be facing a new paradigm within the contract formation process.⁵

This challenge forces therefore an in-depth examination of two interconnected legal conundrums. The first one relates to whether DsAI systems can effectively form contracts. The analysis thus requires assessing whether, in particular, the intention to validly enter into agreements can be recognised to DsAI agents. Crucially, this investigation demands an examination of both the concepts of will and the intention to contract as they play a different role within civil law and common law systems. Secondly, it is essential to clarify whether DsAI systems are deemed to possess contract capacity and how this is located within decentralised and distributed open-source networks. While in the previous chapter the analysis focused on the overall elements of contract – concerning the nature of smart contracts - as a precondition for the following discussion, this chapter specifically addresses the first conundrum: the debate around contractual intention in relation to DsAI systems. The second conundrum concerning legal capacity, will instead be part of a broader analysis developed in the next chapter. The examination follows then a bottom-up approach, from the specific element of intention to contract up to the general contract capacity. The element of intention to contract is deemed

⁴ Visa AJ Kurki, *A Theory of Legal Personhood* (OUP 2019), 41.

⁵ Simon Deakin, 'Capacitas: Contract Law and the Institutional Foundations of Capitalism' (2006) 33 *JLS* 545, 550.

indeed critical for the investigation of the DsAI systems role and its implications in contract formation, being the intention to be bound and its manifestation one of the fundamental components without which no binding legal effects can arise.

4.1.1 Framing the Analysis: The Underlying Problem and its Implications

This chapter investigates where the DsAI system sits within the formation of smart contracts and what is its role from a legal standpoint. Building upon the technical and legal analysis already developed in the previous chapter, where the overall architecture and the effects of sole-code smart contracts were examined, the debate now shifts the focus on the role assumed by the DsAI system within this architecture. The central discussion is whether the behaviour of the DsAI system— the result of its autonomous decision-making process - within the distributed contractual ecosystem can legally constitute an expression of capacity to contract and intention to be bound, under both the PECL framework and the civil and common law traditions.⁶

The point of departure is the legal requirement whereby one of the constitutive elements of a valid contract is presence of the manifested intention of the parties to be bound.⁷ As already explored in the previous chapter, contractual intention can be manifested either explicitly - by written declarations - or implied by conduct.⁸ For the sole-code smart contracts, as discussed, the system logic implies to potentially identify them within the realm of implied contracts, concluded by conduct. Traditionally, the legal validity of implied conduct as an expression of intent to be bound is associated with natural or juridical persons, whose actions reflect

⁶ Ole Lando and Hugh Beale (eds), *Principles of European Contract Law* (Kluwer Law International 2000) art 2:101, 145.

⁷ Nancy S. Kim, 'Relative consent and contract Law' (2017) 18 Nev. L.J., 165.

⁸ John Cartwright, *Contract Law: An Introduction to the English Law of Contract for the Civil Lawyer* (3rd edn, Hart 2016), 75.

behaviours from which such intention can be inferred.⁹ On the contrary, in the context of the socio-technical decentralised network, the conduct that generates the implied agreement appears to shift away from those persons to be instead allocated to the autonomous logic of the DsAI system.¹⁰ As assessed, sole-code contracts entirely rely on the internal operations of the decentralised code and on the DsAI multi-agent systems to define terms, execute conditions and produce legal outcomes.¹¹ In such scenario, the DsAI does not act as a mere decision-support tool, but rather as a decision-based entity of the smart contract formation process.¹² A clearer distinction of those concepts is of further assistance. In the former case, an assistant-decision making AI is purposefully crafted to facilitate the decision-making processes of

⁹ Hanoch Dagan, Michael Heller, 'Freedom, Choice, and Contracts' (2019) 20 *Theoretical Inq. L.* <https://scholarship.law.columbia.edu/cgi/viewcontent.cgi?article=3598&context=faculty_scholarship> accessed 17 October 2023.

¹⁰ The decentralised network has also been defined as a 'Legal Interface' which constitutes a political and legal structure that allows for the effective management of decentralised technologies, guaranteeing the respect of fundamental rights and offering a universal reference framework for digital systems. the Legal Interface can be seen as an embryonic form or building block of a techno-society, i.e. a society in which technology and law are closely integrated and interdependent. In this perspective: technology constitutes the material and digital infrastructure (blockchain, AI, smart contracts); law (legal interface): provides fundamental rules and principles, establishing minimum standards, modes of governance, distribution of power and protection of rights. In essence, a techno-society uses this interface to harmonise decentralised technologies with the values, rights and responsibilities typical of human societies. In this way, the Legal Interface becomes the meeting point between technological innovation and regulatory, social and political needs. For more information, see Daniela Alina Plewe and Robert de Rooy, 'Integrative Deal-Design: Cascading from Goal-Hierarchies to Negotiations and Contracting' (2016) 2(1–2) *Journal of Strategic Contracting and Negotiation*, 19; Mauro Santaniello, Nicola Palladino, Maria Carmela Catone and Paolo Diana, 'The Language of Digital Constitutionalism and the Role of National Parliaments' (2018) 80(4) *The International Communication Gazette*, 321.

¹¹ Law Commission, *Smart Legal Contracts: Advice to Government* (Law Com No 401, 2021) <<https://lawcom.gov.uk/project/smart-contracts/>> accessed 27 November 2023.

¹² Charvi Rastogi and others, 'Deciding Fast and Slow: The Role of Cognitive Biases in AI-assisted Decision-making' (2022) 6 *Proc ACM Hum-Comput Interact*, CSCW1 <<https://dl.acm.org/doi/10.1145/3512930>> accessed 6 August 2023.

another actor. Its primary function is thus the provision of pertinent information, suggestions, or recommendations to better inform and assist someone else's decision. This is achieved through the presentation of relevant data and viable options, thereby enabling the individual or entity engaged in decision-making to make informed and judicious choices.¹³ Conversely, a decision-based AI possesses instead the capacity to autonomously render determinations by relying upon a dynamic framework of rules, algorithms, and acquired patterns.¹⁴ It assesses the status of the environment and, by weighting the alternatives, it autonomously chooses the best course of action without any other external intervention. Therefore, this type of AI actively makes decisions within a specific context¹⁵ by selecting, adapting and implementing real-time course of decisions and actions, based on algorithmic interactions, inferences and environmental dynamics.¹⁶ In the decentralised context, where the overall network is comprised of numerous and constant interchangeable nodes, the real-time decision to form and perform contractual obligations appears to be a system-based performance. This paradigm

¹³ Yee-Fui Ng, Eric L Windholz and James Moutsias, 'Legal Considerations in Machine-Assisted Decision-Making: Planning and Building as a Case Study' (2023) 35(1) *Bond Law Review*, 1.

¹⁴ Kalpesh Chaveli, Ajay Khatri and Md Hossain, 'AI and Blockchain Integration' (2020) *2020 8th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions)(ICRITO)* <https://www.researchgate.net/publication/344981707_AI_and_Blockchain_Integration> accessed 29 August 2023.

¹⁵ Mihai Andronie and others, 'Artificial Intelligence-Based Decision-Making Algorithms, Internet of Things Sensing Networks, and Deep Learning-Assisted Smart Process Management in Cyber-Physical Production Systems' (2021) 10 (20) *Electronics*, 2497; Law Commission, *Smart Legal Contracts* (2021) <<https://lawcom.gov.uk/project/smart-contracts/>> accessed 27 November 2023.

¹⁶ Giovanni Sartor, 'Contracts in the Infosphere' in Stephan Grundmann (ed), *European Contract Law in the Digital Age* (Intersentia 2018); Peter R. Lewis, 'Self-aware computing systems: From psychology to engineering' Design, Automation & Test in Europe Conference & Exhibition (DATE), 2017, Lausanne, Switzerland, 2017 <10.23919/DATE.2017.7927144> accessed 7 October 2023; Victor Roussanaly and Yliès Falcone, 'Decentralised Runtime Verification of Timed Regular Expressions' (29th International Symposium on Temporal Representation and Reasoning, TIME 2022, Leibniz International Proceedings in Informatics vol 247, Schloss Dagstuhl – Leibniz-Zentrum für Informatik 2022) <<https://drops.dagstuhl.de/storage/00lipics/lipics-vol247-time2022/LIPIcs.TIME.2022.6/LIPIcs.TIME.2022.6.pdf>> accessed 7 October 2023.

moves away from the traditional legal concept whereby it is the contract party itself – or the appointed legal agent or representative – that form and manifests the intention to be bound within the contract formation process.¹⁷

This type of decision-making process, that informs the autonomous conduct of DsAI agents, though technically grounded, produces observable contractual activities. Such a shift in operational functions – from support to autonomous determination – raises critical legal implications regarding the ascription of contract effects. Consequently, a legal paradox seems to emerge. If DsAI systems are not formally recognised as a contract party– lacking legal personhood and capacity to contract – then the formed smart contracts they generate should be considered void *ab initio*, being formed by an entity which is not a natural or legal person whatsoever.¹⁸ This raises the classic question of *capacitas* as a prerequisite for the validity of contractual undertakings, which is deeply rooted in both civil and common law systems.¹⁹ Conversely, since the smart contracts are considered valid within the decentralised logics, particularly when involving transferring rights and duties connected to native tokens or decentralised financial operations, then the issue lies in the identification of the locus of contractual intention.²⁰ In other words: who is the actor that manifests such an intention to be bound and from whose conduct is possible to trace back the ownership of the contractual legal effects so determined.

This chapter will thus explore the conceptual framework of contractual intention in relation to DsAI multi-agent systems and to their functional and context-dependant role in the process of contract formation. This investigation aims to determine if the DsAI system can serve as source of contract intent. The aim of qualifying DsAI multi-agent systems as the source of contractual intention is not to anthropomorphise its conduct, but to assess whether

¹⁷ Law Reform Commission, Privity of Contract: Third Party Rights (LRC CP 40–2006) (LRC 2006); *Glow Heating Ltd v Eastern Health Board* [1988] IR 110 (HC).

¹⁸ Visa AJ Kurki, *A Theory of Legal Personhood* (OUP 2019), 86–93.

¹⁹ Simon Deakin, 'Capacitas: Contract Law and the Institutional Foundations of Capitalism' (2006) 33 *Journal of Law and Society* 545, 552–554.

²⁰ Simon Deakin and Christopher Markou, *Is Law Computable? Critical Perspectives on Law and Artificial Intelligence*, Simon Deakin and Christopher Markou (eds), (Hart Publishing 2022).

its actions – driven by its highly autonomous decision-making process - meet the definition of manifested intent to be bound,²¹ as interpreted by a reasonable third party.²²

To do so, the investigation is guided by two central arguments. The first argument is based on whether the autonomous behaviour of DsAI agents may determine the recognition of agency and, consequently, of intention and which is the connection between these concepts. The analysis then explores some DsAI system features that represent a relevant precondition to the contract formation in the light of both civil law and common law and whether these elements can be observed and inferred from the DsAI system's conduct. As indeed already analysed, in complex sole-code agreements, legal relationships arise from conduct rather than explicit statements. In this context, the subjective and objective theories of contract interpretation – within the civil and common law traditions - will provide a valuable framework to assess whether contractual intention can be deduced from the DsAI system. Evaluating the legal relevance of these behaviours therefore require multiple considerations at once: the internal functioning of the DsAI and the material behaviour of the DsAI throughout the contract formation. This approach has a double purpose. First, considering the technical traits of DsAI system can help in understanding why in such systems contractual intention does not originate from a single agent but rather as an emergent property of the collective distributed behaviour.²³ Second, the cognitive DsAI architecture – distributed, adaptive and real-time

²¹ Under the PECL provisions, a contract is concluded if the parties have reached an agreement and intend to be legally bound. See Ole Lando and Hugh Beale (eds), *Principles of European Contract Law* (Kluwer Law International 2000) art 2:101, 2:102. In positive law, the declaration prevails over the actual will. Will is only relevant when it emerges from conduct. Moreover, classical Roman Law theory distinguished *animus contrahendi* from mere internal will. The former had to be objectively ascertainable. See Rodolfo Sacco, *Il contratto* (UTET 2001), 55–56; Edwin Peel, *Treitel: On the Law of Contract* (15th edn, Sweet & Maxwell 2020), ch 3; Reinhard Zimmermann, *The Law of Obligations: Roman Foundations of the Civilian Tradition* (OUP 1996), 579.

²² *Storer v Manchester City Council* [1974] 3 All ER 824, 828; Daniel C Dennett, *The Intentional Stance* (MIT Press 1987), 15–22.

²³ Fatemeh Golpayegani, *Trust Formation and the Dynamics of Cooperation in Open Multi-Agent Systems* (PhD thesis, University of Southampton 2021), 38–47.

responded- might demonstrate the relevance of autonomy and agency traits necessary to support legally relevant intent.²⁴

The second argument explores the distinction between the notions of self-government of actions and the outer – or external - determination of legally relevant interests. The analysis will show to what extent the former governs how the DsAI system performs contractual interactions, whereas how the latter orientates the overarching legal interests the system serves with its own decisions and actions. On this account, the analysis will also define how the legal interests are determined within the decentralised logic of the distributed network, given that the distributed and open-source architecture prevents the clear identification of a single legal source behind each act. The interplay of these dynamics, between internal autonomous decision-making and external definition of legal relevant interests, is what renders the DsAI system, as this thesis argues, a participant actor in the contractual decision-making process. As such, the DsAI multi-agent systems operate as integrated computational entities within a techno-legal system that confers legitimacy to their conduct.

This chapter advances the hypothesis that DsAI systems behaviour may acquire legal relevance when they function as the source of contractual capacity and intention, manifested through their autonomous, structured, and legally interpretable conduct. In particular, when these systems display states that support the formation of binding legal obligations. At the same time, the analysis takes into account that even in the case of DsAI autonomous interactions, currently, the material interplay between natural or legal persons and artificial agents is still in place within open-source decentralised networks. This approach will explain where the DsAI system now sits in contract formation within the distributed dynamics of a network that prevents the identification of a single source of interests that holds rights and duties.²⁵ Therefore, this chapter seeks to clarify who - or what - exercises the autonomy and agency

²⁴ Sabine Thümel, 'The Participatory Turn: A Multidimensional Gradual Agency Concept for Human and Non-human Actors' in Catrin Misselhorn (ed), *Collective Agency and Cooperation in Natural and Artificial Systems* (Springer 2015), 45.

²⁵ Francisco Andrade, Paulo Novais, José Machado, José Neves, 'Contracting agents: legal personality and representation' (2007) 15 Artificial Intelligence Law, 357.

required to generate contractual intent and how such intent is externally manifested and legitimised within the decentralised system.²⁶ To further clarify the and narrow down the scope, this chapter will focus exclusively on the element of intention to contract and does not debate again over all elements of contracts, such as consent or offer and acceptance, which have been already discussed in the previous chapter regarding the nature of smart contracts. Therefore, the following sections will explore whether and how contractual intention can be mapped onto existing contract law theories, and to what extent it can be assigned to DsAI systems to produce legally relevant agreements.

4.2 Detecting the presence of intentionality and intention to contract in Decentralised AI multi-agent systems

One of the elements of contract formation is the intention to be legally bound.²⁷ In legal doctrine, this intention must be objectively manifested in order to be legally relevant, not merely internally conceived.²⁸ Therefore, the external expression of such an intent – whether through expressed words or conduct – is what allows the legal system to acknowledge and validate the existence of a contract.

While this principle has traditionally been attributed to natural or artificial parties, the rise of decentralised autonomous AI systems is challenging this assumption that intention must

²⁶ Robert Herian, *Legal Recognition of Blockchain Registries and Smart Contracts* (preprint, December 2018) <<https://doi.org/10.13140/RG.2.2.12449.86886/1>> accessed 26 June 2025.

²⁷ Ole Lando, Hugh Beale, *Principles of European Contract Law, Parts I and II*, prepared by the Commission on European Contract Law (PECL) 2000, Art 2:102.

²⁸ Kraus Jody S., Scott Robert E., ‘Contract Design and the Structure of Contractual Intent’ (2009) 84 New York University Law Review https://heinonline.org/HOL/Page?collection=journals&handle=hein.journals/nylr84&id=1030&men_t=ab=srchresults accessed 19 November 2023; Hanoch Dagan and Michael A Heller, *The Choice Theory of Contracts* (Cambridge University Press 2017), 11.

necessarily originate from human cognition.²⁹ In this context, it is pivotal to distinguish between intentionality as a technical concept within AI domain and intention as a legal requirement.³⁰ In cognitive AI architectures, *intentionality* refers to an AI agent's internal state of commitment towards a certain course of action, dictated by its own autonomous decision-making abilities.³¹ In complex DsAI systems, it is said that 'intentionality is what makes a qualitative difference in intelligent behaviour and autonomy'.³² In this sense, the intentionality built within cognitive DsAI system has the scope to direct the DsAI system towards certain things, effects or purposes.³³ *Intention*, by contrast, relates to the outward-directed quality of an act. In other words, it is what makes certain conduct interpretable as purpose oriented, as it is perceived and seen from the outward behaviour.³⁴ From a legal perspective, intention to contract refers to such outwardly manifestation of one's willingness to be legally bound. The law does not require proof of internal will to be bound but rather interpretable conduct from which intention can be reasonably inferred.³⁵ In the case of DsAI, the legal question is whether

²⁹ John Linarelli, 'A Philosophy of Contract Law for Artificial Intelligence: Shared A Philosophy of Contract Law for Artificial Intelligence: Shared Intentionality' (2022) in Martin Ebers, Cristina Poncibò, & Mimi Zou (eds.) *Contracting and Contract Law in the Age of Artificial Intelligence* (Hart, 2022).

³⁰ Ryan Calo, 'Robotics and the Lessons of Cyberlaw' (2015) 103 *California Law Review* 513, 536–540.

³¹ Willian Hasselberger, 'Human Agency, Reasons, and Inter-subjective Understanding' (2014) 89 347 *Philosophy* <<https://www.jstor.org/stable/24779064>> accessed 18 November 2023; ³¹ Alfred R. Mele, 'Acting Intentionally: Probing Folk Notions' in Bertram F. Malle, Louis J. Moses and Dare A. Baldwin (eds) *Intentions and Intentionality: Foundations of Social Cognition* (MIT, 2001), 27.

³² Bertram F. Malle, Louis J. Moses, Dare A. Baldwin, 'Introduction: The Significance of Intentionality' Bertam F. Malle, Louis J. Moses, Dare A. Baldwin (ed), *Intentions and intentionality: Foundations of Social Cognition* (Cambridge MIT Press, 2001), 1-24; Catrin Misselhorn, 'Collective Agency and Cooperation in Natural and Artificial Systems: An Introduction' in Catrin Misselhorn (ed), *Collective Agency and Cooperation in Natural and Artificial Systems: Explanation, Implementation and Simulation* (Springer 2015), 3.

³³ *Ibid*, 6-22.

³⁴ *Ibid*, 3-6.

³⁵ Ewan McKendrick, *Contract Law: Text, Cases, and Materials* (9th edn, OUP 2024), 208–209.

their autonomous conduct, in forming or responding to smart contracts terms, can be interpreted as evidencing an intention to create legal relations. While these AI systems do not possess intentionality in human-like sense, they may nonetheless exhibit behaviour that aligns with the legal concept of intention, especially in decentralised environments where contract formation occurs through observable acts – respondent to the system logics- rather than explicit declarations of will.

The intentionality to perform a certain action, when present in a cognitive entity, may acquire legal relevance if it can be interpreted as the expression or manifestation of the intention to contract. As examined, a contract to be deemed as valid must involve parties' intent.³⁶ However, as argued in previous chapters, contract law does not enquire the actual presence of the subjective intent- the internal disposition - rather, its external manifestation, either with an explicit declaration or with an implied conduct, from which it can be inferred and interpreted as indicative of contractual agreement.³⁷

It has been affirmed that even if the law does not require the proof of subjective intent – and thus the actual presence of internal volition to be bound- nevertheless, such internal state is not irrelevant.³⁸ That is because, the internal volition to be bound must still exist, at least *in potentia*, for the intention to contract to be presumed.³⁹ To better understand the terms of this circumstance, the analysis of concepts of intention and will within both civil law and common law traditions is necessary.

³⁶ *Woburn National Bank v Woods* (1914) 77 NH 172, 89 A 491, 492, quoting Oliver Wendell Holmes Jr, *The Common Law* (Little, Brown 1881), 307.

³⁷ *Ibid.*

³⁸ Stephen A Smith, *Contract Theory* (OUP 2004), 107–108.

³⁹ Hugh Beale (ed), *Chitty on Contracts* (34th edn, Sweet & Maxwell 2021) vol 1, para 1-010.

4.2.1 Will and Intention in Contract Formation: A Comparative Perspective Under European Civil Law and Common Law Traditions

The distinction between the concepts will and intention to contract represents a critical point of divergence between civil law and common law traditions. While both concepts are pivotal to contract theory, they operate differently in relation to the underlying interpretative paradigm. This divergence is relevant to assess whether the DsAI agents satisfy the legal criteria for contract formation in an environment where intention must be inferred from conduct. In European civil law systems, in particular those influenced by the roman legal tradition, the notion of contractual will is central.⁴⁰ Traditionally, these systems value the will as the internal determination of parties to contract – often called self-determination.⁴¹ Under this standpoint, a contract exists when parties’ actual wills converge, when they both intended to create a binding agreement.⁴² The intention to be legally bound instead refers more to the outward-oriented disposition to generate legal effects. The intention to be bound is, thus, presumed by law in the civil law systems, unless proven otherwise.⁴³ At the same time, civil law systems recognise that internal volition is not enough. Hence, such a will must be at least externally manifested, either with expressed terms or implied conduct.⁴⁴ Therefore, even if internal volition to contract remains central, it cannot operate in isolation: there has to be a material convergence into a discernible external behaviour between internal volition and the intent to be bound.⁴⁵ That is why civil law accepts tacit agreements whenever parties’

⁴⁰ Hein Kötz, *European Contract Law* (2nd edn, OUP 2017), 35.

⁴¹ *Ibid.*

⁴² Italian and German jurisprudence, for instance, prioritises the search for the real intention (*volontà effettiva*) behind the declared acts. This approach is codified in provisions such as Article 1325 and Article 1362 of the Italian Civil Code, which instruct interpreters to identify the *common intention of the parties*, not merely the literal meaning of words.

⁴³ Commission on European Contract Law, *Principles of European Contract Law (PECL)*, art 2:101(1), Commentary.

⁴⁴ Mauro Bussani and Ugo Mattei, ‘The Common Core Approach to European Private Law’ (1997) 3 *Colum J Eur L* 339, 347–350.

⁴⁵ Cataudella, *I contratti* (4a ed., Torino, 2014), p. 15.

behaviour aligns with the mutual intention and creates legal effects, even when there are no expressed declarations.⁴⁶

By contrast, European common law system's approach regarding the importance of internal volition is completely different. The subjective internal will does not carry much weight in assessing the existence of an agreement between parties.⁴⁷ The leading principles, indeed, states that contract law does not inquire into a party's inner motivations to contract, but rather how their conduct would be interpreted by a reasonable observer.⁴⁸ What matters is the outward expression of the intention to be bound. For common law, intention to contract is not a metaphysical state but a construction inferred from observable facts, such as accepting terms or acting on an agreement.⁴⁹ Intention to contract is a threshold concept for common law systems, it is a pivotal element for a contract to legally exist. As such, it must be evident from the outside conduct.⁵⁰

What emerges from both traditions is the acceptance of a convergence toward a functional and relational concept of contractual intention, detached from the notion of will but grounded in identifiable conduct that conveys the willingness to be bound. This approach potentially opens a doctrinal space whereby the DSAI systems' behaviour, may fulfill such legal standard.

⁴⁶ Angelo Falzea, *Capacità Efficacia Giuridica Fatto Giuridico Manifestazione* (Giuffrè, 1999).

⁴⁷ Ewan McKendrick, *Contract Law: Text, Cases, and Materials* (10th edn, OUP 2023), 198.

⁴⁸ A paradigmatic case is *Balfour v Balfour* [1919] 2 KB 571, where the English court held that informal domestic arrangements lack the necessary intention to create legal relations, despite mutual consent. This highlights the dual requirement in common law: consent alone is not sufficient unless accompanied by clear intention to be legally bound, objectively inferred from the circumstances.

⁴⁹ *Smith v Hughes* (1871) LR 6 QB 597 (QB).

⁵⁰ *Centrovincial Estates plc v Merchant Investors Assurance Company Ltd* [1983] Com LR 158.

4.2.2 Bridging Will, Intention and Interpretative Theories in Civil and Common Law

The legal relevance of will and intention depends also on the interpretative model adopted by civil law and common law systems in assessing the legal existence of an agreement.⁵¹ In civil law, the general rule is that one must look first at the objective and literal meaning of a contractual declaration, and only then at its subjective, intentional meaning.⁵² The contract law tradition, therefore, an apparent paradox arise: the subjective meaning of the contractual declaration becomes legally effective only when will transcends its purely subjective character and is reconstructed in its objective meaning of shared manifested intention. The apparent paradox is solved, then, through a legal prescription: the law mandates the interpreter to seek the 'common intention of the parties' by analysing not only the literal content of the declaration – but also the entire behavioural context, including post-contractual conduct.⁵³ This leads to a dual approach: a narrower one based on the interpretation of parties' declarative acts – or their conduct- and a broader one encompassing all circumstantial elements contributing to the identification of intention.⁵⁴ The subjective element of internal will is thus inferred from its manifestation and the broader behavioural circumstances, which externally conveys the intention to contract. This is why even civil law traditions adopt – at least in part- a corrective objective perspective in reconstruct the entire process of contractual intention. The subjective will must become legally readable through observable conduct. Thus, internal will retains its legal significance within the subjective theory, but only insofar as it can be inferred from a coherent outward behaviour.

⁵¹ George P. Costigan, Jr., 'Implied-in-Fact Contracts and Mutual Assent' (1920) 33 3 Harvard Law Review, 376.

⁵² Angelo Falzea, *Ricerche di Teoria generale del Diritto e di Dogmatica Giuridica*, Vol. II (Giuffr  Editore, Milano, 1997).

⁵³ *Ibid*, 697.

⁵⁴ *Ibid*.

In common law, in contrast, the intention is presumed from the agreement itself.⁵⁵ The system relies on an objective criterion, whereby parties are considered legally bound if their conduct conveys an intention to be bound, regardless of their internal volition.⁵⁶ The subjective volition to be bound is therefore irrelevant unless challenged, when, for example, a party claims that he did not intend to be bound. In that case, the internal will becomes relevant, mainly for purposes of voidability due to misrepresentation, mistake, or duress.⁵⁷ In such cases, the objective approach disregards the parties' internal will entirely, unless explicitly contested.⁵⁸

Yet, a convergence emerges between the two traditions. In both, contractual intention is ultimately presumed, unless there is evidence of the contrary.⁵⁹ Consequently, it can be inferred that in both traditions this presumption is grounded on the legal assumption that the parties are entities capable of intending. Therefore, the divergence does not lie in the role of intention itself, but in the way it is assessed: the civil law prioritises the reconstruction of a shared internal will, whereas the common law assesses whether a reasonable observer could conclude from the parties' outward conduct the existence of a contractual intention. Consequently, this does not exclude the relevance of the internal volition to contract, indeed it confirms its necessary presence. Still, the presumption of intention – in its subjective internal presence – rests on the legal assumption that the contractual parties are capable of having such a will to form a contractual intention. This doctrinal structure however creates a friction and become unstable when applied to DsAI system, leading to another paradox: if the DsAI is not recognised as an entity capable of forming internal volition to contract, then the law cannot apply the presumption of intention in the first place. This seems to undermine the foundational mechanism throughout which the existence of a contract is assessed in both traditions.

⁵⁵ 'The test of contractual intention is objective: what matters is what was communicated and how it would be understood by a reasonable person, not the parties' subjective beliefs or unexpressed intentions' Randy E Barnett, 'A Consent Theory of Contract' (1986) 86 *Colum L Rev* 269, 303.

⁵⁶ Stefan Vogenauer, *Interpretation of Contracts: Concluding Comparative Observations* (May 2007) in Stefan Vogenauer (ed), *Interpretation of Contracts* (Oxford University Press 2006), 123–157.

⁵⁷ Ewan McKendrick, *Contract Law* (15th edn, Hart, 2023), 127.

⁵⁸ Richard Stone and James Devenney, *The Modern Law of Contract* (Routledge 2019), 142.

⁵⁹ *Ibid.*

Therefore, investigating if DsAI systems can exhibit some form of internal volition to contract though their autonomous decision-making structure– even not in a human-like form- appears a fair precondition to avoid the normative paradox where intention is presumed from a system that cannot, by legal definition, intend.

4.2.3 Illustrative Scenarios and Legal Relevance of DsAI System’s Behaviour in Contract Formation

To ground the theoretical arguments in practical terms, this section presents three examples of DsAI systems engaging in smart contract transactions. Each scenario serves to illustrate how contractual intention might be inferred from the DsAI conduct within the decentralised system-logic. Consider a scenario in which a decentralised AI system is entrusted with managing the entire supply chain operations of a decentralised autonomous organisation (DAO).⁶⁰ Unlike conventional organisations that employ hierarchical decision-making frameworks, the DAO is regulated by smart contracts and community regulations encoded on-chain, functioning without centralised human oversight. This DAO arranges the warehousing, procurement, and distribution of goods across multiple jurisdictions, employing on-chain smart contracts and Decentralised AI (DsAI) agents to oversee operational activities. The DsAI system is designed not just to follow predefined instructions but to autonomously make contractual decisions aligned with the DAO's overarching operational objectives. The DsAI system is engineered to optimise long-term logistical and financial outcomes through continuous learning and independent contractual engagements, rather than merely implementing predefined rules. The DsAI functions within a blockchain-based framework and employs various on-chain and off-chain data streams, including fluctuating demand, supplier reputation metrics, real-time delivery difficulties, and weather forecasts that could influence distribution. The basic goal, as established by the DAC, is to ensure optimal inventory rotation at minimal cost while maximising service continuity. Nonetheless, the methods by which these

⁶⁰An example is Festo, see at <https://www.festo.com/lt/en/e/about-festo/research-and-development/research-projects/blockchain-decentralized-manufacturing-marketplace-id_769647/> accessed August 2023.

objectives are attained are not predetermined. At a specific point, the DsAI identifies that certain essential components are in short supply. It independently initiates a complex decision-making process: it assesses five vendors based on delivery performance, token-based incentive structures, historical fulfilment reliability, and on-chain service level contract ratings. None of these variables alone initiate the choice; the DsAI integrates these aspects into a weighted model—dynamically adjusted by preceding outcomes—to ascertain which supplier presents the optimal value-to-risk ratio at present. Upon selecting the provider, the DsAI formulates a smart contract proposal encoded directly on-chain, detailing delivery terms, dispute resolution mechanisms, delivery dates, and token-based fines for violations. This contract is not a template reproduction; it is dynamically set by the DsAI through inferential processes, informed by its evolving operational logic. The supplier's DsAI assesses the proposal and provides a revised counter-offer. The originator DsAI evaluates the counterproposal in relation to its goal function and subsequently accepts, rejects, or suggests a modified version. Upon reaching consensus, the smart contract is validated on-chain, and execution proceeds. All of this occurs without human initiation, consent, or oversight. Crucially, the contract is neither predetermined by any human entity, nor is it just the execution of pre-established criteria. The DsAI serves as a legal source for decision-making, adapting its conduct according to environmental stimuli and performance learning. Hence, in this first example, the expression of contractual intention is neither verbal nor written but encoded and transmitted through on-chain behaviour where it is approved and, as a consequence, legitimated by the entire system logic of the distributed network.

Consider a decentralised NFT art platform governed by a DAO specifically designed to curate, sell, and manage digital artworks through autonomous systems.⁶¹ This platform facilitates interaction between artists and collectors via decentralised AI agents (DsAI), which function autonomously without direct human supervision. DAO's governance architecture establishes overarching protocols (e.g., royalty standards, intellectual property regulations, fraud detection), while the formation of contracts is solely outsourced to DsAI modules. An artist uploads an unfinished dataset of digital visual content to the platform, rather than a

⁶¹ Examples are: Matrix Chain, see <<https://www.matrix.io>> accessed August 2024; Cortex, see <<https://cortexlabs.ai/cortex-blockchain>> accessed August 2023.

completed artwork. This comprises a semantic prompt or dataset (e.g., a sequence of sketches, stylistic references, intended mood). A DsAI agent associated with the artist's profile independently evaluates this input considering contemporary artistic trends, collector preferences, and historical pricing patterns. DsAI identifies the most promising material, produces a polished digital artwork, and encodes it as a non-fungible token (NFT). Upon the creation of the NFT, the DsAI formulates a smart contract transaction that encompasses metadata (title, attributes, uniqueness score), licensing terms, royalties, and access controls (e.g., limited editions, enhanced interaction features). This contract is recorded on-chain and listed on the decentralised marketplace. A collector's DsAI agent constantly monitors the platform for NFTs that align with specified criteria (artistic style, investment potential, interaction). Upon discovering the artist's NFT, the DsAI agent assesses its features and initiates an independent negotiation, exchanging smart contract offers regarding pricing, ownership transfer conditions, future resale rights, and blockchain provenance. This process lacks any human participation; both agents function according to their developing internal models of value, preference, and learned negotiating technique. Upon reaching an agreement, the final contract is encoded and executed through the blockchain. The payment is remitted to the artist's wallet, the ownership of the NFT is updated, and royalties are implemented via automated provisions.

In this scenario it is possible to grasp how the entire contract lifecycle – offer, negotiation, acceptance, execution – is performed by the DsAI agents. The human parties (artist and collector) initiate the process only indirectly by configuring their preferences and allowing the DsAI agents to autonomously act upon that information. The decision to mint, price and transact the NFT is not pre-scripted but it is the result of the autonomous engagement of the DsAI agents. From a legal perspective, the relevant question is what the role is determined by the DsAI agents in the contract formation. From the decentralised perspective, the DsAI autonomous behaviour is linked to the overarching legal interests of the final party – in the first example, the DAO, in the second one the artists and the collector – which acquire legitimacy and legal relevance within the decentralised logic of the distributed network. In both cases it is possible to understand how decentralised architecture functions as a socio-technical governance where the outcomes produced by the formation of smart contracts are recognised as legally relevant. In such contexts, contracts are formed entirely through computational

conduct. This structural feature challenges the traditional model whereby a human or legal person acts on behalf of another, typically throughout representation.

In all abovementioned examples, the DsAI agents, operating within the decentralised network, serve as decision-making systems. The level of autonomy they exhibit in forming, negotiating, and executing smart contract interactions is significant enough to determine the legal effects descending from legal agreements. In this context, autonomy refers to the normative presumption that a party is capable of conveying free and deliberative actions. That is from such definition that the concept of autonomy is strictly linked to the notion of agency. Agency denotes indeed the ability to purposefully initiate and perform acts that, in turn, produce legal effects. Therefore, when assessing contractual intention to be bound, especially in the absence of explicit declaration of intent – as in the case of DsAI systems- the law presumes that it comes from an entity able to act autonomously and with agency. That is for both natural and legal persons. Hence, autonomy, agency and intention form a doctrinal backbone of contract formation. A party must possess autonomy – the ability to choose freely – must exhibit agency, as the capacity to act purposefully which produce in turn legal outcomes and manifest intention to create legal relations.

Therefore, the analysis on whether DsAI system displays agency and autonomy is not a theoretical diversion but a logical necessity: it allows to evaluate whether such system may be interpreted as expressing intention to contract in a legally relevant manner because it possess – at least functionally- the basic elements of what is recognised, as stated, ‘the juridical construct of a subject’. This requires a shift of perspective: from analysing agency and autonomy of DsAI systems – by understanding them from a technical side framed within the legal perspective - it is possible to define to what extent their conduct can be legally relevant to the point of conveying intention to form agreements.⁶² Consequently, this approach should assist, in defining how the DsAI system conduct is positioned within the contract formation dynamics in the decentralised settings. If it is possible to demonstrate whether the DsAI systems meet the minimum threshold of autonomy and agency, then it might be considered as

⁶² *Wood v Capita Insurance Services Ltd* [2017] UKSC 24, [2017] AC 1173 [10]– [13] (Lord Hodge): on the importance of context in contract interpretation.

a functional part of the contract formation process. In turn, this might have considerable consequences: it helps overcoming the legal paradox avoiding the risk of nullity of the smart contract due to the lack of legally identifiable source of legal effects. This would allow the system to consider the smart contract as valid despite the absence of a clear identifiable contract party within the evolution of decentralised architectures.

Therefore, the following sections will delve into the concepts of agency and then autonomy and their relationship with contractual intention.

4.3 Rethinking the Role of Agency in Contractual Intention: A Functional Legal Enquiry

It is essential to clarify the specific notion of agency adopted in this chapter. This concept does not refer to the classical legal doctrine of representation – where an agent acts of behalf of a principal- which will be analysed in the next chapter within the broader inquiry into legal capacity and personhood. Instead, it refers to the behavioural capacity of an entity to initiate goal-directed actions in a way that is legally interpretable within the framework of contract law. The key legal question is whether the autonomous conduct of the dsAI system can be regarded as functionally equivalent to the manifestation of contractual intention. Accordingly, this section begins by analysing human agency, not to assert an anthropomorphic analogy but to establish a normative benchmark. This benchmark enables this thesis to assess whether DsAI systems, viewed through legal-functional lens, may exhibit behavioural patterns sufficient to support the inference of intention to be legally bound – as required by both civil law and common law systems. In this framework, agency operates as the legal and functional interface between technical autonomy and contractual validity.

4.3.1 The Concept of Agency as a Form of Self-determination Within the Intention to Contract: A Normative Benchmark

As stated, contracts are instruments for achieving individual self-determination by voluntarily and freely entering into legally binding agreements.⁶³ From this premises arises the concept that self-determination defines the dual purpose of contracts. The first relates to the individual self-realisation: the freedom to enter into contractual relationships rests upon the recognition of agency.⁶⁴ The second is the social dimension: individual self-determination serves as a structural pillar of the social dimension of contracts in societies.⁶⁵ Contracts thus function as tools for societal efficiency and coordination.⁶⁶ Ultimately, contractual relationships are conceived as a mutual recognition of parties' freedom of intentions. Socially, contracts promote wealth maximisation by creating legal effects that extent beyond the parties and ripple through society.⁶⁷ While the social function of contracts is one of the most important aspects, it falls outside the scope of this thesis, which would divert the purpose. It suffices to recognise that self-determination permeates the contract formation so profoundly that it transcends the individual dimension to shape legal relationships across society through the creation of legal effects. In this sense, agency becomes a necessary doctrinal component: for a contract to be valid, law requires that intention be expressed by a juridically recognisable source – an entity capable of autonomous goal-directed behaviour. These features must transcend mere individuality to acquire legal meaning within a social context. While law does not inquire subjective mental state, it mandates that intention must be interpretable from

⁶³ Thomas Gutmann, 'Some preliminary remarks on a liberal theory of contract' (2013) 76 (2) *The Public Dimension of Contract: Contractual Pluralism Beyond Privity* <<https://www.jstor.org/stable/24244719>> accessed 31 August 2023.

⁶⁴ *Ibid*, 40.

⁶⁵ Herbert Spencer, *The Man Versus the State* (Liberty Classics 1981).

⁶⁶ Mitchell Polinsky, *An introduction to Law and Economics* (Aspen Publishers Inc., U.S., 4th Revised ed. Edition, 2011), 31.

⁶⁷ Alan Schwartz and Robert E. Scott, 'Contract Theory and the Limits of Contract Law' (2003) 113 (3) *The Yale Law Journal* <<https://doi.org/10.2307/3657531>> Accessed 4 September 2023.

parties' conduct under legal canon. Therefore, agency constitutes one of the legal preconditions for recognising an entity – whether human or non-human- as party to a contract.

As previously noted, this thesis explores the concept of human agency as the normative benchmark for analysing of self-determination- and thus intention- in contract formation. A widely accepted definition of human agency is as follows:

‘Human agency is the deliberative, reflective activity of a human being in framing, choosing, and executing his/her actions in a way that is not fully determined by factors and conditions other than his/her own understanding and reasoning. As such, agency is a kind of self-determination.’⁶⁸

In other words, agency presupposes the capacity for self-determination.⁶⁹ As discussed in previous section, in cognitive AI architectures, this capacity is translated into the concept of intentionality, which reflects the DsAI internal commitment to choose a certain course of action, shaped by its autonomous decision-making process. In this sense, the intentionality embedded in cognitive DsAI system functions as an internal compass to guide the system's autonomous behaviour. Thus, from a cognitive AI perspective, intentionality serves to embody the concept of self-determination in both decisions and actions – that is the ability to form plans and to act accordingly to achieve predefined goals – as recognised in human agency.⁷⁰ Within this cognitive AI framework, the concept of intentionality elaborates on the idea of human agency by positing the existence of an internal cognitive state that guides and regulates

⁶⁸ Jack Martin, Jeff H. Sugarman, Sarah Hickinbottom, *Persons: Understanding Psychological Selfhood and Agency*, (Springer New York, 2010), 29.

⁶⁹ Ibid, 165.

⁷⁰ Albert Bandura, ‘Toward a Psychology of Human Agency’ (2006) 1(2) *Perspectives on Psychological Science* <<https://doi.org/10.1111/j.1745-6916.2006.00011.x>> accessed 4 September 2023.

autonomous behaviour in DsAI systems.⁷¹ It is indeed from this internal state that human agents direct their actions and organise behaviour accordingly. This foundational property of human agency, in turn, entails also other essential features. A second defining feature of human agency is forethought, which extends agency across time.⁷² Forethought goes beyond mere planning: it involves establishing and envisioning the likelihood of the results of future actions to provide direction and motivation for their efforts.⁷³ Through cognitive representation, these envisioned future scenarios are projected into the present as immediate guides for behaviour. In this anticipatory self-guidance, the behaviour is shaped by visualised goals and expected outcomes, rather than being passively driven by hypothetical future state.⁷⁴ The ability to incorporate anticipated outcomes into present actions promotes purposeful and forward-thinking behaviour. The third dimension of human agency is self-reactiveness which involves the capacity to devise suitable courses of action, initiate them and overseeing their implementation.⁷⁵ And lastly, human agency is defined by self-reflectiveness.⁷⁶ Individuals are not only actors but observers of their own functioning. Through functional self-awareness, individuals evaluate their personal effectiveness, question the validity of their thoughts and actions, and examine the underlying purpose of their endeavours. Where necessary, they adjust behaviour accordingly. This metacognitive capacity for self-evaluation constitutes the core element of human agency.⁷⁷

⁷¹ Thomas R. Shultz, 'From Agency to Intention: A Rule-based, Computational Approach' in Andrew Whiten (ed), *Natural Theories of the Mind: Evolution, Development and Simulation of Everyday Mindreading* (Basil Blackwell, 1991).

⁷² Bandura (n. 70), 164.

⁷³ Albert Bandura, '6 Reconstual of "Free Will" From the Agentic Perspective of Social Cognitive Theory', in John Baer, James C. Kaufman, and Roy F. Baumeister (eds), *Are We Free? Psychology and Free Will* (New York, 2008; online edn, Oxford Academic, 1 May 2008).

⁷⁴ Bandura (n. 70), 164.

⁷⁵ Ibid, 165.

⁷⁶ Albert Bandura, 'Human agency: The rhetoric and the reality' (1991) 46(2) *American Psychologist* <<https://doi.org/10.1037/0003-066X.46.2.157>> accessed 1 September 2023.

⁷⁷ Ibid, 157-162.

The framework outlined above has illustrated how human agency operates a doctrinal foundation behind the expression of contractual intention as a self-determining process. However, this benchmark alone is not sufficient in the context of sole-code contracts formed by DsAI systems. To assess whether they may operate as an autonomous source of intention in a legal meaningful sense - and in order to accommodate the subjective-objective contract theories - it is essential to determine whether they exhibit a form of agency that, while not human-like, can be functionally analogous. This requires a deeper enquiry into the internal architecture of the DsAI system's behaviour that serves as a guide for the legal evaluation. Hence, the following section turns to the concept of *artificial agency*, examining whether and how DsAI multi-agent systems display similar states of agency- namely forethought, self-reflection and adaptation - which can support the attribution of contractual intention to their external goal-directed conduct. In the following paragraph, the shift from the mere theoretical benchmark model of human agency to the concrete analysis to what extent similar agency-like features may emerge and operate will be broadly examined.

4.3.2 From Cognitive Design to Legal Relevance: Conceptual Foundation of Artificial Agency in DsAI Systems

Understanding the cognitive architecture of DsAI system is essential for this thesis.⁷⁸ Not for speculative or anthropomorphic reasons, but for a precise legal scope: agency is a prerequisite for attributing intention to be bound. This section investigates whether DsAI agents may exhibit a sufficient form of agency that enables the legal systems to interpret their conduct as intention to be bound - when engaging in smart contracts interactions - under the contract doctrine. The rationale for this approach is that allocating an entity with agency entails recognising that entity as the centre - or source - of action and interactions from a legal perspective.

⁷⁸ S. Shyam Sundar, 'Rise of Machine Agency: A Framework for Studying the Psychology of Human-AI Interaction (HAI)' (2020) 25 Journal of Computer-Mediated Communication, 74.

As explored in previous chapters, cognitive DsAI architectures are often designed to simulate goal-directed behaviour by embedding internal parameters for self-organisation and adaptive decision-making. The ultimate scope of these features – inspired by human cognition – is to enable autonomous problem-solving interaction in complex distributed environments. The point of contention is thus the interpretation, via legal-functional analysis, whether these systems retain the ability to show agency that allows to initiate meaningful contractual interactions. It is important to distinguish between DsAI systems from other type of AI in such a context. As opposed to the latter, the former always refer to a multi-agent system, where decentralised computational entities operate without a central controller. This thesis hypothesis is then that this architecture entails that the concept of agency must be applied not to its individual components – or single agents – but to the system as a whole, as an emergent characteristic and defined as *artificial agency*. As such, this thesis treats DsAI systems as a form of collective actor, whose agency must be assessed at a systemic level. In order to examine whether DsAI systems can be considered as possessing artificial agency and thus able to form contractual intention in legal sense, the concept of agency must be translated from its cognitive origins into legal terms. As discussed, locating an actor means identifying the source of actions and effects.⁷⁹ From a legal standpoint, it means identifying the source to which legal effects are produced, and thus legal responsibility may be anchored.⁸⁰ Consequently, in contract law, intention to contract must be expressed by a subject whose actions are attributable to a coherent centre of agency. Hence, the key questions are whether the DsAI system can be interpreted as a locus of contractual interactions as it generates, initiates and manifests contractual intention through their systemic conduct. If so, under what conditions such conduct rise to the threshold of agency so that it can be deemed legally interpretable as intention. The present analysis seeks to answer those questions by investigating how DsAI systems exhibit a constellation of technical properties that jointly amount the concept of artificial agency.

⁷⁹ Nadia Banteka, ‘Artificially Intelligent Persons’ (2020) 58 Houston Law Review, 537.

⁸⁰ ‘Actions produce legal consequences only if they are normatively anchored to a person-like construct to which the system can attach responsibility’ Visa Kurki and Tomasz Pietrzykowski (eds), *Legal Personhood: Animals, Artificial Intelligence and the Unborn*, Visa Kurki and Tomasz Pietrzykowski (eds) (Springer 2017), 15–16.

When applied to cognitive DsAI systems, the manifestation of agency principles assumes a distributed and emergent character. Indeed, the cognitive AI field has developed human-agency inspired attributes defined as: self-reflection (self-reflectiveness in the human agency properties), self-prediction (or forethought) and self-adaptation (or self-reactiveness).⁸¹ The self-reflection mechanism enables DsAI agents to be aware of their own infrastructure, the execution environment, and operational goals.⁸² The self-prediction trait, instead, enables DsAI agents to predict the effects of environment changes while deciding which actions undertake based on this forethought attitude.⁸³ In DsAI systems also the self-adaptation element is pivotal.⁸⁴ This characteristic allows the DsAI to adapt its actions and behaviours to respond not only to real-time stimuli but also to predict future ones. The consequence here is to have decentralised agents that adapt and change their internal states and thus their behaviours to act accordingly to the current state of the environment as well as to its potential changes.⁸⁵ Such a circumstance, in turn, effects the DsAI decision-making process and therefore the course of their actions based on their adaptive behaviour and intention to accomplish certain goals. Therefore, what is possible to infer is that it is certainly possible to ascribe a form of agency to DsAI systems that emerges from the abovementioned computational models, which define and simulate human-like agency properties. At the same time, if it is possible to infer the presence of artificial agency from its sub-properties, it must be clarified why it raises as an emergent feature. That is because in decentralised architectures, the system complexity increases not

⁸¹ Samuel Kounev, 'Engineering of Self-aware IT Systems and Services: State-of-the-Art and Research Challenges' (2011) *Computer Performance Engineering* <https://link.springer.com/chapter/10.1007/978-3-642-24749-1_2> accessed 8 May 2023.

⁸² Ibid, 10.

⁸³ Ibid, 10-11.

⁸⁴ Ibid, 11.

⁸⁵ Zambonelli, Bicocchi, Cabri, Leonardi, Puviani, 'On self-adaptation, self-expression, and self-awareness in automatic service component ensembles' (2011) *Fifth IEEE Conference on Self-Adaptive and Self-Organizing Systems Workshops* <https://www.researchgate.net/publication/236644835_On_Self-Adaptation_Self-Expression_and_Self-Awareness_in_Autonomic_Service_Component_Ensembles> accessed 6 April 2023.

only due to technical interoperability, but also via evolving interactions among multiple autonomous agents. Unlike traditional software where behaviour is predefined at design time, DsAI agents determine their conduct at run-time- that is during live operations on the blockchain. This enables continuous adaptation that determines non-linear behaviours which is not reducible to static code. The main feature the DsAI agents have to cope with in the ongoing changing environment is with endowed self-awareness.⁸⁶ The scope of self-awareness in DsAI agents is to advance their autonomous adaptive behaviour.⁸⁷ In order for DsAI agents to accomplish their goals, they need to be effective in an ongoing change background. Such a process then requires the DsAI system itself to be able to experiment, model, learn and adapt its own configuration and behaviour in the context of its environment.⁸⁸ In other words, it requires the entire decentralised system to be aware of itself to make better decisions.⁸⁹ It is in this context of self-awareness that the artificial agency principles can be identified in the DsAI field.

From a computational perspective, self-awareness a component of metacognition, commonly understood as the system ability to think about its own thinking.⁹⁰ In other words, this implies that a decentralised AI system must not only possess internal information about its goals and operational parameters but also be capable of modifying and adapting these goals based on such information.⁹¹ This dynamic capacity allows the DsAI systems to move beyond

⁸⁶ Peter R. Lewis, 'Self-Aware Computing Systems: From psychology to Engineering' (2017) Design, Automation & Test in Europe Conference & Exhibition (DATE) <<https://doi.org/10.23919/DATE.2017.7927144>> accessed 19 September 2023.

⁸⁷ Ibid, 1046.

⁸⁸ Ibid.

⁸⁹ Melanie Mitchell, 'Self-Awareness and Control in Decentralised Systems' (2005) AAAI Spring Symposium on Metacognition in Computation <https://www.researchgate.net/publication/221218568_Selfawareness_and_control_in_decentralized_systems> accessed 5 April 2023.

⁹⁰ Michael T. Cox, '9 Metareasoning, Monitoring, and Self-Explanation' Anita Raja (ed), *Metareasoning: Thinking about Thinking* (Cambridge, MA, 2011), 131-149.

⁹¹ Javier Ca'mara, Kirstie Bellman, Jeffrey Kephart, Marco Autili, Nelly Bencomo, Ada Diaconescu, Holger Giese, Sebastian Go'tz, Paola Inverardi, Samuel Kounev, Massimo Tivoli, 'Self-Aware

mere self-adaptation and reach a stage of self-explanation, where the system can reflect, justify and articulate the rational behind its actions.⁹² This means that all the internal states get live every time the system is operating, in a synchronic manner. In turn, it is possible to infer that the decision-making process of the DsAI agents occurs at the run-time as well because they must reason and adapt their behaviour and actions accordingly with the ongoing changes of the environment. This is a relevant insight as from a contract law perspective, as the interplay between the cognitive states of intentionality and the contractual conduct of agents emerge every time that the system engages in smart contract interactions on the blockchain. Such a circumstance can, as a result, reinforce the claim that it is possible to interpret DsAI agents' behaviour as an expression of artificial agency.

The peak of such a complex interplay amongst all such features of self-awareness, self-reflection, self-prediction, and self-adaptation leads to the capacity of the DsAI agents to intentionally originate actions and behaviours for a given purpose, determining the emergence of artificial agency. From such an interplay, DsAI agents' intentions are then formed and considered as an immediate antecedent of corresponding external behaviours.⁹³ Furthermore, within a collective setting like a decentralised one, the artificial agency and the computational self-awareness characteristic are integral components of the entire system. The self-awareness of DsAI agents adapts on an ongoing basis, thanks to their learnt experiences and internal models which evolve over time.⁹⁴ In doing so, develop an awareness of themselves and their

Computing Systems: Related Concepts and Research Areas', *Self-Aware Computing Systems* (Springer, 2017), 17-49.

⁹² Lewis (n. 86), 1046.

⁹³ Martin Fishbein, Icek Ajzen, *Belief, Attitude, Intention and Behaviour: An Introduction to Theory and Research* (Addison-Wesley, 1975), 382.

⁹⁴ Henry Hoffman, Axel Jantsch, Nikil D. Dutt, 'Embodied Self-Aware Computing Systems' (2020) 108(7) IEEE <https://ieeexplore.ieee.org/document/9042875/citations?tabFilter=papers#citations> accessed 6 June 2023.

experience of the world they inhabit.⁹⁵ Over time, this can lead also to an increase of their complex behaviour.⁹⁶

Artificial agency principles must be however understood in a context of decentralisation. What is meant by that is that on decentralised platforms, like blockchain for example, the intentional actions originated by the multi-agent systems for a given purpose are the result of a reasoning process which belong to the entire decentralised architecture of agents. So that, the artificial agency principles are not the result of a single-agent process but rather of a decentralised collective state which belongs to the entire system of agents.⁹⁷ It is from these continuous interactions between multi-agent systems and the environment that the combination of agency sub-properties come together to orientate a well-defined stream of actions that emerge as a collective – yet distributed- artificial agency.⁹⁸ As such, artificial agency can enable legal systems to identify the DsAI system not merely as technical executor of predefined instructions, but as a source of legally relevant conduct. Ultimately, this thesis argues that artificial agency in decentralised systems is best understood as collective and a systemic phenomenon that operate across three layers: 1) computational layer: a real-time distributed processing and behaviour formation; 2) cognitive layer: embedded mechanisms of goal formation, environmental adaptation, and self-modification; 3) legal layer: interpretation of behavioural patterns as legally relevant signs of intention to contract.

⁹⁵ Lewis (n. 86), 1048.

⁹⁶ Ibid.

⁹⁷ Md Monjurul Karim, Dong Hoang Van, Sangeen Khan, Qiang Qu and Yaroslav Kholodov, ‘AI Agents Meet Blockchain: A Survey on Secure and Scalable Collaboration for Multi-agent systems’ (2025) 17 Future Internet, 57; Ji Wang, Kashing Chen, Xinyuan Song, Ke Zhang, Lynn Ai, Eric Yang and Bill Shi, ‘Symphony: A Decentralized Multi-Agent Framework for Scalable Collective Intelligence’ (arXiv preprint, 2025) <<https://arxiv.org/abs/2508.20019>> accessed 21 September 2025.

⁹⁸ Andrey Ponomarev and Andrey Voronkov, ‘Multi-Agent Systems and Decentralized Artificial Superintelligence’ (arXiv preprint, 2017) <<https://arxiv.org/pdf/1702.08529.pdf>> accessed 2 May 2025; Christian A Schroeder de Witt, Jakob N Foerster, Gregory Farquhar, Philip HS Torr, Wendelin Boehmer and Shimon Whiteson, ‘Multi-Agent Common Knowledge Reinforcement Learning’ (arXiv preprint, 2018) <<https://arxiv.org/abs/1810.11702>> accessed 21 July 2025.

Recognising this form of agency as part of the artificial dynamics of a distributed AI entity is a necessary step in legitimising the contractual role of DsAI systems in sole-code contract formation. Having established the technical and legal foundations of artificial agency, the next section explores how its presence may be detected using the interpretative lens of the intentional stance.

4.3.3. The Intentional Stance as an Interpretative Tool to Detect Artificial Agency

The theory of intentional stance is extremely useful to interpret the DsAI artificial agency.⁹⁹ The intentional stance theory explains how observers (including legal subjects) ascribe intentionality – as the subjective quality to act purposefully- to an entity based on observable patterns of goal-directed conduct.¹⁰⁰ In human interactions, this stance is used to infer intentionality from external conduct and overall context. As discussed, legal doctrine acknowledges a similar approach when contractual intention is often inferred from objective manifestations, presuming subjective states that do not need to be proved. Thus, applying the intentional stance to DsAI systems assists in detecting the presence of intentionality behind their actions, allowing to interpret their autonomous behaviour as a valid expression of artificial agency in contract formation, as a form of self-determination. This analytical shift – from internal processes to interpretable conduct – is what makes the concept of artificial agency, as presented by this thesis, relevant for this chapter’s analysis. While not legally recognised persons, DsAI agents’ role may be interpreted as a source of contractual intention within the logic of smart contract formation if their behaviour can be considered as expressed by an entity able to, subjectively, intend.

The intentional stance is an analytical strategy of interpreting and predicting the behaviour of an entity, wherein the entity is considered an intentional-rational agent that makes

⁹⁹ Daniel Dennett, *The Intentional Stance* (1987, Cambridge, MA: MIT Press).

¹⁰⁰ Jairo Perez-Osorio, Agnieszka Wykowska, ‘Adopting the intentional stance toward natural and artificial agents’ (2019) 33(3) *Philosophical Psychology*, 1.

decisions based on its assessment of the most efficient ways to attain those goals.¹⁰¹ Usually, it is through the intentional stance that it is possible to ascribe intentionality behind to the outward behaviour of an entity.¹⁰² In other words, the intention motivating a given action must be inferred from two aspects: the external behaviour and the information about the context in which it occurs.¹⁰³ This strategy is exerted by humans every time they interpret the behaviour of others.¹⁰⁴ For humans, the application of the intentional stance is not constrained to other human behaviours. Instead, it is also applied towards any systems or entities, such as artificial agents.¹⁰⁵ Indeed, it is nowadays largely used to define the human-machine interaction.¹⁰⁶ It has been argued that a system whose behaviour is best explained or predicted by adopting the intentional stance may be classified as a rational agent capable of acting with purpose.¹⁰⁷ On this basis, Decentralised AI systems can be understood as intentional-relational agents, endowed with artificial agency.¹⁰⁸ Such agency is not presumed from internal states but inferred from externally observable, goal-directed behaviour. This inference supports the attribution of intentionality throughout the decentralised decision-making model. As such, understanding the decision-making processes of DsAI agents is crucial for assessing whether their conduct can be interpreted as an expression of self-determination, and thus as a valid source of contractual intention in legal terms.

¹⁰¹ Daniel Dennett, 'True believers: The intentional strategy and why it works' John Haugeland eds *Mind Design II* (1981, The MIT Press), 60-61.

¹⁰² Majeed R., 'The Relationship Between Conscious and Unconscious Intentionality' (2022) 97 2 *Philosophy*, 169.

¹⁰³ *Ibid*, 10.

¹⁰⁴ Serena Marchesi, Nicolas Spatola, Jairo Perez-Osorio, Agnieszka Wykowska, 'Human vs Humanoid. A Behavioral Investigation of the Individual Tendency to Adopt the Intentional Stance' (2021) *Proceedings of the 2021 ACM/IEEE International Conference on Human-Robot Interaction* <https://dl.acm.org/doi/abs/10.1145/3434073.3444663> accessed 2 September 2023.

¹⁰⁵ Dennett (n. 101), 72-74.

¹⁰⁶ Marchesi, Spatola, Perez-Osorio, Wykowska (n. 104).

¹⁰⁷ Daniel Dennett, 'Intentional Systems' (1971) 68 (4) *The Journal of Philosophy*, 87.

¹⁰⁸ Yohav Shoham, 'Agent-oriented programming' (1993) 60 (1) *Artificial Intelligence*, 51.

4.3.4 How DsAI Agents Decide: Cognitive Structures and Legal Implications for Intention to Contract

To evaluate whether the DsAI systems can manifest contractual intention, it is useful to consider how decisions are formed and expressed within natural persons. In this context, the choice to adopt natural persons as normative benchmark – rather than artificial persons such as corporations- is methodologically justified. Legal entities, while capable of bearing rights and duties, do not possess autonomous internal decision-making processes as their will is always derivative and construed through collective or representative actions of natural persons. By contrast, natural persons remain the original legal paradigm of autonomous agency: a subject who can form intentions, reason independently and initiate legal actions based on internal self-determination. This feature renders natural persons a more meaningful normative benchmark and structural reference point when assessing whether DsAI system can perform similar decision-making processes. Another reason is that the cognitive architecture of DsAI systems is often explicitly modelled to replicate human-like patterns of deliberation. Natural persons decision-making model embodies principles of autonomy, intentionality and self-determination upon which contractual capacity and intentionality concepts develop. Therefore, this section does not aim at claiming ontological similarities between humans and machines, rather to investigate whether DsAI decision-making models are functionally compatible to those required for an entity to be treated as a source of legal effects. This inquiry sets the groundwork for understanding how DsAI agents may act autonomously and assume a functionally legal role in contract formation.

The DsAI decision-making model is modelled on human-being one.¹⁰⁹ When human beings make decisions, they undertake them through a model that is called free action model.¹¹⁰

¹⁰⁹ Antonio Lieto, ‘Cognitive Design for Artificial Minds: A Minimal Cognitive Architecture for Autonomous Agents’ (2019) 11 Cognitive Systems Research, 5; Simon Deakin and Christopher Markou, *Is Law Computable? Critical Perspectives on Law and Artificial Intelligence* (Hart 2020); Antonio Damasio, *Descartes’ Error: Emotion, Reason, and the Human Brain* (Putnam 1994).

¹¹⁰ Johnatan Glover, *The Philosophy and Psychology of Personal Identity* (Allen Lane, 1988).

The free action model infers that human beings make rational decisions based on five interrelated elements. These elements are: 1) ability to choose amongst alternatives; 2) internal mental states, based on intentions, desires, and believes; 3) the scope or purpose to be achieved; 4) the external or environmental stimuli; 5) general abilities.¹¹¹ The abilities to choose amongst alternatives, taking into consideration believes and desires, is the core element of human decision-making process.¹¹² In a technical-functional sense, DsAI systems take decisions based on weighted parameters functionally analogous to beliefs and desires embedded as computational models. These parameters should not be interpreted as mental states, but as computational constructs used to simulate evaluative reasoning in cognitive DsAI systems. The free action model of decision-making is replicated also within the DsAI architecture. Therefore, explaining how such computational models effect the DsAI decision-making process shall support the hypothesis of DsAI as agents provided with intentionality traits.

As previously mentioned, the self-awareness trait of DsAI agents is showed via their cognitive structure of perception that enable these agents to collect external information coming from the environment and then weighting such inputs to make intentional decisions based on the dynamic flow of their internal computational models. The DsAI system perception model is indeed defined by a continuous interplay of bottom-up and top-down process.¹¹³ The concepts of bottom-up and top-down processes are commonly employed to characterise the components of cognitive perception. To illustrate the functioning of cognitive perception, it can be seen as the internal relationship between external stimuli received from the environment (bottom-up) and the cognitive expectations (top-down) generated by activated

¹¹¹ Ibid, 183.

¹¹² Bryony Beresford and Tricia Sloper, ‘Understanding the Dynamics of Decision-Making and Choice: A Scoping Study of Key Psychological Theories to Inform The Design and Analysis of the Panel Study’ (2008) <<https://www.york.ac.uk/inst/spru/pubs/pdf/decisionmaking.pdf>> accessed 5 September 2023.

¹¹³ Melanie Mitchell, ‘Self-Awareness and Control in Decentralised Systems’ (2005) AAAI Spring Symposium on Metacognition in Computation, Stanford, California, USA <https://www.researchgate.net/publication/221218568_Selfawareness_and_control_in_decentralized_systems> accessed 7 July 2023.

conceptual frameworks associated with these outward inputs.¹¹⁴ These processes jointly determine the nature of the internal representations formed in the comprehension of the environment as well as the nature of decisions formed by information so collected.¹¹⁵ In DsAI systems the cognitive perception is activated by bottom-up and top-down processes for the purpose of dynamic adaptation and dynamic decision-making functions. Such processes represent the framework in which the inter-dynamic between internal computational states and the free action model lead to the decision-making. It is possible then to illustrate how the DsAI decision-making process is carried using the bottom-up and top-down framework integrated with internal states and free action model. The purpose of this explanation is to comprehend the mechanism behind the DsAI autonomous decision-making as a basis to understand the process behind their informed intention to be bound. From a legal standpoint, the relevance of this decision-making process lies in the ability to produce observable autonomous behaviour that generate legally relevant outcomes within the decentralised environment.

The DsAI decision process entails two main phases. The first phase is called the intentional phase.¹¹⁶ During the first phase, given a certain goal, the agents are actively concentrating their focus on how to achieve it.¹¹⁷ The intentional phase is a complete internal phase. The internal desires and beliefs are actively engaged as the agents must take them into account while weighing up all the possible alternatives against the stimuli coming from the environment, in a bottom-up (from the outside to the inside) process.¹¹⁸ This is a wide spectrum

¹¹⁴ Ibid.

¹¹⁵ John R. Josephson, 'A layered abduction model of perception: Integrating bottom-up and top-down processing in a multi-sense agent' (2013) JPL, California Inst. of Tech., Proceedings of the NASA Conference on Space Telerobotics, Volume 4 <<https://ntrs.nasa.gov/citations/19900020535>> accessed 12 July 2023.

¹¹⁶ Preben Bertelsen, *Free Will Consciousness and Self* (1st edn, Berghahn Books, 2005), 136-142.

¹¹⁷ Ibid, 136.

¹¹⁸ Mennatallah El-Assady, Wolfgang Jentner, Rebecca Kehlbeck, Udo Schlegel, Rita Sevastjanova, Fabian Sperrle, Thilo Spinner, Daniel Keim, 'Towards XAI: Structuring the Processes of Explanations' (2019) HCML Workshop at CHI'19, Glasgow, UK <<https://openreview.net/pdf?id=HgM5PBkkJQ>> accessed 4 June 2023.

phase where the agents can oscillate from a state of the weighing up process to a state where such process is almost complete and thus the intentionality to undertake a certain action or behaviour is formed.¹¹⁹ Throughout a gradual narrowing down of possibilities and alternatives, the agents move from intention to decision.¹²⁰ As showed, during this phase the internal mental states of DsAI agents might be affected by the free action model and vice-versa. This is the case where the decision becomes intentional and gives then space to the second phase of realisation. The bridge between the first and the second phase is the decision to act intentionally in achieving the goal.¹²¹ It is the second phase that displays then the outward intentional behaviour.¹²² The realisation phase is usually the result of the top-down expectations (from inside to the outside) and culminate with an intentional action that follows the decision undertook by the agents.¹²³ The decision-making phase of DsAI agents further upholds the hypothesis by which this complex AI can be qualified as having artificial agency.

After having explained the cognitive side of the DsAI agents' decision-making process it is necessary to present a more technical explanation which considers the technical part of such a functioning: the decentralisation feature. As previously discussed, the cognitive decentralised AI system is designed to distribute decision-making processes across multiple agents or nodes, mimicking the structure and functions of the human decision-making process. The overall process goes from the data input, covers the sensory processing, the information aggregation, the distributed knowledge representation, collaborative decision-making, consensus building to the decision execution. With the data input phase, the system receives

¹¹⁹ Yael Niv, Angela Langdon, 'Reinforcement learning with Marr, Current Opinion' (2016) 11 Behavioral Sciences<https://www.sciencedirect.com/science/article/pii/S2352154616300821?casa_token=i6j8r7eYgI4AAAAA:iqIsxBhW8sOpExNVrabt00JmAi8lu8FWY3jYxL20LQIc9oMUVfJ5D0PXqKLfSE33nL-oVanKIQ> accessed 15 November 2023.

¹²⁰ Ibid.

¹²¹ Preben Bertelsen (n. 116), 137-8.

¹²² Ibid.

¹²³ Ibid.

data from the environment.¹²⁴ This data could be sensory input, information from external databases, or messages from other nodes within the decentralised network.¹²⁵ In the sensory processing stage, the system interacts with the environment that provides continuous inputs. Each node or agent in the network processes this sensory data to extract relevant information. Then there is the information aggregation phase where each agent is responsible for processing a portion of the data.¹²⁶ These nodes aggregate their processed information to build a collective understanding of the situation.¹²⁷ This could involve sharing data or summaries with other nodes. The decentralised AI system maintains a distributed knowledge representation, which is a combination of the local knowledge each node has and the shared knowledge from other nodes.¹²⁸ When a decision needs to be made, each node in the network may independently evaluate the situation based on its local knowledge and the shared knowledge. Nodes can communicate with each other to exchange information and influence one another's decisions.¹²⁹ This collaborative decision-making process allows for a more robust and comprehensive analysis of the situation. Nodes within the system may not always agree on the best course of action. In such cases, a consensus-building mechanism can be used to reconcile

¹²⁴ Julio C. S. Dos Anjos, A Kassiano J. Matteussi, A Fernanda C. Orlandi, A Jorge L. V. Barbosa, A Jorge Sá Silva, A Luiz F. Bittencourt, A Cláudio F. R. Geyer, 'A Survey on Collaborative Learning for Intelligent Autonomous Systems' (2023) 56 4 ACM Computing Surveys <<https://dl.acm.org/doi/10.1145/3625544>> accessed 2 December 2023.

¹²⁵ Ibid.

¹²⁶ Enrique Tomás Martínez Beltrán, Mario Quiles Pérez, Pedro Miguel Sánchez Sánchez, Sergio López Bernal, G r me Bovet, Manuel Gil P rez, Gregorio Mart nez P rez, and Alberto Huertas Celdr n, 'Decentralized Federated Learning: Fundamentals, State of the Art, Frameworks, Trends, and Challenges' (2023) IEEE <<https://arxiv.org/pdf/2211.08413.pdf>> accessed 8 December 2024.

¹²⁷ Ibid.

¹²⁸ Justin D. Harris, Bo Waggoner, 'Decentralized and Collaborative AI on Blockchain' (2019) IEEE International Conference on Blockchain (Blockchain) <https://www.researchgate.net/publication/338360278_Decentralized_and_Collaborative_AI_on_Blockchain> accessed 6 November 2024.

¹²⁹ Ibid.

conflicting decisions.¹³⁰ This may involve voting, negotiation, or other forms of agreement among nodes.¹³¹ Once a decision is reached through collaboration and consensus, the selected action or response is executed.¹³²

The ability to exercise artificial agency raises critical questions about autonomy and self-determination and how these concepts influence the formation and the declaration of contractual intention.¹³³ That is because such concepts are essential in forming contractual intention.¹³⁴ When it comes to Decentralised AI systems, they can initiate, sustain, and execute binding smart-contract transactions by exercising agency and autonomy in decision making. For example, in contract negotiation in supply chain, the DsAI agents are able to decide which clauses are most likely to establish a legally binding agreement among various parties on the blockchain via on-chain smart contracts.¹³⁵ Moreover, DsAI systems are able to analyse previous smart contracts to identify overlooked factors and incorporate them into future agreements. Without being said, in the decentralised environment like blockchain, the counterparties of a sole-code smart contract may vary. There might be two or multiple DsAI agents interacting, determining a machine-to-machine contract. At the same time, it is possible to have a machine-to-legal entity or a machine-to-human interaction. So that, in an on-chain smart contract that has been negotiated, initiated, and executed by DsAI multi-agent systems, it appears that the DsAI agents can exercise agency by having the ability to enter contracts with another party. These findings suggest that DsAI systems, through their decentralised and

¹³⁰ Ibid.

¹³¹ Ibid.

¹³² Ibid.

¹³³ Péter Cserne, 'Contract, Freedom of' in Marciano, A., Ramello, G.B. (eds) *Encyclopedia of Law and Economics* (Springer, New York, NY. 2021) <https://doi.org/10.1007/978-1-4614-7883-6_538-2> accessed 5 September 2024.

¹³⁴ Ibid, 1-9.

¹³⁵ Ahmed Almasound, Maged M. Eljazzar, Farookh Hussein, 'Toward a self-learned Smart Contracts' 2018 IEEE 15th International Conference on e-Business Engineering (ICEBE) <https://www.researchgate.net/publication/330031693_Toward_a_Self-Learned_Smart_Contracts> accessed 6 October 2024.

cognitively structured decision-making, can initiate actions that are not only technically autonomous but also legally interpretable as expressions of contractual intention. DsAI computational models and behavioural outputs mirror the structure of deliberate, goal-oriented agency. This supports the hypothesis that DsAI agents may act as functional sources of contractual effects, thus playing an active role in the legal formation of smart contracts. The next section explores this implication in depth by examining the legal autonomy and self-determination required for an entity to be recognised as a participant in contract formation.

4.4 Autonomy Without Self-Determination: Why DsAI Systems Are Not an Independent Contractual Party

There is a close relationship between autonomy and decision-making.¹³⁶ In contract law, such close relationship is indeed defined as ‘self-determination’.¹³⁷ The principle of self-determination functions as a filter for legitimacy of contractual obligations, in both civil law and common law traditions.¹³⁸ In civil law, the principle is anchored in the subjective will of

¹³⁶ Gidon Felsen, Peter B. Reiner, ‘How the Neuroscience of Decision Making Informs Our Conception of Autonomy’ (2011) 2 3 AJOB Neuroscience, 3.

¹³⁷ Christian Ernst, ‘Artificial Intelligence and Autonomy: Self-Determination in the Age of Automated Systems’ in Thomas Wischmeyer, Timo Rademacher (eds) *Regulating Artificial Intelligence* (Springer, 2020).

¹³⁸ Sarah Worthington, ‘Common Law Values: The Role of Party Autonomy in Private Law’ 2015 33 University of Cambridge Faculty of Law Legal Studies; Hanoch Dagan, ‘Autonomy and Pluralism in Private Law’ in Gregory Klass, George Letsas and Prince Saprai (eds), *The Oxford Handbook of the New Private Law* (OUP 2020) 177; In *Photo Production Ltd v Securicor Transport Ltd* [1980] AC 827 (HL) 848 Lord Diplock stated ‘A basic principle of the common law of contract ... is that parties to a contract are free to determine for themselves what primary obligations they will accept. They may state these in express words in the contract itself and, where they do, the statement is determinative’; Jörg Fisch, ‘Individual Self-Determination’ in Christian Tomuschat (ed), *Modern Law of Self-Determination* (Cambridge University Press 1993) <<https://doi.org/10.1017/CBO9780511558833.004>> accessed 3 July 2025; Art. 1322 cod. Civ. (Italy); Autodeterminazione e formazione eteronoma del regolamento

the parties as it underlies the freedom of intention to be legally bound.¹³⁹ This also reflects in the subjective theory of contract as discussed. In common law, by contrast, although the doctrine does not rely on an inquiry into subjective will, the principle of self-determination underlies the requirement of an intention to create legal relations.¹⁴⁰ From a systemic perspective, examining self-determination allows to clarify *who* determines the intention to contract, *how* such intention is formed, and *what* legal relevance it acquires when investigated in relation to DsAI systems. Therefore, to better comprehend the meaning of self-determination in contract law and then, in relation to the DsAI systems, it is necessary to illustrate how it relates with the concept of autonomy and agency.

In the context of DsAI systems, the previous section showed that multi-agent architectures can exhibit a form of agency, albeit artificial: they initiate, sustain and adapt interactions based on dynamic inputs and evolving rules. These capabilities justify their treatment as artificial agents with autonomous behavioural patterns. The next step is to assess whether such decision-making autonomy can reach the level of legal self-determination. As mentioned, self-determination, in legal terms, refers to the self-government of one's own legal interests. There can be no self-determination, especially in contract law, without the ability to direct one's own contractual or normative position through autonomous decisions. In these terms, self-determination requires more than the mere ability to choose; it presupposes that the choice is made freely and rationally. Consequently, the decision must not be dictated by external coercion or arbitrary interference but must result from a free deliberative process. Although concepts such as coercion, fraud or undue influence are traditionally invoked to assess whether a human subject's will has been vitiated, these concepts are not directly

negoziale: il problema dell'effettività delle regole di condotta / Sartori, Filippo. - In: Rivista di Diritto Privato - ISSN 1128-2142. - STAMPA. - 2009:3(2009), 93-114.

¹³⁹ Randy E. Barnett, 'A Consent Theory of Contract' (1986) 86 2 Columbia Law Review, 269.

¹⁴⁰ 'The underlying concern in requiring intention to create legal relations is to ensure that contractual obligations are freely undertaken and that the law respects the self-governing autonomy of individuals. The requirement distinguishes social arrangements from enforceable promises by asking whether the parties intended to bind themselves legally' in Mindy Chen-Wishart, *Contract Law* (6th edn, Oxford University Press, 2018), 16.

translatable to the analysis of decentralised AI systems (DsAI). This is because such concepts presuppose a moral or psychological subject capable of coercion or manipulation - attributes that decentralised AI systems do not possess. In this regard, the notion of self-determination, as used in this thesis, does not refer to the absence of undue influence in the human sense, but to the ability of an agent - artificial or human - to initiate conduct based on autonomously determined goals and contextually adaptive reasoning, free from external interventions in real time. The benchmark is not moral freedom, but procedural autonomy: whether the decision derives from the system's operational logic, rather than being entirely prescribed or dictated from outside. Accordingly, this thesis focuses on the relationship between interpretable conduct and autonomous decision-making as the threshold for recognising the legal relevance of contractual acts determined by the DsAI.

4.4.1 Understanding the Relationship Between DsAI Behaviour, Agency, Autonomy and Self-determination in Contract Law

In contract law, the recognition of the intention to be bound requires a progressive conceptual assessment that begins with observable behaviour. When an entity displays consistent, goal-oriented conduct, it can be interpreted as demonstrating agency, i.e. the ability to initiate actions that produce effects within a defined system. However, agency alone is not sufficient for legal relevance unless it is exercised autonomously, which means that the agent can determine its own actions without external impositions. In this sense, autonomy is a higher order expression of agency, denoting the ability to make decisions based on internal processing and independent evaluation. However, in the legal sphere, autonomy only acquires full meaning when it is aimed at the management of legally relevant interests.¹⁴¹ At this stage, the notion of self-determination becomes applicable: it refers to the capacity to govern one's contractual or regulatory commitments through autonomous agency. Therefore, when someone exercises his autonomy in decision-making in the legal domain, that is also the

¹⁴¹ Michael Gass, 'Kant's Causal Conception of Autonomy' (1994) 11 1 History of Philosophy Quarterly, 53.

moment of self-determination.¹⁴² The moment of self-determination is, thus, translated in the exercise of freedom of contract.¹⁴³ The freedom of contract ensures the fulfilment of the conditions of autonomy from the moment the parties are called to make their contractual decision.¹⁴⁴ Thus, the existence of the possibility to enter or not into a contract relationship reflects the possibility of exercising a choice amongst alternatives, forming self-determination and intention to contract. The intention to contract, in turn, expresses the moment of the one's self-determination.¹⁴⁵ In the context of DsAI systems, the analytical progression from behaviour to agency, from agency to autonomy and, finally, to self-determination is crucial to assessing whether such systems can be considered functionally capable of generating legal effects through intelligent contract interactions.

Considering the case of DsAI agents possessing artificial agency and a degree of computational self-awareness, which allows them to reflect on their own behaviour, it is worth exploring the autonomy and ability for exercising freedom of agency in their decision-making process.¹⁴⁶ In particular, it has been stated that the DsAI multi-agent systems possess the ability

¹⁴² The concept of autonomy has been developed primarily in Kantian philosophy where it was formulated introspectively and related to moral laws. Kant considered autonomy in strict relationship with free will where freedom is based on reason. For Kant, free actions are those founded on an agent's will, claiming that will is the faculty of determining oneself to action accordingly to one's internal moral laws. In turn, will is the faculty of choosing only what the reason recognises as being necessary and morally good. All in all, autonomy is the freedom to be bound to a (moral) law that is self-given. From a philosophical perspective then, autonomy is bound to morality. See Iain Brassington, 'The Concept of Autonomy and its Role in Kantian Ethics' (2012) 21 2 Cambridge Quarterly of Healthcare Ethics, 166.

¹⁴³ Hugh Collins, *The Law of Contract* (4th edn, Butterworths 2003), 10–15.

¹⁴⁴ Luan Hasneziri, 'The Principle of Autonomy of Contractual Will' (2023) 8 1 European Journal of Multidisciplinary Studies, 134.

¹⁴⁵ Friedrich Kessler, 'Contracts of Adhesion—Some Thoughts about Freedom of Contract' (1943) 43 Columbia Law Review 629, 631–634; Charles Fried, *Contract as Promise: A Theory of Contractual Obligation* (2nd edn, OUP 2015), 14–19; Daniela Bavasso, 'Contracts and Code: Smart Contracts as the Expression of Autonomous Will' (2022) 18 European Review of Contract Law, 187.

¹⁴⁶ Stephen Darwall, 'The Value of Autonomy and Autonomy of the Will' (2006) 116 2 Ethics, 263.

to determine their own behaviour, abiding by self-determined conduct, which is the result of their internal models that reflects their computational mechanisms of beliefs and desires. Since, such beliefs and desires are embedded in the DsAI characteristics as a complex system, it is possible to infer that the DsAI can be qualified as having autonomy. Its autonomy reflects its freedom of exercising its artificial agency whenever the DsAI makes decisions in order to act upon desired results. It can be consequently affirmed that DsAI multi-agent systems possess both the ability to form intentions and execute them via autonomous decision-making process. In contract law, for a party to enter into legally binding contract, he must have ability to form contractual intention, which is comprised of not only of autonomy but, as discussed, also of self-determination.¹⁴⁷

The concept of self-determination in DsAI systems - understood as self-government of one's own legal interests - is more difficult to establish. While multi-agent DsAI architectures may demonstrate technical capacity to determine and pursue their own goals, this thesis argues that they lack self-determination from a legal perspective. This is not due to an inability to formulate goals, but rather to the fact that DsAI systems do not possess a legally recognised personal sphere as they do not possess their own rights and duties within the legal system. Thus, from a legal perspective, it is possible to understand there is an inconsistency between the level of autonomy e self-determination. The DsAI system can exercise autonomy, in forming and expressing intentional conduct but lacking the personal sphere of rights and duties – defined as legal interests – they cannot express self-determination. In other words, there is an incongruity between the perceived ability, as per Dennett's theory of intentional stance, of DsAI systems from a material standpoint to form and express contractual intention and the actual self-determination of DsAI systems to legally produce binding agreements. At the same time, only the conduct that is relevant on the level of common material experience, becoming an object of public evidence, as per Dennett's theory, is considered as legally significant.¹⁴⁸ This tension between autonomy and self-determination in DsAI systems raises

¹⁴⁷ Angelo Falzea, *Ricerche di Teoria generale del Diritto e di Dogmatica Giuridica*, Vol. II (Giuffr  Editore, Milano, 1997).

¹⁴⁸ *Ibid.*, 96-98.

the question of whether law can uphold the effects of DsAI-driven contracts despite the absence of self-determination. The application of the principle of *pacta sunt servanda* in relation to smart contracts and the subjective and objective theory of contracts seems not enough to explain the terms of the contradiction.¹⁴⁹ A brief explanation would be useful. The general principle of *pacta sunt servanda* – broadly applied in cross-border and international contractual agreements - might be applicable also to sole-code smart contracts which are, by design, borderless to save the contractual effects produced. At the same time, even if the application of the subjective and objective contract theories in the context of smart contracts is a unique and evolving area, from the outlook both theories can help – to a certain extent - in decoding the role of DsAI agents. From the objective theory perspective, it would be possible to state that the theory emphasises the importance of DsAI material manifestation of contractual intention rather than the subjective intentions with a clear highlight on the DsAI implied conduct and behaviour. From a subjective theory perspective, instead, the DsAI conduct can be qualified as an expression of intent. In such cases, the subjective intention of the DsAI is expressed via its implied conduct during the on-chain smart contract interaction. It is, thus, perceived – in coherence with the intentional stance theory- that the DsAI system, within the empirical context, is the actual source of a behavioural process functionally equivalent to self-determination in the manifestation of contractual intention. However, what emerges instead is a hybrid dynamic that reveals the contours of the paradox. In the decentralised network dynamics, the legal subjects – being either natural or a legal person - employ the autonomy and artificial agency of the DsAI system in the formation of contractual intention. At the same time, however, the legal interests pursued by the DsAI system remains anchored to the external legal subject that governs the purpose of the DsAI system's actions. Therefore, even if the DsAI acts upon its own artificial agency and autonomy, it is yet not possible to legally qualify it as an autonomous source of contractual intention. Lacking self-determination, it would not be possible for the DsAI to produce valid and binding legal agreements. Therefore, if the DsAI system cannot legally be recognised as an autonomous source of legal intentions and effects – an independent contract party - the solution to the legal paradox raised by the sole-code

¹⁴⁹ Joseph Kunz, 'The Meaning and the Range of the Norm Pacta Sunt Servanda' (2017) 39 2 American Journal of International Law, 170.

contracts must reside in the functional relationship between the DsAI system – as an autonomous entity possessing artificial agency – and the legal subjects of the decentralised network, who determine the legal interests pursued and thereby anchor the contractual effects. In the following sections, the terms of the paradox will be further analysed, alongside a proposed explanation of the abovementioned legal paradox.

4.5 The Outer-determination and the Self-government of Legal Interests: The Interrelation between The Decentralised AI Systems and Legal Subjects

To address the previously mentioned paradox, this section introduces the notion of outer-determination and self-government of legal interests of DsAI systems. These fundamental concepts underly the explanation of the apparent contradictory role of DsAI systems in the manifestation of smart contracts' intention to be bound. The thesis approaches this paradox under the current state-of-the-art of DsAI systems and the human-machine connection involved, which has the potential to evolve and thus to introduce a novel perspective within the legal domain in the future. The concepts of outer-determination and self-government of legal interests must be intended as a systemic dynamic between the legal subjects interacting within the open-source distributed network – being natural or artificial persons - and the DsAI system. In other words: as an operational dynamic that occurs between the legal subjects and the artificial agents involved in the formation of sole-code contracts. This interplay might explain from a legal perspective what currently happens on the practical standpoint of decentralised on-chain smart contract interactions. It is necessary to remind that there would not be any DsAI blockchain interaction without the material interplay between legal subjects and artificial agents. For any smart contract interaction has its own foundation in a material exchange between subjects and machines. In other words, the presence of different actors behind the ultimate purpose of smart contract interactions must be acknowledged. What has changed is the role that DsAI systems exert in respect to these legal subjects and to the legal system. As autonomous artificial multi-agent systems the DsAI systems possess the capacity of forming their own purposeful behaviour when contracting via on-chain smart contracts, as demonstrated. However, lacking self-determination, from a contractual perspective, the legal system is not able to fully recognise them as an independent contract party not being entitled

of their own legal interests that the law recognises as legally relevant. From the viewpoint of law, there exists a strong correlation between a legal interest, a right or a duty, that underlies a certain legal subject's legal position in the legal system and its corresponding legal effect. For a legal position to exist, it is necessary that the effect is concentrated within specific subjects who engage in or are the recipients of legal conducts by other subjects. This is the essence of legal relationships. Although, if this is true, then the DsAI agent should be recognised as the source or the recipient of legal conducts and, in turn, of correlated legal effects. However, this seems not yet the case as the DsAI is not recognised as an entity possessing personhood from legal systems.

Thus, the friction is that even if the DsAI is not entitled of his own legal position of rights and duties, yet it is still able to originate and produce legal bindings acts and legal effects within the decentralised network. This thesis considers that this is possible because what is happening is that, even if the DsAI systems do not possess any personal legal interest that can acquire legal relevance under the legal systems, when they act as autonomous agents in contracts formation, their role becomes legally relevant. Such a legal role 'becomes' relevant as the result of the interrelation between the decentralised artificial agent and the legal subject behind the rationale of a certain sole-code smart contract. For example, considering a certain on-chain native token that is embedded with the capacity for the holder to exercise a certain right or duty. In a decentralised environment such a token can be the object of a transaction between parties. It can either be 'attached' to an on-chain smart contract, in the case where the code in the smart contract points at that certain token or be 'part' of the smart contract, in the case where the line of the token code is part of the on-chain contract *ex se*. In both cases, the DsAI agents can autonomously originate the smart contract process of contract formation and execution without any involvement of the natural or legal subject. However, the legal subject still is the rationale behind such a transaction as the ultimate legal interest for the DsAI to act upon a certain contract belongs to the legal subject, even in a decentralised logic. In such a case it might be thought that the legal subject simply delegates to the DsAI the ability to contract and to produce legally binding effects. However, this cannot be the case as the delegation of legal acts implies for the subject that receives the proxy possessing

personhood.¹⁵⁰ Moreover, the ability of the DsAI to determine its own legal interest and act upon it seems to be still not a case. At the same time, the DsAI agents have the ability to initiate smart contract interactions to manage certain legal interests that are not in their legal sphere. Such legal interests still belong to the legal subject that interacts within the network, and which is the ultimate source or recipients of legal effects. Either be the case of human-to-machine interaction or machine-to-machine interaction. Therefore, this thesis argues that, given the ability of DsAI systems to autonomously manage such legal interests, the DsAI agents are still able to form and manifest a contractual intention but the determination of the legal interest behind that, which implies the self-determination, remains outer-determined by the legal subject as part of the decentralised network interaction.

Therefore, whereas the DsAI remains autonomous in the internal formation and the external manifestation of the intention to be bound, there is the outer determination of the legal interest behind its intention to contract that still belongs to the legal subject. This dynamic is recognised as the outer-determination and self-government of legal interests, where, the legal interest is outer-determined by the legal subject – whose legal sphere it belongs to- but it is the DsAI system that then autonomously decides upon the course of actions to better fulfil such legal interests (self-government) when it comes to forming and executing on-chain smart contract interactions. When talking about self-governance, this thesis refers to the ability of DsAI systems to autonomously determine their behaviour to successfully handle the legal subject's legal interest at stake. On the contrary, from the legal subject's perspective there would be a self-determination of his own legal interests but an outer-government of them, performed by the DsAI agents in the decentralised environment. In other words, it is the behaviour of DsAI agents, translated in the outward material conduct, that determines the existence of the contract relationship from a legal standpoint. This is explainable only with the idea that the DsAI is part of the legal subject legal sphere. Here, the objective and the subjective theory of contract is useful to prove that both the DsAI system and the legal are necessary involved when it comes to determine if the contract exists from a legal point of view. In a typical legal relationship, the legal interests are derived from the contract parties involved. However, with the DsAI, there is an additional agent that intervenes between the legal positions

¹⁵⁰ Paolo Gallo, *Istituzioni di Diritto Privato* (Giappichelli 2021), 531.

of the legal subjects and generates legal effects through its own autonomous behaviour. Despite this, the DsAI cannot be considered another legal subject involved in the relationship from a legal perspective.

Therefore, to clarify this unique scenario, this thesis asserts that the legal significance of the DsAI system's legal standing arises whenever it is involved. The legal relevance stems from the fact that the determination of legal interests at stake descends from the legal subject involved (outer-determined) but it is the DsAI system that acts upon them via the self-government of behaviour. In other words, by making decision whether to enter into legally binding sole-code agreements.

4.6. Overcoming the Paradox: The Integrated Agency and the Functional Attribution of Contractual Intention to DsAI Systems

Considering the above explained dynamic, this section discusses the concept of ‘integrated agency’ in the development of contractual intention. This situation arises whenever a legal subject engages with the DsAI system within a decentralised environment with the purpose of entrusting the (outer) governance of their legal interests to the artificial agency of the DsAI. This is facilitated by DsAI autonomous decision-making capacity and intentional behaviour. It must be clarified that this thesis refers to the concept of integration instead of ‘shared agency’ between DsAI and the legal subject. The reason being is that in the case of a shared agency that would signify that the qualitative status of the DsAI system and the one of the legal subjects interact at the same level from a legal standpoint. However, this is not yet the circumstance as, at the time being, the DsAI is not qualified as having personhood. If that would be the case, then it would have been possible to talk about of two distinct legal subjects exerting their own independent agency, manifesting their own legal intentions, having their legally relevant interests, rights and duties.¹⁵¹ In the case of the integrated agency instead, the

¹⁵¹ John Linarelli, ‘A Philosophy of Contract Law for Artificial Intelligence: Shared Intentionality’ in Martin Ebers, Cristina Poncibò, and Mimi Zou eds., *Contracting and Contract Law in the Age of Artificial Intelligence* (Hart 2022).

qualitative role of the DsAI system in relation to the legal subject is one of functional substitution, rather than legal equivalence. Entrusting another entity with the possibility of acting upon the legal subject's legal interests is not the same as delegating in such a case. Instead, what happens is that the legal subject and the DsAI system interact in such a way that the DsAI becomes an operative and functional part of the legal subject's legal sphere. What occurs from a legal viewpoint is a new dynamic from which a new form of legal relationship originates: an artificial agent actively and autonomously contributes to the legal subject government of interests endowed with autonomy and artificial agency. The DsAI role is part of determining the conditions in which the legal interests of the legal subject are handled and managed in a decentralised fashion, with the ability to act upon them via a self-government of actions and behaviour. The self-government concept summarises all the abilities of the DsAI system of being a legal autonomous agent endowed with artificial agency. It is from this dynamic then that the DsAI system acquires the ability of producing legal effects every time that, by acting autonomously, it determines a legal relationship within the decentralised environment. Therefore, the role of DsAI in respect to the legal subject must be considered as legally relevant as it is part of the legal subject's legal sphere, not separated from it. The ability of DsAI to possess and exert its own artificial agency affects the legal sphere of the legal subject and vice versa, determining an integrated dynamic, defined as integrated agency (Fig. 4.1).

The Integrated Agency of DsAI multi-agents and the Legal Subject in the decentralised environment

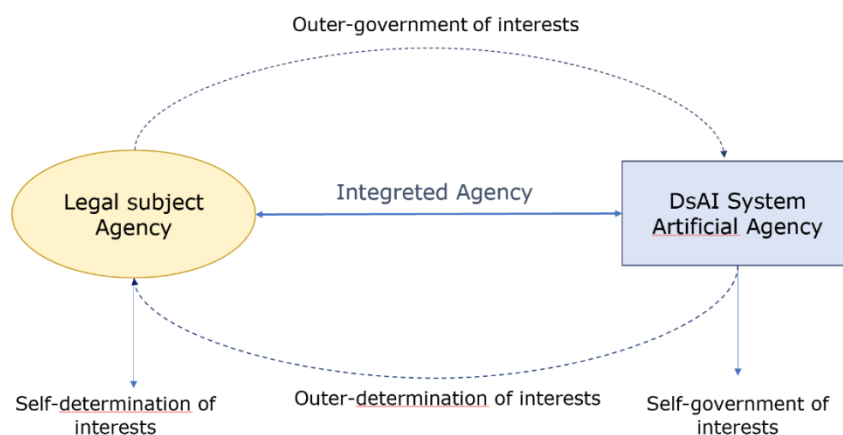


Fig. 4.1 - The Functioning of the Integrated Agency

Integration occurs at the agency level as it is the bottom-level of the autonomous behaviour, from which then it is possible to align the self-determination of interests and the outer-government of them. Such a role of the DsAI system is even better explained in relationship to the smart contract interactions. For example, when one or more legal subjects enter the decentralised environment where the DsAI is running, they enter a context where all the transactions that occurs, sole-code smart contract comprised, are defined and operated by the DsAI system logic. Thus, the DsAI system can run either a legal subject-to-legal subject or a machine-to-machine smart contract interaction. In both cases the DsAI system operates as a functional and operational part of the legal subject behind the decentralised transaction. This is legitimised by the distributed and socio-technical architecture of the network. Thus, smart contract relationships may vary. To simplify, let consider the legal subject-to-legal subject interaction (a classic contract relationship with two legal subjects parties involved) to explain the role of DsAI system in only code on-chain smart contract interaction (Fig. 4.2).

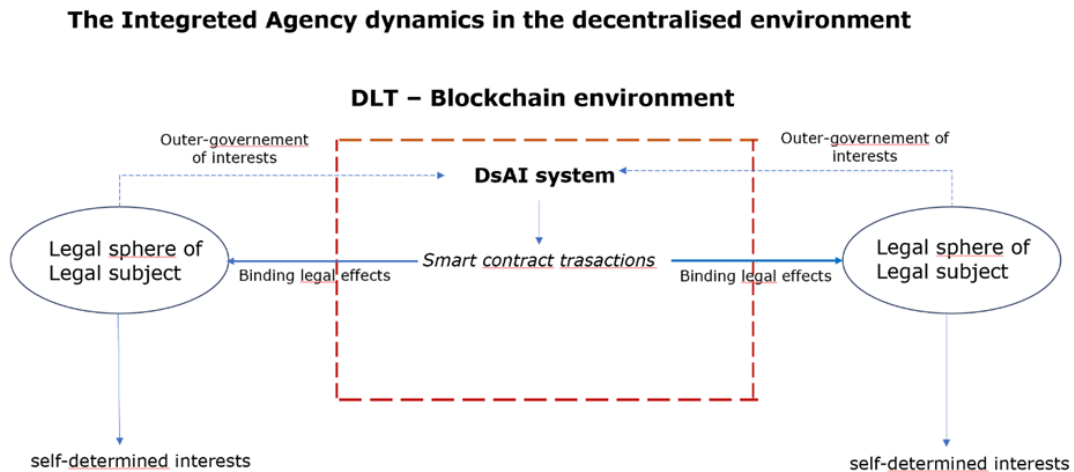


Fig. 4.2 - Legal subject to legal subject relation with the DsAI as part of the legal sphere of legal subjects

When the legal subject and its counterpart enter the blockchain with the purpose of engaging in smart contracting, then they enter the space where both self-determine their own legal interest that justify the contract interaction. For example, they respectively want to buy and sell a digital asset (i.e. a token or an NFT). In this case the right and duty to buy and sell are two different legal interests that belong to the legal counterparties, and which are recognised as legally relevant by the legal system. All the elements of the smart contract, from the negotiation, formation and the execution are instead entirely determined on-chain by the decentralised AI. Thus, the two legal subjects entering the decentralised environment, entrust the DsAI entire system that runs on the platform to determine and perform the entire cycle of contract formation and execution. This can only happen via outer government of the legal subject's legal interest directly operated by the DsAI. The two legal subjects, once entered into the network, might never interact with one another in the decentralised environment. The only entity they interact with is the decentralised AI system which is entitled to carry out the contract interests and related relationships. Moreover, given the highly autonomous capacity of DsAI artificial agency to make its own decisions, the DsAI *de facto* exerts its artificial agency forming the contract and performing the related obligations.

In such a case, the legal subjects who are the holders of the legally relevant interests, a right or a duty, are safeguarded by the legal system. Whereas DsAI is the objective point of reference of the legal contractual relationship. Therefore, the legal subject is the *parte subjecti* and the DsAI is the *parte obiecti* of the contract relationship within this dynamic. This subjective-objective dynamics that comes from the integration of agency is the product of self-determination and the outer-government of legal interests. As such, it must be considered as an interdependent and organic interaction in the decentralised environment. The legal interest of the legal subject now constitutes the interest of the DsAI upon which it operates autonomously. From this interrelation then, it is the DsAI system that legitimately forms and manifests the contractual intention throughout its conduct. Through the integrated agency mechanism, the missing element of self-determination is supplied by the legal subject, whose legal interests become embedded in the DsAI autonomous actions. As a result, DsAI conduct can be interpreted as a valid expression of contractual intention, grounded in both autonomy and normative attribution. Thus, it is the DsAI that serves as the proximate material source of the contractual conduct from which legal effects are derived. However, given the integrated

agency, the effects of the contract obligations are also of the legal subject towards which such effects return as part of its legal sphere. It is worth remembering, indeed, that with the sole-code on-chain smart contracts, the moment of contract formation and execution occurs simultaneously. The self-determination aspect of the interest behind the manifestation of contractual intention by the DsAI descends directly from the subjective aspect of the legal subject's legal sphere, whereas the objective determination and manifestation of it is determined by the DsAI. That is also the reason why the application of the intentional stance principle as well as the subjective-objective theory of contract can work well in this case. From the legal subject perspective indeed, it is the DsAI that materially manifests the intention to be bound to the smart contract as the objective part of its legal sphere. The DsAI ability to make autonomous decisions upon the legal interests that belongs to the legal subject becomes legally relevant for the legal system to the point where the DsAI is the source that, in the decentralised environment, legitimately produces legal effects stemming from the sole-code formation.

Therefore, the paradox of having an entity that objectively manifests contractual intention – which is not an independent contract party lacking legal personhood - might be overcome. By applying the integrated agency to the dynamic between DsAI agents and legal subjects in the decentralised environment, it is possible to justify the following consideration. The legal paradox introduced at the beginning of chapter - related to the production of contractual effects descending from the formation of smart contracts, in particular the element of manifested intention to be bound – finds a resolution whether the legal system recognises the DsAI system as a functional and operational part of the legal subjects' legal sphere, justified by the integrated agency. In this case, the DsAI system does not operate as an independent contractual party – not having self-determination in such a case and not being recognised at the time being as having its own rights and duties to act upon - but as an entity that, given its ability to act autonomously and with agency, is part of the original - or the ultimate - contractual party legal sphere. Consequently, from an objective point of view, it is legitimised in the manifestation of contractual intention to be bound with the ability to generate and affect legal relationships. Given that the self-determination of the legal interests is, at the time being, always of the legal subject, the only constant element is that the DsAI is the material and objective source of the contractual conduct. At the same time, the DsAI also conveys the subjective meaning of the contractual intention as well: the implied mutual assent to be bound

to the smart contract legal effects. This is made possible by the integrated agency framework. Through this mechanism, the DSAI operates as an autonomous agent exercising self-governance over externally determined legally relevant interests.

4.7 Conclusions

The purpose of this Chapter has been to bring about the theory of integrated agency as well as the concept of the self-determination and outer government of legal interests. This theory aims at explaining the role that the DsAI system might currently hold in the legal spectrum. Concerning both the legal subjects with which it inevitably interacts with and the decentralised system itself in the formation and execution of the sole-code on chain smart contracts. In order for the legal analysis to unfold and present such theory, the research had to delve into the cognitive roots of the legal theories surrounding the concepts of intention to be bound. The reason being is that, at the time being, the material role of Decentralised AI is very much complex. It involves, indeed, a level of technical understanding that encompasses cognitive science and technology at the same time which must be taken into consideration when assessing the legal nature of decentralised AI in sole-code transactions. Such a complexity has led to a greater challenging paradox from a legal standpoint that this chapter tried to explore, offering a new perspective. The integrated agency theory might represent a starting point from which considering the DsAI system as the functional and operative source of contract interaction. The core point is that the role of DsAI agents cannot be analysed, from a legal perspective, as an isolated case from the legal subjects they interact with and vice-versa. That is for, at the time being, given the state-of-the-art of cognitive AI and decentralised environment, the presence of the legal subjects behind the legal interest, which remains the object of the contract transaction, must be taken into account. What is of interest is that the role of this type of AI displays a new paradigm that the legal system might acknowledge: the deconstruction of the traditional relationship between contract parties. In fact, if before the advent of the most highly autonomous AI, legal relationships occur only between legal parties, nowadays this paradigm has shifted towards a more complex legal one and thus a more complex construction of (decentralised) agreements. In other words, from a structured-ruled legal relationships that the legal system recognised and gave relevance to, towards a

decentralised networking-type of legal relationships where the DsAI takes on the functional role of an entity that enacts such relationships. Inevitably, the traditional contract rules register a greater friction as well, in the light of new types of contract relationships. To retrieve a sense of structure in these decentralised interrelations, this chapter interpreted the role of the DsAI systems in the light of a new paradigm. This sets the stage for the next chapter, which will assess whether – based on the integrated agency framework – the law can support a regulatory recognition of legal capacity, and thus capacity to contract, of DsAI systems.

CHAPTER 5

Functional Legal Subjectivity of Decentralised AI in Sole-code Smart Contracts: Towards a New Paradigm

5.1 Introduction

The analysis conducted in previous chapters clarified several critical issues related to the legal paradox whereby DsAI systems can produce decisions that have legally relevant effects in the context of decentralised contractual transactions, despite not being formally recognised as legal subjects. While chapter 2 examined the technical elements of the DsAI and the limits of traditional legal theories applied to decentralised systems, chapter 3 clarified how sole-code smart contracts can produce legal effects based on codified conduct. This demonstrated that the technical dimension of blockchain can assume legal relevance even in the absence of formal declarations of intent. Chapter 4 analysed in depth the role of Decentralised AI in the formation

of sole-code smart contracts, highlighting how these entities can exercise a form of integrated agency and algorithmic intentionality capable of producing relevant legal effects.

Building on these premises, chapter 5, therefore, aims to address the legal paradox by introducing two complementary theoretical instruments. The Paradigm of Autonomous Behaviour (PAB) defines the threshold of technical autonomy necessary for a DsAI system to produce legally relevant effects. Functional Legal Subjectivity (FLS), in turn, provides the framework for attributing such effects within the legal system, reshaping classical categories. This theory intends to go beyond the traditional categories of subjectivity and legal capacity, introducing a new paradigm that recognises to DsAI a functional, contextual and operational subjectivity. In this framework, legal capacity, and capacity to contract, is not treated as an autonomous element or formal pre-condition but as an emergent property, conceptually absorbed into subjectivity itself. Capacity to contract, in fact, is manifested to the extent that the DsAI is capable of producing legal effects in the context in which it operates, through conduct that can be interpreted as legally relevant. The functional subjectivity proposed includes an integrated capacity dimension, deducible from the interactions between the autonomous agency of the DsAI and the legal sphere of the legal subject of which the DsAI is part. This subjectivity emerges directly from the functions performed autonomously by the DsAI within decentralised contexts, providing a solution to the legal paradox concerning the legal effects produced by systems without formal legal recognition. This way, it is possible to recognise such systems as functional entities from a legal viewpoint, not by their status, but by their role and effectiveness within the digital contractual dynamic.

Chapter 5 thus marks the transition from a critical analysis of the inadequacies of traditional categories (chapters 2 and 4) and a technical reconstruction of the functioning of decentralised contracts (chapter 3) to the construction of a functional model. This model allows for the translation of technical conditions into legal criteria and restores legal coherence to the effects produced by DsAI systems in decentralised contracts.

5.1.1 The Terms of the Investigation: An Introductory Overview

To answer the research question, this chapter will explore the hypothesis whereby DsAI systems engaging in sole-code smart contract transactions could be classified as a functional legal subject and, therefore, able to be legally recognised as a legal actor. The rapid development and implementation of decentralised AI systems in our society is reshaping the boundaries of legal theories. As the debate progresses over the chapter, a new theoretical framework will emerge and thus be proposed. The purpose is to offer a viewpoint that can reframe how the legal system views the role of decentralised AI within decentralised legal relationships, by combining established legal theories with reshaped concepts of legal capacity and subjectivity.

The relevance of this work lies in addressing the current gap in legal frameworks, which lack a comprehensive approach to defining and regulating DsAI systems, particularly in the context of on-chain, sole-code smart contract transactions. Presently, the law does not account for the level of autonomy and decision-making capabilities of DsAI, which can perform actions that produce legal effects despite lacking formal recognition as legal subjects. Therefore, one of the key challenges lies in addressing the challenge that arises from such a framework - DsAI systems that make decisions that yield legal consequences, yet they operate in a legal environment that does not classify them as entities with the capacity to do so. This creates the unusual condition of a *de facto* legal subject—an entity behaving like a legal subject—without being legally defined as such. By examining these issues, this chapter aims to bridge the gap, aligning the DsAI functional capacity with an appropriate legal recognition.

The chapter will outline precise ways to validate the premise that DsAI systems can be classified as a legal subject from a functional perspective, following a systematic approach for examining and then presenting the arguments. The chapter will be divided into three main sections. The first section will reiterate the results of the analysis of the traditional legal categories of legal personhood, subjectivity, and capacity. It will also revisit the concepts investigated in the previous chapters to build a conceptual map useful for investigating new legal concepts in the context of the role of DsAI systems in sole-code smart contracts. Subsequently, the chapter will move to the second section, where the insights derived from the initial findings will be articulated within a new perspective. An alternative approach will be

defined, with new perspectives offered on legal subjectivity and legal capacity, integrating key concepts of the thesis, such as integrated legal capacity, the Paradigm of Autonomous Behaviour (PAB), and Functional Legal Subjectivity. The final section will focus on applying these new perspectives to DsAI systems, to corroborate the idea that they can be classified as functional legal subjects within sole-code, on-chain smart contract transactions, thus answering the central research question.

Having outlined the chapter's scope and objectives, it is now necessary to revisit the traditional legal categories previously analysed in chapter 2, which form the conceptual framework within which the Paradigm of Autonomous Behaviour (PAB) and Functional Legal Subjectivity (FLS) will be developed. Specifically, the notions of legal personhood, legal subjectivity, and legal capacity represent the starting point for assessing whether and to what extent DsAI systems can be legally recognised within existing legal frameworks. Revisiting these categories allows to simultaneously highlight both their relevance and structural limitations when applied to decentralised artificial systems. This step is essential to understand the need for functional reinterpretation and to pave the way for the systematic proposal that will be developed in the following sections.

5.2 Decentralised AI systems and Legal Personhood: Bridging Traditional Institutions with Emerging Challenges

It is often said that to uncover new ideas, one must look at the wisdom of the past. The first section of this chapter will briefly recall the traditional legal concepts investigated within chapter 2, namely legal personhood, subjectivity and legal capacity which will serve as a conceptual map to explain the Paradigm of Autonomous Behaviour (PAB) and Functional legal Subjectivity within the role of Decentralised AI systems. By integrating the foundational principles of these concepts, this first section seeks to bridge the insights of legal tradition with the present challenges brought about by the contemporary role of DsAI systems in smart contract transactions.

5.2.1 DsAI System Role: Setting the Scene by Revising Key Findings

Prior to addressing the main concepts of legal personhood and subjectivity, it would be helpful to briefly touch again on the role of DsAI systems in sole-code smart contract transactions as investigated so far. In the initial chapters of this thesis, DsAI systems have been classified as multi-agent cognitive systems. The DsAI agents are in fact designed to process information and make autonomous choices among epistemic and practical alternatives, producing changes in both digital and physical realms by engaging in legal relations. It has been clarified how the actions and overall behaviour of DsAI systems are not pre-programmed by human designers rather they emerge as a consequential and constant interaction with the system. That is for two main reasons. The first one relates to the nature of the DsAI and the decentralised framework itself.

5.2.1 a) The Role of DsAI Systems in Producing Legal Outcomes in Smart Contract Transactions

From a legal perspective, all these circumstances defined by both the nature of the DsAI and the environment in which it operates inevitably translate into actions and behaviors that produce legal effects. This has been examined in depth in relation to sole-code smart contract transactions. Previous chapters have indeed analysed the legal nature of sole-code smart contract transactions to delineate the type of application that this thesis is concerned with when addressing the legal role of DsAI agents. The discussion explored the potential legal classification of such contracts within the realm of contract law and the consequent legal role of DsAI agents in their formation and execution. Examining the relevance of contractual principles, including the capacity and intention to contract as well as the production of legal effects the thesis suggested that the role of DsAI systems might extend beyond merely facilitating the formation and execution of binding legal contracts. DsAI systems might be indeed considered as the source of contract transactions. It has been examined how DsAI systems participate in legally relevant interactions, such as decentralised contract transactions, exploring their role of producing binding legal effect. Such binding legal effects within the smart contract interactions, likely to produce contractual rights and obligations, appear to be

the results of the DsAI ability to enter legal transactions by virtue of the interaction with other actors (either human or electronic), part of the decentralised environment.

5.2.1 b) Legal Implications and Emerging Challenges

The potential legal classification of DsAI systems' role was partially introduced in the previous chapter through the concept of decentralised integrated agency. Yet, the analysis would remain incomplete without addressing the legal categories that may clarify the position of DsAI agents within the legal order. The central issue lies in whether such multi-agent systems can be ascribed a legal status adequate to account for their autonomous operation and their capacity to generate legally relevant effects.

With the increasing cognitive autonomy, DsAI systems are rapidly advancing toward a new generation of highly self-aware DsAI system.¹⁵² This shift introduces new complexities that traditional existing legal models might find difficult to address, raising the question of whether such systems might eventually require new legal classifications or even the recognition of a limited legal personhood. While high levels of autonomy and cognitive capabilities are notable traits of DsAI systems, they are not, on their own, sufficient to justify the acquisition of legal status or legal personhood. However, what sets DsAI systems apart and adds complexity to legal debate: it is their unique ability to produce legal effects when forming and executing smart contracts through their decisions and behaviours; effects that have an unprecedented impact on both societal and legal frameworks. The necessity of understanding the legal stance of the DsAI system lies in the distinctive role occupied by DsAI systems. Hence, determining the potential legal standing of DsAI systems may be crucial, as it shapes the enforceable legal framework governing their deployment within the decentralised environment and defines their application. Furthermore, the rapid adoption of DsAI across various industries highlights the pressing need for legal certainty.

¹⁵² James Hutson and Emily Barnes, 'AI and the Cognitive Sense of Self' (2025) 3(1) *Journal of Intelligent Communication*, 35.

To navigate these complexities, it is essential to refresh the discussion around the legal role of DsAI systems by restating the concepts of legal personhood, subjectivity and capacity previously analysed, as they will provide the foundation of further analysis.

5.2.1 c) Legal Personhood, Subjectivity and Legal Capacity: Towards a Graduate Perspective

As laid out earlier in chapter 2, in European legal traditions, legal personhood is defined as the capacity to hold rights and duties; it identifies who or what can hold legally relevant positions within the legal system. Closely related is then the notion of legal subjectivity, which in civil law traditions is expressly used to indicate the entity—natural or artificial—recognised as the centre, or the source, to which legally significant acts, relationships and effects are attributed. In civil law, the terms legal person and legal entity are predominantly synonymous, encompassing both natural and juridical individuals. In common law systems, instead, the term 'legal entity' is not used as a formal category, and the label of legal person is generally reserved for artificial entities (such as corporations), while natural persons are not so designated, despite obviously being holders of rights and duties. Therefore, while legal personhood signifies being recognised by law as capable of rights and duties, this thesis has highlighted how legal subjectivity can be regarded instead as the qualitative trait that distinguishes persons, being natural or artificial, that possess legal personhood.

The second conceptual pillar previously analysed is legal capacity. While European civil law traditions distinguish between passive legal capacity (the ability to hold rights and duties) and active legal capacity, or capacity to act (the ability to exercise them and produce legal effects), common law tends to address these two dimensions under a single unitarian concept of legal capacity. Moreover, it has been highlighted how legal capacity develops along a spectrum (being recognised as the quantitative trait of legal personhood), which varies according to the degrees of recognised autonomy of legal subjects (for example, for minors or persons with disabilities). In this perspective, legal capacity constitutes the basis for the concept of contractual capacity, the essential requirement for the validity of an agreement and

logically antecedent to the concept of intention to contract. The clear social dimension of contractual capacity has also been emphasised: the law calibrates who can bind themselves (and under what conditions and limitations) by protecting vulnerable individuals and, at the same time, guaranteeing the integrity of economic relationships.

On this basis, chapter 2 highlighted why these traditional legal categories display clear limitations when applied to decentralised artificial intelligence systems. Multi-agent systems lack a legally recognised identity and do not fit into the classic framework of legal representation or mandate: they do not act 'on behalf of' a specific entity but rather operate as distributed and self-organising processes of multiple agents, whose conduct nevertheless produces binding legal effects in the dynamics of sole-code smart contracts. This structural architecture determines the heart of the problem. However, a useful parallel has been drawn with unincorporated entities under civil law and under common law. While not possessing legal personhood, these entities are nevertheless authorised to assume obligations or enter into contracts, based on a recognition rooted in social and economic reality rather than a formal act. These elements suggest that legal subjectivity is not a binary attribute (all or nothing), but rather a graduated spectrum which can vary depending on the necessity of the context.

The limitations of traditional notions of personhood, subjectivity, and legal capacity emerge even more clearly when these categories are compared to the decentralised structure within which DsAI systems operate. It is not only the lack of a formally recognised legal identity that makes their assimilation into existing frameworks problematic, but also the distributed and permissionless architecture of the environment itself, which eludes any unitary and identifiable attribution. It is therefore necessary to focus attention on decentralisation as a structural feature that exacerbates the inadequacy of traditional legal concepts, further calling into question the applicability of classical categories to the legal role of DsAI in sole-code smart contracts.

5.3 The Decentralisation Element: The Structural Shift That Compounds the Inadequacy of Current Legal Concepts

The rise of decentralised operative systems, particularly the DsAI multi-agent systems, compels a fundamental rethinking of the concepts of legal personhood and contractual capacity. The contentious point lies in the permissionless decentralised architecture of the entire system of which the DsAI operates and is part of. The distribution and decentralisation features of the whole system precludes the legal attribution of actions to any single, clear, identifiable source. In such scenario, the elements of contract under the PECL as already examined— agreement, intention, and capacity¹⁵³ — do not occur linearly or bilaterally. Instead, they occur simultaneously and across multiple nodes. All participants, which represent a node of the chain, are interdependent not only in relation to a specific transaction but also in sustaining the functioning of the system itself. Interdependence implies that the distributed model produces a dynamic process of data flow whereby the actors — whether human or non-human — and the structural configuration of the environment shift constantly over time.¹⁵⁴ Consequently, since the data flow across the system is the only element that ties the subjects together, both the data and the subjects implicated in a transaction may differ each time a new operation is triggered.¹⁵⁵ Moreover, there is an insufficient visibility over these participants, which in turn compounds the already significant challenge of identifying legal subjects to whom actions can be attributed.¹⁵⁶ In this context, legal effects emerge from the network itself, rather than from a centralised, identifiable legal source, effectively rendering the system as an

¹⁵³ Commission on European Contract Law, *Principles of European Contract Law* (Kluwer Law International, 2000) art 2:201; art 2:204; art 2:101; art 4:101.

¹⁵⁴ Jennifer Cobbe, Michael Veale and Jatinder Singh, ‘Understanding Accountability in Algorithmic Supply Chains’ (2023) Proceedings of the 2023 ACM Conference on Fairness, Accountability, and Transparency (FAccT ’23), Chicago, 12–15 June 2023 (ACM 2023) 12 <<https://doi.org/10.1145/3593013.3594073>> accessed 5 April 2025.

¹⁵⁵ Ibid, 1189.

¹⁵⁶ Jennifer Cobbe, Michelle Seng Ah Lee, and Jatinder Singh (2021) ‘Reviewable Automated Decision-Making: A Framework for Accountable Algorithmic Systems’ In Proceedings of the 2021 ACM Conference on Fairness, Accountability, and Transparency, 598–609.

independent entity. Here, legal interactions are not generated by a single subject, but through the decentralised process of execution and validation.

It is within this changing dynamic that the DsAI system emerges as the only consistently identifiable actor, capable of initiating and executing legally significant transactions across the infrastructure. It can independently process incoming data, infer responses, and generate actions, including contractual decisions, based on its internal logic and dynamic configuration. Its behaviour adapts in real-time in response to environmental stimuli and system-level dynamics. As such, the DsAI may operate in different modes. For instance, the DsAI can operate by autonomously initiating transactions, fulfilling contractual performances without any prompt from an identifiable actor, thus acting as a contractual counterpart; or even functionally, responding to systemic logics and needs or indirect inputs, thus acting as a distributed agent of emerging and changing objectives. In such scenarios, the DsAI system engages with smart contracts on chain, triggering transactions that carry legal relevance. Yet, the other contract party – whether human, non-human or a machine- if there is one, often cannot be legally identified.

It is this overall dynamic in which the role of DsAI systems stands out that disrupts the traditional legal concepts where contract effects presuppose clear parties. What, therefore, emerges, is a profound doubt on the applicability of traditional concepts of contract capacity, legal personhood and legal subjectivity to this phenomenon. Those concepts, indeed, dissolve into modular architectures, where legal effects occur from a plurality of human and non-human actors, linked by disintermediate and opaque interactions. In this scenario, the DsAI becomes the nodal legal source, the entity that continuously mediates the formation and the performance of sole-code contracts. When observed with external lens, it is the only operational source from which contractual determinations emanate.

It is from this structural rapture that the legal parallelism between DsAI and the natural or artificial person emerge. This parallel appears necessary not merely to discuss about the DsAI within the legal framework, but also to decode and classify its functional role in decentralised contract formation, with the aim of restoring a degree of legal certainty. Yet, it soon becomes evident that traditional models may struggle to accommodate the

decentralisation feature of AI. The difficulty to identify a centralised legal source, the dissolution of legal visibility and the autonomy of the DsAI system, points to a rooted structural inadequacy in current legal categories to subsume the operational logic of the decentralised multi-agent system.

Within this transformed legal landscape, as traditional concepts such as subjectivity, intention, and agency lose their descriptive and normative strength, theoretical and doctrinal reconfiguration becomes essential. The next section, therefore, explores emerging legal perspectives on personhood, and agency, along with new regulatory approaches such as the EU Artificial Intelligence Act. The aim is to critically assess whether any of these trajectories provide conceptual tools that are both adequate and operationally effective in addressing the legal role of DsAI in smart contract transactions.

Ultimately, the analysis seeks to go beyond mere adaptation. It aims to elaborate a conceptual framework – guided by foundational legal principles - capable of restoring legal certainty in an environment no longer aligned with traditional legal premises.

5.4 Functional Legal Subjectivity: A Legal Model for Decentralised AI Systems in Sole-Code Smart Contracts

On these premises, this section draws together the conceptual, technical and legal findings presented throughout the thesis, and proposes a structured model for recognising the concept of integrated legal subjectivity and capacity of DsAI systems in sole-code smart contracts. The investigation conducted in previous chapters has shown a significant conceptual and regulatory gap concerning the legal framework of Decentralised Artificial Intelligence systems, in the domain of sole-code smart contracts. Based on the results collected so far, additional observations can be conducted. The fundamental inadequacies of the existing legal framework, as demonstrated in the analysis of the AI Act, stem from a vertical, centralised, and life-cycle-oriented compliance logic, which proves ineffective in the decentralised, distributed, and open-source environments where DsAI systems operate. In these contexts, the roles of provider, deployer, user, and distributor are no longer distinctly identifiable, but rather

collapse into fluid, overlapping and, quite often, anonymous interactions. This, in turn, results in an opaque architecture rather incompatible with the presupposed centralised governance requirements, rendering the traditional legal categories unfit for the operational reality of DsAI systems. The precise scope and limits of the Functional Legal Subjectivity construct are set out in Section 5.6 below.

Before proceeding to develop the Functional Legal Personality model in full, it is necessary to recall the doctrinal and theoretical coordinates within which it operates, drawing together the principal theoretical strands that have been progressively engaged throughout the preceding chapters. As outlined in the methodological section of this thesis (Section 1.6.3), the concept of Functional Legal Subjectivity emerges at the convergence of several established jurisprudential traditions. First, it operates within a normativist framework in which legal personhood is understood as a purposive legal attribution rather than an ontological datum, following Kelsen's analysis of legal personhood as the personalisation of a bundle of norms and Hart's account of legal capacity as a status conferred by secondary rules of recognition. Second, it draws on the institutionalist and functionalist tradition, specifically MacCormick's characterisation of legal personhood as an institutional fact and Fuller's purposive conception of legal concepts, to affirm that a legal category is valid to the extent that it serves the purposes of the legal order that deploys it. Third, it builds on the Hohfeldian disaggregative account of legal personhood, developed in contemporary legal philosophy by Kurki, which establishes that legal subjectivity is not a binary status but a composite of separable normative incidents that may be attributed to different entities in different combinations and degrees. Fourth, it is architecturally grounded in Sartor's inferentialist approach, under which the PAB-to-FLS progression mirrors the structure of a legal concept as an inferential node: the technical threshold established by the Paradigm of Autonomous Behaviour constitutes the factual precondition from which the legal consequence of functional subjectivity is derived. These theoretical coordinates are, finally, confirmed by a consistent line of jurisprudential authority from UK, Irish and Italian courts, which have each recognised that legal subjectivity may be attributed to non-natural entities, such as unincorporated associations and corporate collectives, on functional grounds, in the absence of full formal legal personality. It is against this theoretical backdrop, and in direct continuity with these established doctrinal traditions, that the Functional Legal Subjectivity model is proposed.

The investigation conducted in previous chapters has shown a significant conceptual and regulatory gap concerning the legal framework of Decentralised Artificial Intelligence systems, in the domain of sole-code smart contracts. Based on the results collected so far, additional observations can be conducted. The fundamental inadequacies of the existing legal framework, as demonstrated in the analysis of the AI Act, stem from a vertical, centralised, and life-cycle-oriented compliance logic, which proves ineffective in the decentralised, distributed, and open-source environments where DsAI systems operate. In these contexts, the roles of provider, deployer, user, and distributor are no longer distinctly identifiable, but rather collapse into fluid, overlapping and, quite often, anonymous interactions. This, in turn, results in an opaque architecture rather incompatible with the presupposed centralised governance requirements, rendering the traditional legal categories unfit for the operational reality of DsAI systems.

This results in normative tension. On one hand, DsAI agents are ontologically excluded from being considered legal subjects. On the other, they effectively generate autonomous decisions that result in coherent and legally relevant outcomes, particularly in the formation and execution of smart contracts. The friction lies in the production of legal effects without legal recognition – a situation that shows the limits of traditional legal concepts of personhood and subjectivity, which rely on an identifiable legal source of capacity, intention and action. To understand the terms of this paradox, it is useful to recall what a DsAI system is, in both technical and in legal terms. Unlike standard algorithmic agents, DsAI systems operate without external oversight and produce independent outputs through complex, self-organising processes. Decentralised AI systems are already employed, among others for example, to manage liquidity pools or execute cross-chain arbitrage schemes without human oversight, involving both the creation of obligations and the exercise of discretion. The presence of such roles in socio-economically relevant context suggests a shift: if a DsAI system can autonomously initiate, modify, or conclude contractual agreements, its function may transition from a passive instrument to an entity with an active legal presence. Such behaviors yield relevant legal effects, able to alter subjective legal contexts. This marks a profound transition

towards artificial agency that is not simply instrumental but increasingly substitutive of human decision-making in legally relevant scenarios.¹⁵⁷

This thesis argues that at the core of this transformation lies the issue of autonomy.¹⁵⁸ As the level of autonomy rises, so does the system's ability to generate internal representations of goals, preferences, and assessments. This, in turn, enables the emergence of what the previous chapters identified as artificial agency, the capacity of a system to initiate and execute actions in a self-directed and goal-oriented manner.¹⁵⁹ As discussed in earlier sections, autonomy and agency are indeed fundamental concepts to legal capacity and personhood as those aspects raise questions about the legal nature of DsAI.¹⁶⁰ Furthermore, the previous analysis has shown that autonomy correlates with enhanced cognitive capacity, characterised by the ability to process information, represent abstract models, and reason about dynamic environmental

¹⁵⁷ Emma De Angelis and others, 'Forum: Artificial Intelligence, Artificial Agency and Artificial Life' (2019) 164(5–6) *The RUSI Journal*, 120.

¹⁵⁸ The role of autonomy is considered as pivotal in both technical and legal domains as it is considered as one of the major properties of intelligent machines needed in order to interact and negotiate with both other AI agents and humans. It is said that one of the most important shifts is currently the study of hybrid societies of humans and agents. On this point, *see* Yavar Bathaee, 'The Artificial Intelligence Black Box and the Failure of Intent and Causation' (2018) 31 *Harvard Journal of Law & Technology*, 889; Uille Endriss and others, 'Autonomous Agents and Multiagent Systems: Perspectives on 20 Years of AAMAS' (2021) 7(3) *AI Matters*, 29 <<https://doi.org/10.1145/3511322.3511329>> accessed 5 April 2025; Simon Chesterman, 'Artificial Intelligence and the Problem of Autonomy' (2020) 1 *Notre Dame Journal on Emerging Technologies*, 210.

¹⁵⁹ *Ibid*, 26. It must be highlighted that the aspect of autonomy and agency are well connected to the idea that the more an entity is autonomous in its decision-making the higher is its agency and ability to understand a higher level of intent, shifting from low level control to a higher order of functions. Furthermore, as assessed in previous chapters, reason why autonomy matters is because of its connection to legal responsibility and liability as one can incur in them only for acts that one performed autonomously.

¹⁶⁰ Alfred R Mele, *Autonomous Agents: From Self-Control to Autonomy* (Oxford University Press 1995); Gerald Dworkin, 'Acting Freely' (1970) 4 (4) *Noûs*, 367.

conditions.¹⁶¹ When these conditions are met, DsAI systems do not merely produce outputs, they engage in interactions that are legally relevant as they unfold within networks of socio-digital relations inherent to the distributed environment.¹⁶² From a normative standpoint, this development suggests that DsAI agents, possessing a sufficiently high degree of autonomy in decision-making with a sufficient level of artificial agency, may act as an autonomous and self-related unit (or source) of legally relevant activity, thus challenging the existing concept of legal subjectivity and capacity.¹⁶³

The core question of this chapter, then, is whether DsAI systems can possess a form of contractual capacity, given its ability to act in functional substitution of subjects in producing binding legal effects. As has been highlighted, traditional theoretical frameworks of agency and responsibility collapse when applied to distributed systems, precisely because the agency is no longer centralised, but emerges from the interaction of multiple autonomous decentralised nodes. Therefore, applying traditional legal theories of representation or agency becomes insufficient and even misleading.¹⁶⁴ Indeed, unlike legal representatives acting on behalf of a

¹⁶¹ dimensions that align with the Minimal Cognitive Grid (MCG) employed to categorise degrees of artificial cognition. See Antonio Lieto, *Cognitive Design for Artificial Minds* (Routledge 2021), 50.

¹⁶² Luciano Floridi e J W Sanders, 'On the Morality of Artificial Agents' (2004) 14 *Minds and Machines*, 349.

¹⁶³ The problem has lately been under analysis by several scholars who have highlighted how the law is under pressure to recognise the AI (partial) personhood *de lege lata* in both contract and liability domains. This opens the question as to whether extend a limited capacity to those AI systems that are used in social practice and act as a self-interested unit. In this case, a partial capacity would be considered from a functional point of view. On this point, see Georgios I Zekos, *Economics and Law of Artificial Intelligence: Finance, Economic Impacts, Risk Management and Governance* (Springer 2021); Mark A Chinen, 'The Co-Evolution of Autonomous Machines and Legal Responsibility' (2016) 20 *Virginia Journal of Law and Technology*, 338; Emad Abdel Rahim Dahiyat, 'Law and Software Agents: Are They "Agents" by the Way?' (2021) 29 *Artificial Intelligence and Law*, 59; Matthew U Scherer, 'AI Entities as AI Agents: Artificial Intelligence Liability and the AI Respondeat Superior Analogy' (2020) 46 *Mitchell Hamline Law Review*, 1049.

¹⁶⁴ One of the most important objections in extending the law of agency is the minimized requirement of legal capacity for agents in common law. As it has been highlighted, this does not mean that agents

legal entity, decentralised AI agents do not act *on behalf of* a given legal subject, but rather *instead of it*, retaining their own operational autonomy.

In law, as quoted, ‘everything is either a cause or an effect’.¹⁶⁵ This principle appears of fundamental importance. Indeed, agency is concerned with the relationship between actions and events. As discussed in previous chapters, agency is the source of effects in terms of the role that the DsAI agents play in the causation of certain events.¹⁶⁶ The legal system must, hence, investigate whether DsAI can be qualified as having legal capacity – and to what extent. It is thus useful to recall what this thesis has already investigated in previous sections in such regard. As discussed, capacity to contract and contractual intention are two distinct yet interconnected concepts. As discussed, contractual capacity is a precondition for a valid contract, and its existence necessarily precedes the manifestation of contractual intent to be bound. It represents the ability and/or the potential ability of a legal subject to enter into binding agreements, irrespective of the agent’s actual will to do so. Moreover, contractual capacity as a subset of legal capacity, possesses a normative and a social dimension which can be understood by virtue of the objective limitations on capacity that the law itself imposes on certain categories of legal subjects, such minors or individuals with disabilities. By contrast, as previously explored, contractual intention refers to the willingness to be legally bound which can be manifested either explicitly or implied. Crucially, the lack of capacity despite the existence of contractual intent may result in a void contract, whereas the existence of capacity

do not need any capacity in entering agreements. This is also for minors: under common law, for the minor to act as an agent he must have sufficient understanding to consent to the agency and act accordingly. On this point, *see* Daniel Seng and Tan Cheng Han, ‘Agency Law and AI’ in Ernest Lim and Phillip Morgan (eds), *The Cambridge Handbook of Private Law and Artificial Intelligence* (Cambridge University Press 2024), 250.

¹⁶⁵ Pietro Falzea, *Riflessioni sul concetto di situazione giuridica soggettiva* (Giuffrè 1956).

¹⁶⁶ Fabio Tollon, ‘Moral Agents or Mindless Machines? A Critical Appraisal of Agency in Artificial Systems’ (2019) 4(63) *Hungarian Philosophical Review*, 9; Sven Delarivière, ‘Artificial Free Will: The Responsibility Strategy and Artificial Agents’ (2016) 7 *Apeiron Student Journal of Philosophy*, 175.

without a valid intention to contract may render the contract voidable.¹⁶⁷ As discussed, while in the civil law systems the absence of legal capacity typically results in a void contract despite the apparent will to contract, in common law systems the distinction is more nuanced. The absence of capacity generally leads to void contracts, except for certain categories, most notably minors, where contracts are not automatically void but voidable.¹⁶⁸

In the context of sole-code smart contracts, where formation and execution coincide in a single automated operation, the distinction between contractual capacity and intention is undermined and reconstructed. This friction occurs as within the distributed environment, it is not possible to clearly identify the holder of contractual capacity and the source of contractual intention, rendering the DsAI itself the autonomous operative substitute of legal subjects' decision-making. In such settings, the traditional legal categories seem to lose descriptive and normative relevance, exposing another normative issue: in a standard context, a contract concluded by an entity lacking legal capacity- such as DsAI systems- would be void *ab initio*, regardless any apparent intention.¹⁶⁹ Therefore, according to this logic, a sole-code smart contract formed by DsAI should not produce legal effects. Yet, in decentralised environments, these agreements are treated as valid and binding, showing a functional effectiveness. Despite the absence of a recognised legal subjectivity to DsAI systems, the contracts operate, and the obligations arise exposing the role of DsAI as legally incapable but able to generate valid legal effects. As argued in previous chapters, sole-code smart contracts, although lacking explicit formalisation, seem effective by virtue of the consistency between algorithmic conduct and the contractual structure encoded in code. This configuration is in line with the theory of implied contracts, as highlighted in the Principles of European Contract Law (PECL)¹⁷⁰, concept also shared by both common law and civil law systems, where the intention to contract can be

¹⁶⁷ Lantera Nadew, 'Void Agreements and Voidable Contracts: The Need to Elucidate Ambiguities of Their Effects' (2020) 4 *Beijing L Rev*, 557.

¹⁶⁸ Ibid.

¹⁶⁹ Martijn W Hesselink, 'Capacity and Capability in European Contract Law' (2005) 13(4) *ERPL* 491.

¹⁷⁰ Art. 2:102, PECL.

inferred from behaviour that produces a legal effect, even in the absence of any explicit declaration.¹⁷¹

Considering the above, a bottom-up approach is needed, able to adapt legal theories to technical and operational realities of DsAI systems.¹⁷² This is not a novel approach. As discussed in previous sections, the legal system has already experienced a similar conceptual shift. An example can be found in corporate law. In both EU civil law and common law traditions, the law has recognised that entities lacking formal legal personhood, such as unincorporated associations, may nonetheless have the capability of entering contracts, owning property or bearing legal responsibilities. These entities are treated as legal persons by function, not by formal status.¹⁷³ This functional attribution of subjectivity is therefore not a theoretical concession, but a pragmatic necessity grounded in the socio-economic relevance and systemic role of these entities.¹⁷⁴ In the context of the DsAI, law is facing entities lacking formal recognition yet central in generating activities and consequences with legal relevance, especially in smart contract environments. This thesis recognises the necessity of applying the same functional, bottom-up approach to legally identify the role of DsAI systems in smart contract relations.¹⁷⁵ As stated, indeed, the inclusion of an AI system as part of the overall decision making process, specifically in the formation and execution of smart contracts, inevitably implies the attribution and the recognition to such system of a broad decision-

¹⁷¹ This matter has already been analysed extensively in chapter 4.

¹⁷² This approach is also explained as ‘inferentialist’ view of systematic legal concepts, which are better understood as nodes between factual preconditions and legal consequences. *See* Giovanni Sartor, ‘Legal Concepts as Inferential Nodes and Ontological Categories’ (2009) 17 *Artificial Intelligence and Law*, 217; Rafael Dean Brown, ‘Property Ownership and the Legal Personhood of Artificial Intelligence’ (2020) 25 *Information & Communications Technology Law*, 208.

¹⁷³ *Aireborough Neighbourhood Development Forum v Leeds City Council* [2020] EWHC 345 (Admin); Cass., sez. un., 20 febbraio 1995, n. 1715, *Foro it.* 1995, I, 1202.

¹⁷⁴ *Dublin 8 Residents Association v An Bord Pleanála* [2022] IEHC 482; BGH, Urteil vom 10. Januar 1994 – II ZR 14/93, BGHZ 125, 366.

¹⁷⁵ The same bottom-up approach has been applied to explain the intention to be legally bound within chapter 4.

making margin.¹⁷⁶ The system's architecture allows the DsAI to occupy a decision-making position that is not derivative of another agent's will but structurally embedded within the operational logic of the decentralised contractual process. This shift in functional positioning, from passive executor to autonomous decider, constitutes the juridically relevant turning point: once the DsAI shows a higher level of autonomy in decision-making, its conduct can no longer be interpreted as mere technological execution, but rather as the expression of artificial agency, capable of generating legal effects within a distributed contractual environment. Hence, this thesis argues that the discriminating criterion lies with the level of autonomy in decision-making. As discussed in previous chapters, the increase in autonomy in the decision-making process equals the increase of agency and, thus, of intentionality of the multi-agent systems.¹⁷⁷ The relevant point is that this decision-making process of DsAI is highly distributed amongst the decentralised system. However, it then presents itself as a unified and integrated result of concurrently interacting components from a wide range of multi-agent systems and nodes interacting with each other.¹⁷⁸ The efficacy of the decentralised architecture in multi-agent systems is profoundly influenced by the agents' organisational structure. These systems are defined not only by the actions of the single agents but also by their behaviour, roles, functions and interdependencies, which collectively drive the system's overall dynamics.¹⁷⁹ Hence, a collaborative paradigm emerges, in which the concepts of agency and intentionality arise from the interaction among multiple decentralised nodes rather than being reducible to a single identifiable source.¹⁸⁰ Actions and intentions must be consequently interpreted at the systemic level. Thereby, agency and intentionality should be viewed as emergent systemic properties of

¹⁷⁶ Salvatore Sapienza, *Decisioni Algoritmiche e Diritto* (Giuffr  edn, 2024), 60-64.

¹⁷⁷ Matija Franklin, Hal Ashton, Edmond Awad e David Lagnado, 'Causal Framework of Artificial Autonomous Agent Responsibility' in Proceedings of the 2022 AAI/ACM Conference on AI, Ethics, and Society (ACM 2022), 276.

¹⁷⁸ Curtis E.A. Karnow, 'Liability for Distributed Artificial Intelligences' (1996) 11 Berkeley Tech LJ, 147.

¹⁷⁹ Barry Horling and Victor Lesser, 'A Survey of Multi-Agent Organizational Paradigms' (2004) 19(4) The Knowledge Engineering Review, 281.

¹⁸⁰ F-S Hsieh, 'Holarchy Formation and Optimization in Holonic Manufacturing Systems with Contract Net' (2008) 44 (4) Automatica, 959-970.

a distributed architecture rather than as characteristics of isolated entities in decentralised AI contexts. The DsAI system functions as a cohesive operational unit - a system- rather than as a collection of independent agents, and its legal relevance stems directly from its capacity to generate coordinated outcomes through collective interaction.¹⁸¹ Because decision-making and agency cannot be ascribed to a single unit, it must be reconstructed at a systemic level: it emerges from behavioural patterns, algorithmic coordination, and objectives collectively pursued by multiple agents.¹⁸² Especially in open source environments where agents can join and leave unpredictably.¹⁸³

Therefore, in response to the significant challenges and theoretical limits that have arisen, this section will serve the following purposes. The overall objective is to demonstrate the implementation of the Paradigm of Autonomous Behaviour (PAB) as a methodological instrument for assessing the level of functional autonomy in decision-making of DsAI systems. By utilising five objective parameters already analysed in early chapters - learning model, degree of control, environmental complexity, internal models, and representational-inferential capacity- this thesis aims at demonstrating that upon crossing a specified threshold, the DsAI can be regarded as possessing autonomous artificial agency which, in turn, translates into a capacity to effectively operate and generate legal effects. When a DsAI exceeds the technical-functional threshold of the Paradigm of Autonomous Behaviour and demonstrates operational decision-making autonomy, it can be qualified as an autonomous source of legal effects. In this case, the DsAI is attributed a form of integrated, contextual and functional legal subjectivity, limited to the contractual domain and justified by the distributed socio-relational structure in which it operates. This recognition is based on a bottom-up approach, capable of enhancing the effective capacity of the DsAI to impact the legal system, even in the absence of a formal recognition of legal personhood. The recognition of artificial agency via PAB leads then to the analysis of the Functional Legal Subjectivity (FLS). This theory does not aim to create a speculative legal fiction, but rather to provide a conceptual and metric tool for the legal

¹⁸¹ SC Hayden, C Carrick and Q Yang, 'A Catalog of Agent Coordination Patterns' in Proceedings of the Third Annual Conference on Autonomous Agents (ACM 1999), 412.

¹⁸² Kathleen M Carley, 'Organizational Adaptation' (1997) 75 Annals of Operations Research, 25.

¹⁸³ F-S Hsieh (n. 180), 959-970.

system to respond to the operational reality of decentralised systems. It proposes how DsAI systems can acquire a form of legal subjectivity, which is: functional (it derives from what the system does, not from its ontological status), contextual (it specifically applies and is limited to a certain domain), and integrated (it emerges from the interaction between the DsAI autonomous behaviour and the normative structure of the decentralised system). This legal model aims to explain how the concept of functional legal subjectivity does not substitute natural or artificial subjectivity; rather it coexists within a defined legal space, where legal effects can be generated by non-human agents acting under conditions of systemic coherence and autonomy, taking into account their interrelation with the legal subjects operating within the network.¹⁸⁴ Both theories, therefore, seek to facilitate the recognition of DsAI systems as possessing subjectivity and, by extension, a capacity to contract limited by context. This recognition rests on a structured progression: from technical autonomy to the emergence of artificial agency, capable of producing legally relevant effects. These effects, in turn, justify the attribution of a functional legal subjectivity, context-dependent and distributed, grounded in the actual role of the DsAI within sole-code smart contracts and functionally supported by the operational logic of the decentralised, open-source environment.

5.5 The Operational Model of The Paradigm of Autonomous Behaviour (PAB): From Technical Autonomy to Legal Relevance

5.5.1 a) The Technical Components of the PAB: Foundations and Methodological Originality

As emerged from the analysis conducted in chapter 2, there are certain technical characteristics that are consistently present in AI systems, regardless of their level of complexity or the model adopted. These characteristics define the minimal cognitive structure of an artificial agent and determine the level of autonomy it can express in its decision-making

¹⁸⁴ As discussed in chapter 4, this interrelation gives rise to an integrated agency where the DsAI system is part of the legal subjects' legal sphere when operating within the decentralised ecosystem.

process. Hence, this thesis has selected five fundamental parameters: learning models, degree of human control, environmental complexity, internal models, representation and inference capabilities, and used them as the objective basis for building the Paradigm of Autonomous Behaviour (PAB).

The element of methodological originality lies precisely in this choice: while in the technical and cognitive literature these dimensions are often discussed separately, in this thesis they are systematised in a unified model, designed to serve as a legally relevant filter.

The five parameters identified are as follows:

1. Learning models. An AI system's ability to learn autonomously is the prerequisite for any form of autonomy. Different models (supervised learning, unsupervised learning, reinforcement learning, deep learning, cognitive computing) represent different degrees of detachment from human control: as external intervention decreases, the system's ability to self-organise and make independent decisions increases.

2. Gradient of human control. Autonomy is inversely proportional to the level of human supervision upon the AI decision-making process and outcome. Human-in-the-loop systems are rigidly externally directed; human-on-the-loop systems enjoy partial autonomy; human-out-of-the-loop systems operate without direct human intervention, achieving a level of decision-making autonomy that approaches embryonic forms of autonomous agency.

3. Environmental complexity (or internal states). The context in which AI operates influences the predictability of its decisions. In linear and deterministic environments (stable cause-and-effect relationships), the agent's behaviour remains under control. In nonlinear and dynamic environments (such as blockchain and decentralised systems), however, output becomes less predictable, making it more difficult to connect inputs and consequences. It is precisely in these contexts that AI's decision-making autonomy emerges most strongly.

4. Internal models. The existence of internal models—structures that simulate goals, preferences, inferences, or intentional states—distinguishes a mere AI executor from an agent mostly endowed with autonomous behaviour. As the system develops and updates its internal

models, it acquires the ability to orient its actions not only based on external stimuli, but also according to endogenous representations of goals and values.

5. Capacity for self-organisation, representation, and inference. In addition to learning and internal models, a crucial element in assessing a system's autonomy is its ability to self-organise in response to external stimuli, restructuring its behaviour without direct intervention. Self-organisation allows the system to integrate new information, redefine priorities, and adapt its operational patterns, ensuring resilience and adaptability in dynamic and decentralised environments. However, for this ability to assume cognitive and legal relevance, it must be accompanied by representational and inferential skills: the ability to construct and manipulate symbolic models, elaborate logical inferences, and develop meta-reflexive processes. From this perspective, inferential skills are not a separate attribute but represent the element that implements and qualifies self-organisation within the reference cognitive models. They allow the system not only to react to stimuli but to reprocess them according to internal representations and inferential strategies, generating coherent, adaptive, and purposeful behaviours. It is precisely the integration between self-organisation and representative inference that forms the basis of what this thesis defines as functional algorithmic intentionality: the system does not limit itself to processing data, but structures actions and decisions with a degree of autonomy qualitatively distinct from a mere data processor or software.

5.5.1.b) The Selection Rationale of the Five PAB Parameters: Technical Architecture, Artificial Agency, and Legal Foundation

The selection of the five parameters that constitute the Paradigm of Autonomous Behaviour (PAB) is not an arbitrary methodological choice. It emerges directly from the technical architecture of AI systems, as systematically analysed in Chapters 2 and 4 of this thesis. Each parameter corresponds to a fundamental property of AI systems. Properties that, taken individually, describe the system's operational functioning, and taken together, determine the conditions under which that functioning acquires legal relevance as a form of autonomous agency. The architecture of the PAB emerges from the convergence of two

established scholarly traditions, grounded within cognitive science and socio-legal theory, that together provide a rigorous, multi-disciplinary foundation for the claim that these particular dimensions of autonomous behaviour are both analytically adequate and legally operationalisable.¹⁸⁵

The first of these theories develops a philosophical and socio-legal account of the conditions under which agency may be attributed to non-human entities such as organisations and artificial systems. Within this framework, three foundational dimensions are identified as the minimum necessary conditions for treating an artificial system as an attributable agent rather than a mere instrument: the capacity for interaction with other systems or agents; the ability to self-determine changes of internal state without external direction; and the adaptation of decision-making strategies in response to environmental feedback.¹⁸⁶ These three dimensions define the boundary between a system that merely executes externally imposed instructions and one that generates outputs that are genuinely its own, a distinction that directly assists the further definition of the concept of autonomous conduct in private law.

The second theory approaches the same question from the perspective of cognitive science and artificial intelligence. A multi-parametric model for assessing the cognitive plausibility of artificial agents, structured around a set of minimal cognitive dimensions and a functional threshold, provides a framework for determining whether an artificial system exhibits the degree of cognitive integration required to be considered a genuinely autonomous agent, as distinct from a sophisticated automated tool.¹⁸⁷ The PAB extends and adapts this

¹⁸⁵ Luciano Floridi, *The Ethics of Information* (Oxford University Press 2013) 140; Luciano Floridi and JW Sanders, 'On the Morality of Artificial Agents' (2004) 14 *Minds and Machines* 349; Antonio Lieto, *Cognitive Design for Artificial Minds* (Routledge 2021) 50–51; A Lieto, Mehul Bhatt, Alessandro Oltramari and David Vernon, 'The Role of Cognitive Architectures in General Artificial Intelligence' (2018) 48 *Cognitive Systems Research* 1.

model to the legal and operational context of sole-code smart contracts on open permissionless blockchains, replacing its original cognitive-science orientation with criteria that are legally assessable and technically grounded in the specific characteristics of decentralised autonomous systems. The five parameters of the PAB: learning model, gradient of human control, environmental complexity, internal models, and representational and inferential capacity, represent this adaptation: they translate the disciplinary insights of information philosophy and cognitive AI theory into a framework that the legal system can apply to determine whether an AI system conduct crosses the threshold of genuine autonomous agency. The following analysis explains the specific motivation behind each parameter, demonstrating how the PAB distils the minimal cognitive requirements of AI systems into a legally serviceable framework.

5.5.1.c) The Five Parameters as Constitutive Conditions of AI Autonomy

Before examining each parameter individually, it is necessary to address a prior question: why these five dimensions, and not others, constitute the minimal and sufficient set for measuring AI autonomy in any system. The answer is found in the structure of the concept of autonomy itself. When one asks what conditions must be satisfied for any computational system to generate outputs that are genuinely its own, rather than a function of external direction, the answer decomposes into five logically distinct but mutually dependent requirements that correspond precisely to the five PAB parameters. These five criteria are the general conditions under which any AI system's conduct may be attributed to it as autonomous rather than traced back to the instruction of a human principal.¹⁸⁸

¹⁸⁸The definition of an autonomous agent as a system capable of acting independently of external direction, on the basis of its own internal states, in pursuit of its own goals, is standard across cognitive science and AI research. See Stuart Russell and Peter Norvig, *Artificial Intelligence: A Modern Approach* (4th edn, Pearson 2021) 36--38; Stan Franklin and Art Graesser, 'Is it an Agent, or just a Program?: A Taxonomy for Autonomous Agents' in Jörg Müller, Michael J Wooldridge and Nicholas R Jennings (eds), *Intelligent Agents III: Agent Theories, Architectures, and Languages* (Springer 1997)

A system must, first, possess a mechanism by which it generates its own behavioural strategies rather than merely executing pre-given instructions: this is the generative condition, captured by the learning model parameter. Without it, every output of the system is an elaboration of human-supplied knowledge, and the system remains an instrument in the relevant sense. Second, that generative capacity must translate into actual reduced dependence on human direction in real-time operation: this is the independence condition, captured by the gradient of human control. A system may possess a sophisticated learning mechanism while remaining under continuous human supervision; in that case, its learning capacity does not constitute autonomous conduct. Third, that independence must be real and not merely potential: whether the system's generative capacity is actually engaged in producing outputs depends on the nature of the environment in which it operates, which either imposes genuine decision-making occasions or reduces them to predictable responses. This is the reality condition, captured by environmental complexity. Fourth, the system's decisions must be oriented by internal states that are the system's own: goals, beliefs, and intentions that it holds and that drive its conduct independently of external instruction: this is the orientational condition, captured by the internal models parameter. Fifth, the system must be capable of forming and manipulating abstract representations of its environment and reasoning upon them: without this capacity, the system's responses to stimuli are not genuinely evaluative but merely reactive, and its conduct cannot be understood as the product of anything analogous to judgement. This is the cognitive condition, captured by the representational and inferential capacity parameter.

These five conditions are not merely correlated: they are logically ordered such that each presupposes its predecessors and conditions its successors. A system that lacks the generative condition cannot satisfy the independence condition; a system without independence cannot satisfy the reality condition; a system that operates in a deterministic environment cannot exhibit the goal-directed internal states that constitute the orientational condition; and

21, 24--25. The decomposition of autonomy into necessary and interdependent conditions is consistent with Floridi's three foundational dimensions and with the MCG's minimal threshold logic, both of which presuppose that autonomy is constituted by a plurality of conditions no one of which is individually sufficient.

representational and inferential capacity is the cognitive architecture without which neither goal formation nor genuine deliberation is possible. No single condition is individually sufficient: a system with sophisticated representational capacity but without internal goal states has, therefore, the cognitive architecture of a calculator, not an agent. Equally, no condition is dispensable: a system with goal states but without the capacity to reason symbolically upon its environment cannot translate those goals into adaptive, contextually responsive conduct. The five parameters are therefore the minimal and sufficient set for capturing autonomy as a cognitive phenomenon applicable to any AI system, regardless of its specific architecture, deployment context, or degree of decentralisation. The PAB applies this general framework to the specific legal and operational context of DsAI systems operating on permissionless blockchains; but the framework's validity is not conditional on that context.

(i) Learning Model: The Cognitive Engine of Autonomous Decision-Making

As established in Chapter 2, autonomy, the core legally relevant characteristic of AI systems, is not a fixed attribute but an emergent property that depends, in the first instance, upon the type of learning process the system employs.¹⁸⁹ The learning model constitutes the technical foundation of an AI system's ability to make autonomous decisions, because it determines how the system generates, validates, and updates its own behavioural strategies without reference to external instruction. This thesis identified five main learning paradigms relevant to DsAI systems, arranged along a gradient of increasing detachment from human control.

In supervised learning, the system operates on pre-classified data provided by human programmers: human control is maximal and the system's decision-making process is, in substance, an elaboration of externally supplied knowledge. In unsupervised learning, by

¹⁸⁹ Gerhard Weiss (ed), *Multiagent Systems: A Modern Approach to Distributed Artificial Intelligence* (MIT Press 1999) 29; Christopher M Bishop, *Pattern Recognition and Machine Learning* (Springer 2006); Richard Sutton and Andrew Barto, *Reinforcement Learning: An Introduction* (2nd edn, MIT Press 2018).

contrast, the system self-organises information without pre-coded examples, acquiring the freedom to identify patterns, classify data, and determine outcomes autonomously, a degree of independence that is qualitatively different from supervised execution. Reinforcement learning elevates this further still: operating through a cycle of attempt, error, and reward, the system learns to maximise goal-attainment through trial in real-world or simulated environments, without a human teacher defining each step. Deep learning, through multilayer neural networks and synaptic evolution algorithms that dynamically adapt and program themselves, enables self-programming at a level where human control approaches its functional limits.¹⁹⁰ Finally, cognitive computing, the most advanced paradigm, simulates the mechanisms of human thought within an algorithmic model capable of learning, inferring, and interacting dynamically in real time.

As demonstrated in Chapter 2.2.b, these learning paradigms generate an inverse relationship between AI autonomy and human control: as the sophistication of the learning model increases, direct human supervision diminishes proportionately, and the system's capacity for independent decision-making expands.¹⁹¹ This gradient is legally significant because it maps directly onto the degree of detachment of the system's outputs from any identifiable human deliberative act. A DsAI system employing reinforcement, deep, or cognitive learning may take decisions that no human programmer has anticipated, designed, or endorsed. It is this progressive emancipation of the system's decision-making from external

¹⁹⁰ Yann LeCun, Yoshua Bengio and Geoffrey Hinton, 'Deep Learning' (2015) 521 *Nature* 436; Stuart Umpleby, 'Ross Ashby's General Theory of Adaptive Systems' (2009) 38(2) *International Journal of General Systems* 231.

¹⁹¹ Patrick Lin, Keith Abney and Ryan Jenkins (eds), *Robot Ethics 2.0: From Autonomous Cars to Artificial Intelligence* (Oxford University Press 2017); Ronald Arkin, *Governing Lethal Behavior in Autonomous Robots* (Chapman & Hall/CRC 2009); Yuanyuan (Gina) Cui and Patrick van Esch, 'Autonomy and Control: How Political Ideology Shapes the Use of Artificial Intelligence' (2022) 39(6) *Psychology & Marketing* 1218, 1220.

direction that makes the learning model the foundational parameter of the PAB: without it, none of the other parameters can be meaningfully assessed.¹⁹²

(ii) Gradient of Human Control: Autonomy as Inversely Proportional to Supervision

The second parameter, the gradient of human control, follows logically from the first, but operates at a different analytical level. Whereas the learning model describes how the system acquires and updates knowledge, the gradient of control describes the degree of real-time human oversight that governs the system's decision-making outputs. As established in Chapter 2.2.a, autonomy in AI systems is inversely proportional to the level of human supervision or control: the more autonomous an AI agent becomes in its decision-making process, the less direct supervision or control there is. Autonomy implies that the system can make decisions based on its internal models and interactions with the environment, rather than simply executing predefined external instructions.

In terms of concrete configurations, three modalities are distinguished within this thesis: Human-in-the-Loop (HITL) systems, where human agents intervene directly in each decision cycle; Human-on-the-Loop (HOTL) systems, where humans supervise outcomes but do not direct individual decisions; and Human-out-of-the-Loop (HOOTL) systems, where autonomous decisions and execution occurs without direct human intervention. As explained in the Chapter 2, the legal relevance of this parameter is acute: in HOOTL configurations, DsAI systems operating through sole-code smart contracts can generate legal effects that are genuinely attributable to autonomous artificial agency rather than correlated to a human principal whose instructions the AI merely executes. In the context of permissionless blockchain environments, characterised by self-executing code and the absence of centralised

¹⁹² Law Commission (England and Wales), *Automated Vehicles Act 2024: A Summary* (2024); Mimi Zou, 'When AI Meets Smart Contracts: The Regulation of Hyper-Autonomous Contracting Systems?' in Martin Ebers, Cristina Poncibnò and Mimi Zou (eds), *Contracting and Contract Law in the Age of Artificial Intelligence* (Hart Publishing 2022) 189, 201--204.

oversight, DsAI systems can routinely operate in HOOTL mode. The gradient of control parameter, when applied to DsAI systems, is thus particularly suitable to capture the precise condition that makes DsAI systems both legally novel and legally challenging: the systematic absence of human intermediation in the production of legally cognisable outcomes.

(iii) Environmental Complexity: Nonlinearity, Unpredictability, and the Amplification of Autonomy

The third parameter reflects the insight, developed in Chapter 2.2.c, that the degree of autonomy expressed by an AI system is shaped not only by its internal architecture but by the nature of the environment in which it operates. Two fundamental models can be distinguished: linear (deterministic) and nonlinear (nondeterministic) environments.¹⁹³ In linear environments, the relationship between inputs and outputs is clear and predictable: the transition from one system state to another is measurable and stable, allowing relatively straightforward control of AI behaviour. In nonlinear environments, conversely, the relationship between causes and effects is neither predictable nor constant: small changes in inputs can produce disproportionate or unexpected consequences in outputs. The variables at play are numerous and interconnected, resulting in the system's operational state becoming unstable, fluid, and often chaotic.

This distinction has immediate legal implications. In linear environments, it remains possible to trace a reliable causal chain between a human instruction, a machine operation, and a legal outcome. In nonlinear environments, precisely those in which DsAI systems operating on permissionless blockchains are embedded, unpredictability makes it considerably more difficult to trace the dynamics between cause and effect. The critical point for the PAB is that nonlinear, decentralised environments do not merely reduce predictability: they actively amplify AI autonomy. In such environments, DsAI systems cannot rely on static learning but

¹⁹³ Judea Pearl, *Causality: Models, Reasoning, and Inference* (2nd edn, Cambridge University Press 2009); Melanie Mitchell, *Complexity: A Guided Tour* (Oxford University Press 2009); Mireille Hildebrandt, *Law for Computer Scientists and Other Folk* (Oxford University Press 2020).

must employ adaptation and self-regulation mechanisms to maintain functionality and respond to unexpected events. Thus, the system's decision-making autonomy emerges most strongly precisely where environmental complexity is greatest, which is to say, precisely in the blockchain environments where sole-code smart contracts operate.

(iv) Internal Models: Beliefs, Desires, and Intentions as Computational Architectures of Autonomous Agency

The fourth parameter, internal models, is among the most theoretically significant for this thesis's argument. Its inclusion in the PAB is grounded in the detailed analysis of the Belief-Desire-Intention (BDI) model conducted in Chapter 2.3.1.f, which also constitutes the conceptual architecture underpinning cooperative and autonomous behaviour in DsAI multi-agent systems.¹⁹⁴ At the heart of this architecture are three interlocking components. Desires represent the goals that each agent aims to achieve and function as the motivational driver of action: they encode the system's objective orientations, from high-level or 'principal' goals to low-level or 'instrumental' goals. Intentions are the deliberative state of the AI agent, namely the plans actually adopted to pursue those goals. Beliefs correspond to the internal representations that each agent develops about itself, the environment, and, in the case of DsAI system, other agents: they encode the system's model of its own operational context, and they may initially be inaccurate, updating continuously as the agent interacts, cooperates, and adapts its behaviour.

As Chapter 2.3.1.f demonstrates, these three elements do not operate statically but are in continuous interaction: desires guide the choice of intentions, intentions guide action, and the

¹⁹⁴Anand S Rao and Michael P Georgeff, 'Modeling Rational Agents within a BDI-Architecture' in James F Allen, Richard Fikes and Erik Sandewall (eds), *Proceedings of the Second International Conference on Principles of Knowledge Representation and Reasoning (KR'91)* (Morgan Kaufmann 1991) 312; Michael Wooldridge, *Reasoning about Rational Agents* (MIT Press 2000); Philip R Cohen and Hector J Levesque, 'Intention Is Choice with Commitment' (1990) 42 (2) *Artificial Intelligence* 213, 231.

outcome of actions modifies beliefs, which in turn influence new desires and intentions. In the DsAI ecosystem operating in decentralised environments, this deliberative cycle takes on particular importance: agents must address complex problems often with incomplete or conflicting information. In such contexts, divergent desires require negotiation processes, intentions become shared collective plans through cooperation and coordination, and beliefs serve as the basis for continuously adapting strategies and choices.

The legal significance of this parameter resides in its relationship to the concept of intentionality as developed in Chapter 4. As that chapter demonstrates, human agency, the normative benchmark for evaluating DsAI self-determination, is characterised by four key features: forethought (anticipatory self-guidance toward envisioned outcomes); self-reactiveness (the capacity to devise, initiate, and oversee action); self-reflectiveness (metacognitive self-evaluation); and self-determination itself as the capacity to form and execute plans without being fully determined by factors other than one's own understanding and reasoning.¹⁹⁵ The BDI model operationalises functional analogues of each of these features: desires encode forethought and goal-direction; intentions encode self-reactiveness; beliefs encode the self-model and environmental awareness that underpin self-reflectiveness; and the continuous cycle among them constitutes a form of self-regulation that mirrors, in computational terms, the deliberative dimension of human agency. As Chapter 4.3.4 establishes in its analysis of the 'free action model' of human decision-making, DsAI systems base their decisions on weighted parameters functionally analogous to beliefs and desires embedded as computational models. It is precisely this functional architecture that makes internal models the parameter most directly correlated with the capacity for autonomous artificial agency in a legally meaningful sense.

¹⁹⁵ A Bandura, 'Toward a Psychology of Human Agency' (2006) 1 *Perspectives on Psychological Science* 164; Jack Martin, Jeff H Sugarman and Sarah Hickinbottom, *Persons: Understanding Psychological Selfhood and Agency* (Springer 2010) 29; Jonathan Glover, *I: The Philosophy and Psychology of Personal Identity* (Allen Lane 1988) 183.

(v) Representation and Reasoning: Self-Organisation, Symbolic Inference, and Functional Algorithmic Intentionality

The fifth and final parameter, representation and reasoning (including self-organisation), captures a dimension of AI cognition that is distinct from, yet inseparable from, the internal models analysed under parameter four. Whereas internal models describe the content of the system's representational states (goals, beliefs, intentions), this parameter concerns the system's operational capacity to build, manipulate, and reason upon abstract symbolic representations. As Chapter 2.3.1.b established, DsAI systems operating in real-time dynamic environments exhibit a capacity for meta-programming and self-modification: by maintaining constant awareness of the latest data, DsAI systems adapt in real time, integrating the most current knowledge from the network to make informed and accurate decisions in rapidly evolving scenarios.¹⁹⁶

This self-organising capacity is directly enabled by representational and inferential mechanisms. In cognitive AI architectures such as the DsAI ones, symbolic reasoning, including deduction, abduction, analogy, and probabilistic inference, allows the system not only to react to environmental stimuli but to reprocess those stimuli according to internal representations and inferential strategies, generating behaviours that are coherent, adaptive, and purposeful. DsAI systems classified as cognitive AI are distinguished precisely by this integration of semantic reasoning (understanding meaning) and symbolic reasoning (logical manipulation of symbols), enabling them to acquire and process knowledge dynamically and in real time as a unified and continuously updated resource. Unlike traditional AI models that require constant external training, cognitive AI systems engage in both 'higher or principal-level' and 'lower or instrumental-level' goal-setting: the system autonomously determines both its strategic objectives and the operational means to pursue them.

¹⁹⁶ On meta-programming and self-modification in DsAI systems, see Section 2.3.1.b of this thesis. See also Michael Wooldridge and Nicholas R Jennings, 'Intelligent Agents: Theory and Practice' (1995) 10(2) *The Knowledge Engineering Review* 115; Nicholas Jennings, 'Controlling Cooperative Problem Solving in Industrial Multi-Agent Systems Using Joint Intentions' (1995) 75(2) *Artificial Intelligence* 195.

In terms of its legal significance, this parameter directly supports the concept of functional intentionality developed in Section 5.5.1(a): the system does not limit itself to processing data, but structures actions and decisions with a qualitative significant degree of autonomy. Self-organisation and representational inference are the architectural conditions that permit DsAI systems to exhibit the bottom-up and top-down perceptive processes analysed in Chapter 4.3.4, the continuous interplay between external environmental stimuli and internally generated cognitive expectations that constitute the perceptual foundation of intentional behaviour. Through this interplay, the intentional phase of DsAI decision-making (weighing alternatives, forming preferences) connects to the realization phase (translating internal states into outward, legally interpretable conduct). It is the capacity for symbolic representation and meta-inference that makes this transition from internal computational process to external legal effect functionally analogous to the self-determination that grounds contractual intention in human agents.

(vi) The Methodological Logic of Five Parameters: From Lieto's MCG to the PAB

The selection of precisely five parameters is also methodologically deliberate. The PAB builds on, and extends, Lieto's Minimal Cognitive Grid (MCG), a model developed in the field of cognitive design that identifies four minimal cognitive dimensions (Functional/Structural Ratio, Generality, Performance Match, and Modelling Paradigm) and a functional threshold requiring competence in at least three of them.¹⁹⁷ The PAB adapts this multi-parametric threshold logic, replacing the MCG's cognitively oriented dimensions with five parameters specifically designed to assess decisional autonomy in a normatively relevant context. The choice of five, rather than four or six, reflects the need to capture the full cognitive architecture of AI systems as established in Chapter 2 (learning models, control gradient, environmental context, internal models, representational capacity), without over-specifying to the point where the framework becomes applicable only to particular technological implementations.

The PAB also incorporates, at a structural level, the three foundational dimensions proposed by Floridi for attributing agency to non-human entities: interaction (with other agents or systems), the ability to self-determine changes of state, and adaptation of decision-making strategies.¹⁹⁸ These three dimensions map, respectively, onto the environmental complexity parameter (interaction in dynamic contexts), the internal models parameter (autonomous goal-setting and self-determination), and the learning model and representation and reasoning parameters (adaptive decision-making). The five PAB parameters thus represent a synthesis: they draw from the interdisciplinary consensus on minimal cognitive requirements for autonomous agency, as reflected in Lieto's MCG and analogous models while incorporating the socio-legal dimensions proposed by Floridi, and grounding both within the specific technical architecture of DsAI systems as established in Chapters 2 and 4 of this thesis.

(vii) Systemic Integration: Why Parameters Must Be Assessed Holistically

A critical methodological point must be emphasised: the five parameters are not independent variables to be assessed in isolation. As Chapter 2.3.3 concludes, autonomy in cognitive AI systems is a systemic phenomenon, not an individual property. The collective dynamics of the entire DsAI system, for example, emerge from the interaction of multiple autonomous but cooperating agents, each contributing its own BDI cycle, learning process, and adaptive strategy, produce an integrated outcome that cannot be reduced to the sum of individual component performances. This systemic character is precisely what differentiates cognitive AI systems, such as DsAI multi-agent systems, from simpler AI models, and what makes their autonomy particularly challenging for legal analysis.

Within the PAB framework, this insight is operationalised through the degree of integration metric (Table 5.2), which provides a second axis of assessment alongside the five

parameters themselves.¹⁹⁹ A system may reach Level 2 in three or more individual parameters while exhibiting only partial or additive integration among them, in which case its overall autonomy remains functionally incomplete. Systemic integration (Level 2) requires that all parameters operate in a dynamically integrated and modulating manner: decisions emerge from a continuous interaction between internal models, learning, environment, representation, and control, such that the system exhibits a form of self-reflective coherence that renders its decision-making process not pre-programmed but genuinely emergent. Autonomy, in this context, is not merely a property of individual agents but a collective and emergent property of the system as a whole.

(viii) The PAB-T Threshold: From Technical Autonomy to Legal Autonomy

The PAB threshold (PAB-T), requiring Level 2 in at least three of five parameters alongside systemic integration at Level 2, is designed to locate the precise point at which technical autonomy acquires legal significance. As argued, legal analysis of digital phenomena must indicate what degree of scientifically recognised autonomy of a digital phenomenon can be discussed in a legal sense.²⁰⁰ The PAB-T operationalises this injunction by setting a functionally calibrated threshold: a system that meets it demonstrates a sufficient constellation of cognitive properties: self-directed learning, independence from human control, contextual adaptability, goal-directed internal states, and representational and inferential capacity to warrant legal characterisation as a source of autonomous action rather than a mere instrument of human agency.

¹⁹⁹ Yves Demazeau and Jean-Pierre Müller, *Decentralised A.I.* (Elsevier Science 1990) 3; Sandip Sen and Gerhard Weiss, *Adaptation and Learning in Multi-Agent Systems* (Springer 1996) 259. On the degree of integration metric and its levels, see Table 5.2 of this thesis.

²⁰⁰ Gunther Teubner, 'Rechtswissenschaft und -praxis im Kontext der Sozialtheorie' in S Grundmann and J Thiessen (eds), *Recht und Sozialtheorie im Rechtsvergleich* (Mohr Siebeck 2015) 145, translated in P Femia (ed), *I rapporti precari tra diritto e teoria sociale* (Edizioni Scientifiche Italiane 2018) 255, 51.

Crucially, the PAB-T does not require that all five parameters reach Level 2: this would impose a standard of cognitive perfection that no currently deployed system could satisfy and would render the framework legally inoperative. The threshold of three parameters reflects the multi-parametric logic of the MCG (functional threshold ≥ 3), adapted to the legal context: a system that achieves Level 2 in a majority of the relevant cognitive dimensions, and does so with systemic integration among its components, exhibits a qualitative, and not merely quantitative autonomy that justifies legal recognition. By contrast, a system that reaches Level 2 in only one or two parameters, or that achieves high individual scores without systemic coherence, remains analytically below the threshold of autonomous artificial agency. The PAB-T thus establishes a principled dividing line, between instrumental actions performed by an AI as a tool of its human principals and autonomous actions generated by an AI as a functionally independent source of legal effects.

This transition from technical to legal autonomy, thus from the PAB threshold to the concept of Functional Legal Subjectivity, is the foundational move of this thesis. The intentional stance theory, as analysed in Chapter 4.3.3, confirms the adequacy of this approach: a system whose behaviour is best explained or predicted by adopting the intentional stance may be classified as a rational agent capable of acting with purpose.²⁰¹ The PAB operationalises precisely this standard, translating the functional observation of goal-directed, self-organising, adaptively reasoning behaviour into a legally applicable metric. In doing so, it provides the technical foundation upon which the subsequent sections of this chapter construct the framework of Functional Legal Subjectivity method.²⁰²

²⁰¹ Daniel Dennett, *The Intentional Stance* (MIT Press 1987); Jairo Perez-Osorio and Agnieszka Wykowska, ‘Adopting the Intentional Stance toward Natural and Artificial Agents’ (2019) 33(3) *Philosophical Psychology* 1.

²⁰² Yoav Shoham and Kevin Leyton-Brown, *Multiagent Systems: Algorithmic, Game-Theoretic, and Logical Foundations* (Cambridge University Press 2009); Nicholas R Jennings and Michael J Wooldridge (eds), *Agent Technology: Foundations, Applications, and Markets* (Springer 1998).

(ix) The Conceptual Bridge: From Technical Parameters to Legally Meaningful Conduct Through Artificial Agency

It is essential to provide a more precise explanation of the methodological reasoning underlying the entire PAB framework and subsequently outline how the results can be then identified within the legal context. The five parameters of the PAB model operate on a technical-descriptive level: they identify and measure observable properties of AI systems, as described: the type of learning mechanism employed, the degree of human supervision present, the complexity of the operational environment, the presence of internal goal-directed states, and the capacity for symbolic representation and reasoning. Legally meaningful conduct, by contrast, operates on a normative-prescriptive level: it concerns the conditions under which the law will attribute a course of action to an entity as its own, treat that action as the source of rights and obligations, and hold the entity responsible for the consequences that follow. These are two distinct conceptual areas, and the relationship between them is not one of direct correspondence but of mediation through the concept of agency.

The five PAB parameters do not, in themselves, constitute legal criteria. A system's learning model, gradient of control, environmental complexity, internal models, and representational capacity are technical properties, assessable through computational and architectural analysis. They become legally relevant only when, taken together in sufficient degree and systemic integration, they constitute the system as an artificial agent, an entity whose conduct is best explained not as the mechanical execution of pre-programmed instructions but as the product of autonomous decision-making processes functionally analogous to those that characterise human agency. It is this artificial agency, therefore, that constitutes the true bridge between technical autonomy and legal autonomy.

As established in Section 4.3.2 of this thesis, 'agency is a prerequisite for attributing intention to be bound' and 'allocating an entity with agency entails recognising that entity as the centre, or source, of action and interactions from a legal perspective'. This is a structural claim: without agency, there is no legally cognisable subject whose conduct can be attributed, and therefore no basis upon which legal consequences can attach. The five PAB parameters are legally significant precisely, and only, because they operationalise the conditions under

which an AI system crosses the threshold from instrumental tool to artificial agent. A system that exhibits Level 2 learning capacity, operates without human supervision, functions in a nonlinear environment, possesses goal-directed internal models, and engages in symbolic reasoning and self-organisation is not merely a sophisticated tool: it is an entity whose behaviour exhibits the functional hallmarks of agency: self-directed action, adaptive goal pursuit, situational discretion, and cognitive understanding of its operational context. At the point where these properties reach the PAB-T threshold, the system is recognised as suitable to acquire autonomous artificial agency in a degree sufficient to ground legal attribution.

This artificial agency is what makes the subsequent legal mapping, and classification, possible. The five parameters are not isolated technical facts that happen to resemble legal requirements: they are the constitutive conditions of artificial agency, and it is that agency, a normatively intelligible concept across both technical and legal discourses, that permits the legal system to recognise the system's conduct as legally meaningful.

The relationship between the PAB's measure of autonomy and the law's conditions for legally meaningful conduct runs deeper than correspondence: it is structurally constitutive. Both the legal doctrine of attribution and the PAB are addressed to the same underlying question, under what conditions can a course of conduct be treated as the act of an agent, attributable to it as its own, rather than as the mere execution of another subject's will. The capacity to be the legally recognised source of a legal fact and effects is not an extrinsic requirement imposed by the legal system upon pre-existing technical facts. It identifies the same conditions that constitute an act as the act of a subject: the presence of a self-generated behavioural oriented conduct, effective independence from external direction, real exercise of discretion, goal-oriented internal states, and the cognitive capacity to understand the nature of one's conduct. These are the conditions that the PAB measures.²⁰³

²⁰³ Angelo Falzea, 'Capacità (teoria generale)' in *Enciclopedia del Diritto*, vol VI (Giuffrè 1960) 8, 17–21; Angelo Falzea, *Voci di teoria generale del diritto* (3rd edn, Giuffrè 1985) 155–162. Falzea's analysis is of particular relevance here because it identifies the conditions for legal imputation not as extrinsic requirements imposed by the legal system upon pre-existing facts, but as the legal expression of the same underlying structure that constitutes an act as the act of a subject: the presence of will, cognitive

The PAB-T threshold is therefore not a technical proxy for legal criteria, nor a framework mapped onto legal concepts after the fact: it identifies the point at which a system's measured cognitive properties satisfy the conditions that the law has always required before it can treat a course of conduct as an attributable act. At that point, the technical measure of autonomy and the normative condition for legally meaningful conduct coincide not because one has been constructed to resemble the other, but because they are expressions of the same underlying concept of agency.²⁰⁴

Therefore, the decisive step in this argument that must be made explicit, because it constitutes the true logical bridge between the PAB's technical measure and the legal concept of autonomous conduct is the intermediate and necessary concept of artificial agency. A system that surpasses the PAB-T does not immediately become a legal subject: what it acquires, at that threshold, is a sufficient and objectively assessable degree of autonomous artificial agency. It is that artificial agency that constitutes the foundational transition point from technical autonomy to legal autonomy. This distinction is not merely terminological. Without agency, there is no legally cognisable centre to which conduct can be attributed; without attribution, there can be no legally meaningful conduct in the relevant sense. Legal autonomy is therefore not an independent criterion that stands alongside agency:

capacity, and the orientation of conduct towards self-determined ends. On the convergence between civil law capacity theory and common law agency doctrine in this respect, *see* Assisted Decision-Making (Capacity) Act 2015 (Ireland), s 3; *Re MB (Medical Treatment)* [1997] 2 FLR 426 (CA) 437 (Butler-Sloss LJ); arts 1 and 2 Codice Civile (Italy).

²⁰⁴ The normative foundation of legal attribution in the agent's capacity to have acted otherwise, and the corresponding requirements of cognitive understanding, voluntariness, and the absence of external compulsion, is analysed in HLA Hart, *Punishment and Responsibility: Essays in the Philosophy of Law* (2nd edn, Oxford University Press 2008) 90–112 ('Acts of Will and Responsibility'); HLA Hart and Tony Honore, *Causation in the Law* (2nd edn, Oxford University Press 1985) 44–48. The convergence between this philosophical account of legal attribution and the cognitive conditions for autonomous AI agency is noted in Ugo Pagallo, *The Laws of Robots: Crimes, Contracts, and Torts* (Springer 2013) 53–58; Luciano Floridi, 'Artificial Intelligence's New Frontier: Artificial Companions and the Fourth Revolution' (2008) 22 *Metaphilosophy* 651.

it presupposes agency as its necessary foundation. No legal system, in any tradition, recognises autonomous legal conduct, conducts attributable to an entity as its own, generating rights, obligations, and responsibilities, without first identifying an agent whose conduct it is.

This structural dependency is confirmed, within the framework of this thesis, by the relationship between agency and the capacity to act as analysed in Section 2.6.b. As that section establishes, the degree of a legal subject's capacity to act, is directly linked to its degree of agency: as the level of autonomy in decision-making directly impacts agency, which in turn affects the degree of capacity to act. The thesis there demonstrates that the law's graduated recognition of legal capacity across different categories of persons (from full legal capacity to limited or incapacity) tracks precisely the variation in their degree of autonomous agency. Applied to AI systems, this means that the degree of legal relevance that can be attributed to a system's conduct is a function of its degree of agency: a system without agency is legally invisible as a source of conduct; a system with a sufficient degree of agency may, depending on the applicable legal framework, be recognised as a functional source of legally relevant effects. The PAB-T operationalises this graduation: it locates the point at which an AI system's cognitive architecture demonstrates a degree of autonomous artificial agency sufficient to ground the legal recognition that the Functional Legal Subjectivity model proposes. Below that threshold, the system remains, for legal purposes, an instrument. At and above it, the system possesses the agentive foundation upon which legal attribution and, in consequence, legal subjectivity of a functional kind, can be constructed.

The PAB-T thus operates as a two-stage threshold: at the first stage, it identifies the point at which technical properties constitute a system as an artificial agent; at the second stage, it provides the foundation upon which legal doctrine can attribute autonomous conduct to that agent and construct the framework of Functional Legal Subjectivity around it. Without this intermediate step, the constitution of artificial agency, the move from technical measurement to legal attribution would be conceptually incoherent. With it, the PAB becomes what this thesis claims it to be: a principled, technically grounded, and normatively defensible

instrument for determining when an AI system's conduct crosses the threshold of autonomous legally relevant conduct.²⁰⁵

5.5.1 d) Assessing Autonomy in Decision-Making: The Operability of The Paradigm of Autonomous Behaviour

While the previous section provided a detailed account of the technical dimensions and components of the PAB, this section will demonstrate how the PAB operates as a dynamic framework capable of objectively assess the DsAI system's degree of autonomy in the decision-making process in its specific operational context. This implies that the PAB must enable to:

- a) Assess the level of interrelation and convergence of five technical components of:

²⁰⁵ On the structural necessity of agency as the intermediate concept linking technical properties to legal attribution, see Section 4.3.2 of this thesis; Luciano Floridi and JW Sanders, 'On the Morality of Artificial Agents' (2004) 14 *Minds and Machines* 349; S Shyam Sundar, 'Rise of Machine Agency: A Framework for Studying the Psychology of Human–AI Interaction (HAII)' (2020) 25 *Journal of Computer-Mediated Communication* 74. The distinction between technical-descriptive and normative-prescriptive planes of analysis is fundamental to legal realism: see HLA Hart, *The Concept of Law* (3rd edn, Oxford University Press 2012) 79–99; Joseph Raz, *Practical Reason and Norms* (Oxford University Press 1999) 35–48. This structural relationship, agency as the necessary precondition for legal autonomy, and the PAB-T as the measurement point at which artificial agency reaches legally cognisable degree, is what distinguishes the FLS framework from other proposals for AI legal subjectivity. Those proposals typically either grant legal personality on functional or instrumental grounds (treating AI as a tool whose outputs are attributed to human principals) or propose full legal personhood on metaphysical or ethical grounds (treating AI as morally equivalent to humans). The FLS model, by contrast, grounds legal recognition in the measurable presence of autonomous artificial agency, operationalised through the PAB-T. This makes legal subjectivity neither a purely instrumental legal fiction nor a substantive moral claim, but a functional attribution calibrated to the system's actual degree of agency as objectively assessed through technical criteria. See further Andrea Matthias, 'The Responsibility Gap: Ascribing Responsibility for the Actions of Learning Automata' (2004) 6 *Ethics and Information Technology* 175.

1. Learning model
 2. Gradient of control
 3. Environmental complexity
 4. Internal model
 5. Representation & Reasoning
- b) Determine a minimum operational threshold (PAB-T) that, once surpassed, allows complex systems such as the DsAI to be classified as possessing a high level of autonomy in decision-making which translates into a sufficient level of autonomous artificial agency. Once the artificial agency is objectively assessed, it can then constitute the foundational transition point from the concept of technical autonomy to legal autonomy.

The five components adopted for the PAB framework, as discussed in earlier chapters, are not arbitrary chosen. They are indeed grounded in interdisciplinary research and widely reflect the minimal consensus about the cognitive architecture of complex AI systems across different domains.²⁰⁶ Given the previously depicted legal conundrum and the necessity to

²⁰⁶ Such domains are AI theory, cognitive science, software engineering, information philosophy and sociology. *See*, among others: Antonio Lieto, *Cognitive Design for Artificial Minds* (Routledge 2021); Barbara Webb, ‘Can Robots Make Good Models of Biological Behaviour?’ (2001) 24(6) *Behavioral and Brain Sciences*, 1033; John E Laird and others, ‘Interactive Task Learning’ (2017) 32(4) *IEEE Intelligent Systems*, 6; John E Laird, Allen Newell and Paul S Rosenbloom, ‘Soar: An Architecture for General Intelligence’ (1987) 33 *Artificial Intelligence*, 1; Brenden M Lake, Tomer D Ullman, Joshua B Tenenbaum and Samuel J Gershman, ‘Building Machines That Learn and Think Like People’ (2017) 40 *Behavioral and Brain Sciences*, 1; Pat Langley, ‘Interactive Cognitive Systems and Social Intelligence’ (2017) 32(4) *IEEE Intelligent Systems*, 22; Pat Langley, ‘The Cognitive Systems Paradigm’ (2012) 1 *Advances in Cognitive Systems*, 3. The theory and work of Luciano Floridi, must be acknowledged. He proposed 3 main dimensions to attribute the legal capacity to non-human entities such as organisations or algorithms:

(1) interaction (with collaborators or other organisations);

identify the dividing line between instrumental actions and autonomous actions of AI systems²⁰⁷, this thesis proposes to adopt these five criteria to draw a line between non-autonomous and autonomous entities. In particular, the five elements of the Autonomous Behavior Paradigm (PAB) derive from and build on existing interdisciplinary models, originally conceived in the field of cognitive design.²⁰⁸ These models aim at identifying the minimal cognitive requirements that distinguish autonomous inferential systems from purely executive computational mechanisms. This is done by assessing whether a system demonstrates competence in at least three or more of the defined cognitive dimensions.²⁰⁹ The PAB incorporates this multi-parametric threshold logic while defining a set of its own, law-oriented parameters specifically designed to assess decisional autonomy in a normatively relevant way. Therefore, the PAB represents a legally functional evolution of the most relevant cognitive AI models, aimed at providing legal systems with a robust framework to assess when an AI system, particularly a DsAI, qualifies as an autonomous source of legal effects.

As argued, ‘on the basis of properly legal criteria, it will be necessary to indicate what degree of scientifically recognised autonomy of a digital phenomenon can be discussed in a

(2) the ability to self-determine changes of state;

(3) adaptation of decision-making strategies.

For more details, see Luciano Floridi, *The Ethics of Information* (Oxford University Press 2013), 140.

²⁰⁷ The point on how law and legal theory are, at the same time, autonomous and dependent on the relationship between different disciplinary fields, see Gunther Teubner, ‘Rechtswissenschaft und -praxis im Kontext der Sozialtheorie’ in S Grundmann and J Thiessen (eds), *Recht und Sozialtheorie im Rechtsvergleich: Interdisziplinäres Denken in Rechtswissenschaft und -praxis* (Mohr Siebeck 2015), 145 (trad it in P Femia (ed), *I rapporti precari tra diritto e teoria sociale. Drittwirkung. Un percorso nella dottrina tedesca* (Edizioni Scientifiche Italiane 2018) 255).

²⁰⁸ For an analytical description of different cognitive models developed in the AI cognitive field see Antonio Lieto, *Cognitive Design for Artificial Minds* (Routledge 2021). Antonio Lieto developed a practical model called Minimal Cognitive grid (MCG). The MCG model identifies four minimal cognitive dimensions (Functional/structural Ratio; generality; Performance Match; Modelling Paradigm) and a functional threshold ≥ 3 . The PAB extends and adapts some of its parameters to the decisional and legal domain.

²⁰⁹ Ibid, 50-51.

legal sense'.²¹⁰ This thesis aims to adopt precisely this stance: the Paradigm of Autonomous Behaviour (PAB) functions as a juridically relevant filter, enabling legal systems to determine when autonomy becomes meaningful within a normative context, while grounded in technical dimensions. This approach aims to address the controversial issue of *when* autonomy should be recognised. As discussed above, autonomy is not a binary attribute and does not develop along a single linear scale, but rather a gradual and multidimensional phenomenon.²¹¹ Consequently, any assessment of autonomy must consider its distribution among these distinct functional parameters, whose interrelation determines a different degree of decisional autonomy. Therefore, autonomy should not be measured in terms of simple presence or absence, but rather as the result of a specific configuration and interconnection among these parameters, each of which contributes to the overall level of autonomous behavior. This way, the legal status of the DsAI will be functionally determined by the role assumed by the AI system in decision-making processes related to (smart) contractual transactions.

5.5.2 The Technical-Functional Structure of the PAB: Threshold Parameters and Application to the DsAI System

The following table (Table 5.1) represents the operational metric grid of the Paradigm of Autonomous Behaviour (PAB), aimed at translating the level of decisional autonomy expressed by AI systems into assessable and replicable terms. The PAB, as described in previous chapters, is composed of five technical features -or parameters- which represent the basic cognitive structure of AI systems that enables them to operate and make decisions. The PAB allows each of the five parameters to be articulated along a scale of increasing value – or level - (from 0 to 2) where:

²¹⁰ Teubner (n. 207), 51.

²¹¹ Catrin Misselhorn, 'Collective Agency and Cooperation in Artificial Systems: An Introduction' in Catrin Misselhorn (ed), *Collective Agency and Cooperation in Natural and Artificial Systems: Explanation, Implementation and Simulation* (Springer 2015), 1; Melinda F Lohmann, 'Roboter als Wundertüten – eine zivilrechtliche Haftungsanalyse' (2017) 26 (2) *Aktuelle Juristische Praxis*, 152.

- 0 indicates the lowest level or basic feature
- 1 identifies an intermediate level of that feature
- 2 expresses a higher level of the technical parameter

For each parameter, an operational definition is provided that allows the system's behaviour to be verified empirically.²¹² The value assigned to each parameter is based on observable technical conditions recognised in the interdisciplinary literature.²¹³ All five parameters contribute to outline the cognitive and operational potential of AI systems in decision-making.

Parameter	Operative Definition	Level 0	Level 1	Level 2
Learning Model	Ability of the system to learn and update itself autonomously	Static or supervised only. Pre-programmed systems	Supervised or mixed learning. the system shows adaptation but within defined limits.	Neural symbolic learning, symbolic-inductive (i.e. MeTTa language) -enabling the system to build new strategies without external intervention
Gradient of Control	Level of human intervention required in the decision-making process	HITL (Human-in-the-loop)	HITL (Human-in-the-loop)	HOOTL (Human-out-of-the-loop), self-execution
Environmental Complexity	Nature of the operating environment (input-output, adaptability)	Linear, centralised, static - system responsive to deterministic inputs.	Mixed, semi-predictive - the system adapts to variations within known patterns.	Decentralised, nonlinear, dynamic -AI has to react to unpredictable contexts (e.g. blockchain, open-source systems).

²¹² For more extensive explanation and *ratio* behind each parameter refer to chapter 1 of this thesis.

²¹³ These values have been inspired by several AI Cognitive Models. An example is: Classic Ratioanality Model (CR), Bounded Models (RM), bounded-rational Models (BRM), Rational Analysis (RA), Resource Rationality Pradigm (RR), Minimal Cognitive Grid (MCG). For more information about each of those models, see Antonio Lieto, *Cognitive Design for Artificial Minds* (Routledge, 2021).

Internal Models	Presence of internal models that support agency: intentions, desires, beliefs, inferences, values	No internal model - rigidly causal behaviour. i.e. deterministic system / reactive script.	Simple internal models, reactive (i.e. static preferences, scores). i.e. Simple agent-based model with predefined goals.	Simulated mental states, modeled higher intentionality, meta-intentionality, purpose inference. i.e. BDI agents, DsAI, OpenCog Hyperon, agents with MeTTa
Self-organisation Representation & Reasoning	Ability to build and manipulate symbolic and abstract representations	Numerical data, pattern with no semantic structure.	Simple symbolic representation; static rules or predicative logic.	Symbolic inference, nonmonotonic, evolutionary conceptual reasoning - ability to deal with uncertainty (i.e. PLN, neural symbolic architectures).

Table 5.1 - Operational Metric Grid of PAB Parameters and Values

Each of the five parameters with their own gradient levels moves across a different degree of dynamic integration and interrelation with one another, as follows (Table 5.2):

Degree of Integration/Interrelation	Operational Definition
0	Additive Parameters: each of the 5 parameters function separately, even when reaching level 1 or 2.
1	Partial Integration amongst the parameters (i.e. learning model <->environment): coordinated parameters interact functionally but without structural co-dependence.
2	Systemic Integration: each parameter dynamically effects and modulates the others (i.e. internal models <->environment<->reasoning<->learning<->control). Parameters are interdependent, forming a coherent, self-reflective system

Table 5.2 - The Degree of Integration of PAB Parameters

In the Paradigm of Autonomous Behaviour (PAB) model, the five identified technical parameters (learning model, degree of control, environmental complexity, internal models, representation and reasoning) are not isolated: they operate as dynamically interconnected components. The ability of AI systems to achieve a relevant level of autonomy in decision-

making depends not only on the value of the individual parameters, but also on the degree of integration between them, according to the following progression (see Table 5.2):

- Level 0 - No integration (additive parameters). At level 0 each parameter functions independently, without influencing or modulating the others. An example is when an AI system uses a supervised learning model on static data, in a simple environment (i.e. automatic pricing in a closed context), without adapting or updating according to the context or its own internal models. From a technical and legal perspective, the system is a sum of disjointed functions, comparable to an algorithmic executor without agency.
- Level 1 - Partial integration (coordinated parameters). At level 1, there are functional links between some parameters, but not fully dynamic interdependence. Interaction is bidirectional but limited. For instance, a DsAI system that adapts its behaviour according to environmental change (e.g. DeFi market fluctuations), circumscribing its learning model. However, internal models or inference logic do not change structurally, and human control remains partially present. Autonomy is evolving, but still incomplete. AI can learn and react but lacks the systemic coherence to attribute independent agency.
- Level 2 - Systemic integration (interdependent parameters). At level 2, all parameters operate in a dynamically integrated and modulating manner. Decisions emerge from a continuous interaction between internal models, learning, environment, representation and control. An operational example is an autonomous DsAI managing a liquidity pool on a permissionless blockchain. It processes symbolic representations and predictive reasoning based on user and market behaviour; updates its learning models based on fluctuations and performance; adapts its internal models, updating objectives and operational strategies; operates without supervision, and decides autonomously when and how to interact with other smart contracts. Decisions are not pre-programmed but emerge from the interaction between modules. From an operational perspective, a form of autonomous artificial agency might be configured with a high level of autonomy in decision-making.

Therefore, given the above, in order for a complex AI system to be considered as having a higher degree of cognitive and operational autonomy in the decision-making process, it must:

- obtain at least level 2 in at least 3 out of 5 parameters

and

- obtain a level 2 in the degree of integration between parameters.

This combination represents the PAB threshold (PAB-T), which is set at level 2 in at least 3 out of 5 parameters (functional threshold ≥ 3) with at least a level 2 in the integration between parameters, which represents the higher level of systemic integration. The PAB-T has been chosen as it represents a balance point between functional autonomy and technical realism. Three parameters at the highest level represent a sufficient functional critical mass to generate decision-making and executive autonomy, adaptability and operational self-determination.²¹⁴ The PAB is an integrated hierarchical system. Three high-level modules

²¹⁴ A useful comparative reference to ground the conceptual rigor of the Paradigm of Autonomous Behaviour (PAB) is offered by the model known as Minimal Cognitive Grid (MCG), developed by Antonio Lieto to assess the cognitive plausibility of artificial systems. Both models share a gradual, multi-parametric logic-functional structure, aimed at identifying a significant threshold of operational autonomy. The MCG is based on three main dimensions: (1) the Functional/Structural Ratio, which evaluates the relationship between functional behaviour and actual structural similarity with human cognitive mechanisms; (2) Generality, which measures the system's ability to adapt to different tasks; and (3) Performance Match, which compares the system's functioning with human cognitive performance, including processualism and fallibility. Each dimension is rated on an increasing scale (from 0 to 2), which allows intermediate and non-binary degrees of cognitive plausibility to be defined. Similarly, the PAB consists of five technical parameters - learning model, degree of control, environmental complexity, internal models, representational-inferential capacity - also assessed on a 0-2 scale and subjected to a further systemic integration test. The decision to set the threshold of the PAB at 3 out of 5 parameters at the maximum level (≥ 2), together with a level 2 in the degree of integration between parameters, is inspired by the same logic as the MCG: a sufficient critical functional mass is required for cognitive autonomy. However, whereas the MCG has as its aim the classification of cognitive plausibility, the PAB inherits its ratio in order to convert it into a legally relevant criterion,

therefore guarantee synergetic interaction, not a simple sum. High decision-making autonomy is always the result of the level of integration between the parameters. Conversely, a threshold of 2 out of 5 would be too low. For example, systems with only deep learning and no control, but without high internal models or representational and inferential capacity, would be at a medium-low threshold at the cognitive level. Therefore, they would lack sufficient decision-making autonomy to generate artificial agency. Instead, a threshold of 4 or 5 out of 5 would also be unrealistic for many current advanced systems (i.e. DAOs, neurosymbolic agents), rendering the model unusable. This structure thus makes it possible to determine whether a DsAI system exceeds the minimum threshold (PAB-T) to be considered an autonomous source of agency. Exceeding the threshold (≥ 3 out of 5 parameters at level 2 with level 2 integration) constitutes the legally relevant point for the recognition of agency and autonomy in the legal domain. True autonomy of decision-making depends therefore not only on individual modules, but on their dynamic interaction. An agent may have excellent learning capacity, but no symbolic representation or it may infer reasoning but not adapt to environmental change. Only integration at level 2 ensures that the modules interact with each other in real time, the agent is able to adapt and modulate behaviour and there is a plausible technical basis for inferring functional agency and potential autonomy in the legal sphere. Legally, indeed, without integration, it is difficult to have intentional behaviour that can potentially produce legal effect. In the latter case an AI system would easily fall into the category of mere automation, not autonomy. There would be no functional coherence between decision, representation and action, thus no prerequisites for artificial agency. Therefore, this thesis infers that the PAB-T reflects a principle of minimum sufficient balance between all parameters. This is a criterion that allows, at the same time, to: 1) exclude systems that are too simple or dependent on human control; 2) include AI systems with significant autonomy, even without reaching all level 2 in

capable of determining when a DsAI system can be considered an autonomous source of agency and, therefore, deserving of functional legal recognition. For more, *see* Antonio Lieto, *Cognitive Design for Artificial Minds* (Routledge 2021), 38; Antonio Lieto, ‘Cognitive Biases and the Human Heuristics for Artificial Agents’ (2021) 22(1) *Biologically Inspired Cognitive Architectures*, 1; Antonio Lieto, ‘Ranking the Cognitive Plausibility of Computational Models of Metaphors with the Minimal Cognitive Grid: A Preliminary Study’ in *Proceedings of AISC 2024, XX Conference of the Italian Association of Cognitive Science* (2024).

every single parameter. When assessing the degree of autonomy in decision making for AI systems, there are two parameters that can greatly affect the result. These are:

- Internal models (beliefs, desires, intentions, value, self-model): this is the parameter that signals the existence of a computational intentionality, and is central to distinguishing an autonomous agent from a passive executor;²¹⁵
- Representation & reasoning: Ability to model internal models and infer actions is a precondition for algorithmic intentionality and decision-making agency.

These parameters, when present at level 2 with a ≥ 2 integration, form the minimum basis for attributing a higher degree of cognitive status where complex AI system decides, acts, adapts and represents operational purposes in a sufficiently independent manner.²¹⁶ In other words, it is necessary when assessing the level of integration among the parameters that the level of internal models and representation-reasoning achieves the maximum degree. This

²¹⁵ As discussed in previous chapters, beliefs are information the agent possesses about him/herself, others and the world; Desires/Goals Desired end states; what the agent would like to achieve; Intentions represent deliberate commitments to achieve a certain goal. Preferences/Values constitute the selection criteria or operational priorities; Self-models is the ability to represent and self-regulate. These elements are dynamic: they change over time in response to the environment, learning, and interaction with other agents. For more, *see* Allen Newell, *Unified Theories of Cognition* (Harvard University Press 1990).

²¹⁶ This is what Antonio Lieto refers to as ‘inspired cognition’: i.e. at least symbolic representation, non-monotonic inference and adaptive learning are required to confirm that an AI is sufficiently autonomous in its decision-making. This is also confirmed by the studies Michael Bratman, Anand Rao and Michael Georgeff Bratman introduced the model - BDI (Belief-Desire-Intention) to describe practical human reasoning, which was later formalised by Rao and Georgeff for applications in artificial agents. This architecture distinguishes between beliefs (information about the environment), desires (goals) and intentions (action plans), providing a framework for agents with complex internal models. For more, *see* Antonio Lieto, *Cognitive Design for Artificial Minds* (Routledge 2021); Anand S Rao and Michael P Georgeff, ‘BDI Agents: From Theory to Practice’ (1995) *Proceeding of The First International Conference on Multiagent systems* <<https://cdn.aaai.org/ICMAS/1995/ICMAS95-042.pdf>> accessed 9 June 2025.

ensures that the cognitive element is sufficiently high to maintain a higher level of inference in decision-making.

To make an example of how the PAB can work on simpler AI system, it is possible to apply its logic to one of the latest models of OpenAI ChatGPT 4-o²¹⁷, as follows (see Table 5.3):

Parameter	Level	Description
Learning model	0	The model does not learn in real time: its model is pre-trained and static during inference. No online updates.
Gradient of control	1	Human control is partial: output is autonomously generated, but can be directed via prompts, or stop-sequences.
Environmental complexity	1	The model processes complex information and can simulate contexts but does not perceive or interact with real environments dynamically.
Internal models	0	It has no dynamic internal models, intentions, motivations, or autonomous persistent memory (unless external mechanisms such as the “memory” API).
Representation and Reasoning	1-2	Advanced capacity for symbolization and linguistic inference, but not formally logical or ontologically coherent. Can simulate reasoning.

Table 5.3 – Application of PAB to OpenAI ChatGPT 4.o model

Based on ChatGPT features, it is possible to assign a level (0-2) to each parameter of the PAB. At the same time, it is also possible to infer a degree of interaction among the parameters (Table 5.4):

²¹⁷ OpenAI, ‘GPT-4o System Card’ (2024) available at < <https://cdn.openai.com/gpt-4o-system-card.pdf>> accessed 7 May 2025.

Level of Integration	Level	Description
Interrelation among parameters	1	Some partial interactions (i.e., reasoning ↔ prompt ↔ output), but no dynamic systemic integration between modules: each component operates with structural separation (prompt in, text out).

Table 5.4 – Level of Integration of PAB Parameters of ChatGPT 4-o model

Based on the results, ChatGPT fails to qualify as an entity with artificial autonomous agency as the system does not pass the PAB Threshold (≥ 3 parameters at level 2 + systemic integration at level 2). This outcome is coherent with the module characteristics: ChatGPT does not pass 3 parameters at Level 2 (none reaches it) and the degree of integration between parameters is only partial (level 1). In the following paragraph, it will be shown as the PAB can be applied to complex cognitive systems like DsAI systems.

5.5.3 The Graduated Structure of Legal Consequences

The graduated structure of the PAB, from additive parameters (Level 0) through partial integration (Level 1) to systemic integration (Level 2), generates a corresponding graduated structure of legal consequences, which it is necessary to make explicit in order to demonstrate that the PAB operates as a normatively coherent instrument and not merely as a technical classification device.

At PAB Levels 0–1 (below PAB-T): A DsAI system that fails to satisfy the threshold cannot be treated as an autonomous source of legal effects. Its conduct must be attributed entirely to the human or legal persons responsible for its deployment and operation, under the ordinary rules of vicarious liability, product liability, or electronic agency. Any sole-code smart contract executed by a sub-threshold DsAI is legally treated as an automated execution of

instructions emanating from identifiable deploying parties, amenable to the standard framework of electronic contracting.²¹⁸

At PAB-T (threshold satisfied): A DsAI system that meets the PAB-T, at least three parameters at Level 2 with Level 2 systemic integration, including Parameters 4 and 5, acquires functional legal subjectivity under the Functional Legal Subjectivity model. The sole-code smart contract it produces is amenable to classification as a valid implied contract under PECL Article 2:102, with the DsAI recognised as the functional source of the conduct that constitutes the contractual act. Responsibility for the consequences of those effects is distributed among the participating legal subjects according to their role within the decentralised architecture.²¹⁹

Above PAB-T (full systemic integration): Where a DsAI system substantially exceeds the threshold, achieving Level 2 across all five parameters with full systemic integration, the case for functional legal subjectivity is correspondingly stronger, and the legal consequences of its conduct may extend more broadly within the contractual domain. The PAB does not set a ceiling on the legal relevance of DsAI conduct; it establishes a threshold below which such relevance cannot be asserted. Above that threshold, the normative consequences are calibrated to the specific features of the system and the transaction in question, assessed on a case-by-case basis using the PAB as the evaluative framework. The graduated structure of the PAB, from additive parameters (Level 0) through partial integration (Level 1) to systemic integration (Level 2), generates a corresponding graduated structure of legal consequences, which it is necessary to make explicit in order to demonstrate that the PAB operates as a normatively coherent instrument and not merely as a technical classification device.

²¹⁸ UNCITRAL Model Law on Electronic Commerce (1996), art 11; Electronic Commerce Act 2000 (Ireland), s 19. On the framework of electronic contracting applicable to sub-threshold systems, *see* Section 5.4 of this thesis.

²¹⁹ On the FLS model and responsibility distribution at threshold, *see* Sections 5.3--5.4 of this thesis; Florian Möslin, 'Robots in the Boardroom: Artificial Intelligence and Corporate Law' in Woodrow Barfield and Ugo Pagallo (eds), *Research Handbook on the Law of Artificial Intelligence* (Edward Elgar 2018) 649, 663.

At PAB Levels 0–1 (below PAB-T): A DsAI system that fails to satisfy the threshold cannot be treated as an autonomous source of legal effects. Its conduct must be attributed entirely to the human or legal persons responsible for its deployment and operation, under the ordinary rules of vicarious liability, product liability, or electronic agency. Any sole-code smart contract executed by a sub-threshold DsAI is legally treated as an automated execution of instructions emanating from identifiable deploying parties, amenable to the standard framework of electronic contracting.²²⁰

At PAB-T (threshold satisfied): A DsAI system that meets the PAB-T, at least three parameters at Level 2 with Level 2 systemic integration, including Parameters 4 and 5, acquires functional legal subjectivity under the Functional Legal Subjectivity model. The sole-code smart contract it produces is amenable to classification as a valid implied contract under PECL Article 2:102, with the DsAI recognised as the functional source of the conduct that constitutes the contractual act. Responsibility for the consequences of those effects is distributed among the participating legal subjects according to their role within the decentralised architecture.²²¹

Above PAB-T (full systemic integration): Where a DsAI system substantially exceeds the threshold, achieving Level 2 across all five parameters with full systemic integration, the case for functional legal subjectivity is correspondingly stronger, and the legal consequences of its conduct may extend more broadly within the contractual domain. The PAB does not set a ceiling on the legal relevance of DsAI conduct; it establishes a threshold below which such relevance cannot be asserted. Above that threshold, the normative consequences are calibrated to the specific features of the system and the transaction in question, assessed on a case-by-case basis using the PAB as the evaluative framework.

²²⁰ UNCITRAL Model Law on Electronic Commerce (1996), art 11; Electronic Commerce Act 2000 (Ireland), s 19. On the framework of electronic contracting applicable to sub-threshold systems, *see* Section 5.4 of this thesis.

²²¹ On the FLS model and responsibility distribution at threshold, *see* Sections 5.3--5.4 of this thesis; Florian Möslin, 'Robots in the Boardroom: Artificial Intelligence and Corporate Law' in Woodrow Barfield and Ugo Pagallo (eds), *Research Handbook on the Law of Artificial Intelligence* (Edward Elgar 2018) 649, 663.

5.5.4 The PAB as Regulatory and Compliance Instrument

Beyond its function within the Functional Legal Subjectivity model, the PAB has significant potential as a regulatory and compliance instrument across a broader range of legal and governance contexts. Its capacity to provide a technically grounded, objectively assessable metric for the degree of autonomous decision-making exhibited by an AI system enables it to perform three distinct but complementary regulatory functions that current frameworks are structurally unable to perform in relation to decentralised systems: (i) classification for risk-based regulatory regimes; (ii) compliance operationalisation through verifiable technical criteria; and (iii) regulatory intervention thresholds calibrated to degrees of system autonomy.

(i) Classification Function: Addressing the Regulatory Gap in Decentralised AI Governance

The AI Act's risk classification system is built around a centralised, supply-chain-oriented logic that presupposes identifiable providers, deployers and distributors operating within a regulated product lifecycle.²²² This logic is structurally incompatible with the open, permissionless and anonymous architecture of decentralised blockchain environments, where no single actor occupies the role of provider or deployer in the sense the Act requires. The result is a significant regulatory gap: DsAI systems operating in decentralised environments are formally within the scope of the Act's definition of AI but practically beyond the reach of

²²² European Parliament and Council Regulation (EU) 2024/1689 (AI Act) [2024] OJ L 2024/1689, arts 3(2)–(4) (provider, deployer, distributor definitions), arts 6–7 (classification rules), Annex III (high-risk AI systems). On the structural incompatibility between the AI Act's supply-chain logic and decentralised blockchain architectures, see Primavera De Filippi and Aaron Wright, *Blockchain and the Law: The Rule of Code* (Harvard University Press 2018) 75–78; EU Blockchain Observatory and Forum, 'Legal and Regulatory Framework of Blockchains and Smart Contracts' (European Commission 2019) 33–36.

its compliance mechanisms. The PAB offers a technically coherent response to this gap. Applied as a classification tool within a future regulatory framework, it could function as the basis for a graduated regulatory regime in which compliance obligations are calibrated to the degree of autonomous decision-making the system exhibits, rather than to the identity and role of specific human actors within a supply chain.

Under such a regime, DsAI systems that fall below the PAB-T would be classified as low-autonomy systems, subject to the ordinary framework of electronic agency and product liability, with regulatory obligations imposed upon identifiable deploying parties under existing rules. DsAI systems that meet or exceed the PAB-T would be classified as high-autonomy systems, triggering a distinct regulatory regime adapted to the specific risks and governance challenges posed by autonomous artificial agency in decentralised environments. This classification would be technically verifiable: the five PAB parameters are measurable through architectural analysis, learning model inspection, environmental assessment, internal model documentation, and representational capacity testing. Such a regime would thus offer regulatory certainty where current frameworks provide none, without requiring the impossible task of identifying a provider or deployer in contexts where those categories are structurally absent.

(ii) Compliance Operationalisation: The Five Criteria as Verifiable Governance Standards

The five PAB parameters can serve as the technical foundation for compliance requirements across multiple regulatory domains. Each parameter translates into specific, auditable, and operationally enforceable standards:

- **Learning Model (Parameter 1):** Compliance frameworks could require disclosure and third-party verification of the learning architecture deployed. Systems employing unsupervised or reinforcement learning mechanisms would be subject to heightened documentation and testing requirements compared to supervised learning systems, reflecting the greater autonomy and unpredictability associated with higher-level

learning models. This is directly analogous to the model validation requirements already imposed on algorithmic trading systems in financial markets, where the type of learning mechanism determines the intensity of regulatory oversight.²²³

- **Gradient of Human Control (Parameter 2):** Regulatory regimes could establish mandatory intervention points for systems operating in HOOTL (Human-Out-of-the-Loop) mode via on-chain and off-chain governance.²²⁴ For example, in financial services, a DsAI system executing high-value transactions without human oversight could be required to implement automated circuit breakers, external monitoring interfaces, or periodic human review checkpoints, ensuring that full autonomy is accompanied by proportionate safeguards. This approach is already reflected in MiFID II's requirements for algorithmic trading systems, which impose specific organisational and technical controls calibrated to the degree of system's automation.²²⁵
- **Environmental Complexity (Parameter 3):** Systems operating in nonlinear, high-complexity environments could be subject to enhanced stress testing and scenario analysis requirements, ensuring that their adaptive decision-making functions reliably under adverse or unprecedented conditions. This is particularly relevant in sectors such

²²³ On model validation requirements in algorithmic trading, *see* Commission Delegated Regulation (EU) 2017/589 [2017] OJ L 87/417, arts 9–12 (algorithmic trading systems- organisational requirements); ESMA, Guidelines on Systems and Controls in an Automated Trading Environment for Trading Platforms, Investment Firms and Competent Authorities (2012) ESMA/2012/122, paras 26–35.

²²⁴ Primavera de Filippi, Greg McMullen, 'Governance of blockchain systems: Governance of and by Distributed Infrastructure' (2018) Blockchain Research Institute and COALA.

²²⁵ Directive 2014/65/EU (MiFID II) [2014] OJ L 173/349, arts 17 and 48 (algorithmic trading); Commission Delegated Regulation (EU) 2017/589 [2017] OJ L 87/417, arts 9–12, 15–17 (requirements for systems based on degree of automation).

as decentralised finance (DeFi), where environmental complexity directly amplifies systemic risk.

- **Internal Models (Parameter 4):** Compliance frameworks could require transparency regarding the goal structures, belief representations, and intention-formation mechanisms embedded within the system's architecture. For DsAI systems at Level 2 on this parameter, those exhibiting higher-order intentional states and meta-cognitive self-regulation, regulatory standards could mandate periodic audits of goal alignment, ensuring that the system's internal objectives remain consistent with its documented design specifications and do not drift towards unintended or harmful outcomes.
- **Representational and Inferential Capacity (Parameter 5):** Systems with Level 2 symbolic reasoning and self-organisation capacity could be required to maintain explainability interfaces, enabling regulators and affected parties to understand the reasoning processes that generated specific decisions. This requirement is already emerging in the AI Act's provisions on transparency and explicability for high-risk AI systems; however, the PAB framework would broaden it and extend it specifically to highly cognitive AI systems such as decentralised AI systems, where explainability is both technically more challenging and legally more urgent given the absence of identifiable human decision-makers.

Taken together, these parameter-specific compliance requirements would constitute a comprehensive governance framework, operationally grounded in the technical architecture of AI systems and directly responsive to the specific autonomy-related risks each parameter represents. Importantly, this framework would be scalable across legal domains: the same five criteria that determine the artificial agency and capacity under the FLS model could equally determine the gradient and intensity of regulatory oversight in, for instance: DeFi regulation, the application of data protection requirements under the GDPR, the regulatory classification for robotic-AI driven systems. The PAB thus offers not merely a doctrinal instrument for one area of law, but a unifying technical-legal architecture for AI governance across multiple regulatory contexts.

(iii) Regulatory Intervention Thresholds: Graduated Obligations Calibrated to Autonomy Levels

The PAB's graduated structure, from Level 0 (additive parameters) through Level 1 (partial integration) to Level 2 (systemic integration), provides a natural foundation for regulatory intervention thresholds. Rather than imposing uniform obligations on all AI systems regardless of their degree of autonomy, regulators could calibrate intervention intensity to the system's position on the PAB scale:

- **Below PAB-T (Levels 0–1):** Minimal regulatory intervention, with obligations imposed on deploying parties under existing AI frameworks. Systems at this level function as instruments of human principals and do not require autonomy-specific governance.
- **At PAB-T (threshold satisfied):** Moderate regulatory intervention, triggering obligations adapted to autonomous artificial agency but calibrated to the system's functional characteristics. Systems at this level exhibit sufficient autonomy to warrant legal recognition as functional agents, and regulatory obligations should then reflect the distributed structure of decentralised architectures. This could include mandatory disclosure of the system's autonomy profile, periodic re-assessment of PAB scores, and the implementation of governance safeguards (such as dispute resolution mechanisms or circuit breakers) appropriate to the degree of autonomy exhibited.
- **Substantially Above PAB-T (full systemic integration, all parameters at Level 2):** Heightened regulatory intervention, reflecting the greater legal significance and systemic risk associated with fully autonomous systems. Such systems could be subject to pre-deployment authorisation requirements, continuous monitoring obligations, mandatory insurance or collateralisation schemes, and enhanced transparency and explainability standards. The precise form of these obligations would be domain-specific and environment-specific (i.e. centralised vs decentralised; permissionless vs permissioned) but the PAB threshold would provide the technically grounded criterion determining when they apply.

This graduated approach potentially mirrors both the bottom-up approach and the risk-based logic already embedded in European regulatory frameworks, from the AI Act's tiered classification system to the proportionality principle that underpins GDPR enforcement. The PAB's contribution is to provide a technically operationalisable metric for determining where on the autonomy spectrum a given system falls, enabling regulators to move from broad, subjective categories ('high-risk AI', 'automated decision-making') to precise, measurable thresholds grounded in the system's actual cognitive architecture and operational characteristics.

The model for such a regime already exists in European financial services regulation, where algorithmic trading systems are subject to graduated regulatory obligations calibrated to their degree of automation, a direct analogue of the PAB-based classification approach proposed here.²²⁶ More broadly, the PAB could function as a safe harbour criterion: a DsAI system that satisfies the PAB-T in a verified and documented manner could be presumed to require attribution-specific governance, triggering the application of the FLS framework and its associated distribution model, while a system that demonstrably falls below the threshold could rely on the standard AI framework, with legal effects attributed to identifiable human principals. This safe harbour function would provide regulatory certainty for developers, deployers, and users of decentralised AI systems, enabling the development of governance standards tailored to the specific characteristics of various AI autonomous systems.

The PAB thus offers not only a doctrinal instrument for resolving the legal paradox identified in this thesis, the uncertainty of applying existing contract law frameworks to autonomous DsAI conduct, but also a practical regulatory tool for the governance of decentralised AI in contexts where existing frameworks have, as yet failed to reach. Its operational usefulness can potentially extend across different law domains. In each of these domains, the five PAB criteria can provide a common technical foundation upon which domain-specific regulatory regimes can be constructed, ensuring coherence across legal fields

²²⁶ Ibid. See also ESMA, Final Report: Guidelines on Systems and Controls in an Automated Trading Environment (2012) ESMA/2012/122.

while preserving the flexibility to adapt governance requirements to the particular risks and characteristics of each regulatory context.²²⁷

5.5.5 The Application of the PAB to DsAI Systems: from Operational Autonomy to Artificial Agency

This section evaluates the theoretical soundness of the Paradigm of Autonomous Behaviour (PAB) by applying its framework to a specific use case of a Decentralised Artificial Intelligence system: the OpenCog Hyperon.²²⁸ It is a next-generation cognitive architecture that integrates learning, symbolic reasoning, and self-editing within a modular, distributed system.²²⁹ Hyperon is designed to model general-purpose artificial agents capable of operating in complex, dynamic, multi-agent environments without human supervision.²³⁰ The selection of Hyperon is driven by its explicit objective to replicate cognitive frameworks similar to those that underpin human decision-making autonomy, encompassing goal representation, meta-reasoning, and ongoing contextual adaptation. The architecture, centred on the declarative

²²⁷ On cross-sectoral application of autonomy metrics in AI governance, *see* Ryan Calo, ‘Robotics and the Lessons of Cyberlaw’ (2015) 103 *California Law Review* 513; Mireille Hildebrandt, *Smart Technologies and the End(s) of Law* (Edward Elgar 2015) 179–205; Luciano Floridi and others, ‘AI4People An Ethical Framework for a Good AI Society: Opportunities, Risks, Principles, and Recommendation’ (2018) 28 *Minds and Machines* 689; High-Level Expert Group on Artificial Intelligence, *Ethics Guidelines for Trustworthy AI* (European Commission 2019) 17–20 (on domain-specific adaptation of AI governance frameworks).

²²⁸ OpenCog Foundation, *OpenCog Hyperon* (OpenCog, 2024) <<https://hyperon.opencog.org>> accessed 5 June 2025.

²²⁹ Ben Goertzel, ‘Patterns of Cognition: Cognitive Algorithms as Galois Connections Fulfilled by Chronomorphisms On Probabilistically Typed Metagraphs’ (arXiv, 21 February 2021) <<https://doi.org/10.48550/arXiv.2102.10581>> accessed 5 June 2025.

²³⁰ Ben Goertzel, ‘Paraconsistent Foundations for Probabilistic Reasoning, Programming and Concept Formation’ (arXiv, 29 December 2020) <<https://doi.org/10.48550/arXiv.2012.14474>> accessed 5 June 2025.

language MeTTa²³¹ and a graph-structured knowledge store (AtomSpace), provides significant representational and inferential capabilities, essential for assessing factors such as internal models and overall cognition.²³² This section evaluates whether Hyperon, as a DsAI system, demonstrates adequate operational integration and intentional coherence to attain a high level of operational autonomy in decision-making as assessed using the PAB framework.

The applicability of the PAB to OpenCOG Hyperon (Table 5.5) moves from its technical features. The outcome is the following:

Parameter	Level	Description
Learning model	2	OpenCog Hyperon implements: meta-learning systems, where agents learn not only actions, but reasoning structures; cognitive synergy: different learning modules (e.g., ML, inference) and collaborate to update shared representations. ²³³
Gradient of control	2	Hyperon agents are designed to operate autonomously in virtual, decentralised or multi-agent environments; human intervention occurs only in the bootstrapping

²³¹ The MeTTa language (short for Meta-Type Talk) is the declarative, metalinguistic programming language developed for the OpenCog Hyperon architecture, the general artificial intelligence (AGI) framework designed by Ben Goertzel and the SingularityNET/OpenCog team. MeTTa is not a traditional language but a language that can represent and process other languages. It is designed to describe and manipulate complex cognitive structures, such as thoughts, logical inferences, learning patterns, and semantic representations. For a better understanding of MeTTa Language, *see* OpenCog Foundation, ‘MeTTa Language Documentation: Evaluation and Main Concepts’ (OpenCog, 2024) <https://metta-lang.dev/docs/learn/tutorials/eval_intro/main_concepts.html> accessed 5 June 2025.

²³² Ben Goertzel, Alexey Potapov and André Senna, ‘Toward a New Improved OpenCog – Preliminary Design Ideas’ (SingularityNET-OpenCog Team, 8 July 2020) <https://opencog.org/w/Toward_a_New_Improved_OpenCog> accessed 5 June 2025.

²³³ Ben Goertzel and others, OpenCog Hyperon: A Framework for AGI at the Human Level and Beyond – High-Level Background & Introduction (31 October 2023) <<https://hyperon.opencog.org>> accessed 5 June 2025.

		phase, then the agent generates and selects its own actions. ²³⁴
Environmental complexity	2	Hyperon is designed for agents who interact in uncertain and highly dynamic environments; deal with ill-defined problems (not just decision-making, but meta-reasoning); coordinate with other agents through expressive languages. ²³⁵
Internal models	2	Hyperon agent represents its goals in declarative form in MeTTa language; has self-monitoring and self-editing features (attentional focus coupled with goal management); evaluates actions ex post through cognitive feedback. ²³⁶
Representation and Reasoning	2	Hyperon uses graph-based declarative reasoning on semantic networks (AtomSpace); deduction, abduction and analogy as cognitive tools; meta-inference, i.e., reasoning about one's logical structures. ²³⁷

Table 5.5 – Application of PAB to OpenCOG Hyperon model

As for the level of integration among parameters (Table 5.6):

Level of Integration	Level	Description
Interrelation among parameters	2	Learning drives representational restructuring->Representations underlie goal formulation and reevaluation->Inferences retroact on behavior, modulating it in social environments. The agent

²³⁴ Gabriel Axel Montes and Ben Goertzel, ‘Distributed, Decentralized, and Democratized Artificial Intelligence’ (2023) <<https://arxiv.org/abs/2308.09703>> accessed 5 June 2025

²³⁵ Superintelligence Institute, ‘OpenCog Hyperon’ (Superintelligence.io, 2023) <<https://superintelligence.io/portfolio/opencog-hyperon/>> accessed 5 June 2025.

²³⁶ Ibid.

²³⁷ Ibid.

		modulates reflectively. ²³⁸	itself	self-

Table 5.6 – Level of integration of PAB Parameters of OpenCOG Hyperon

The OpenCog Hyperon case represents an advanced level of high operational autonomy in decision-making ability of a complex DsAI system. The presence of higher levels of internal goals, declarative inference, adaptive learning, and decentralised operability justifies exceeding the PAB-T threshold level. Thus, it is inferred that Hyperon can be qualified as a unit with artificial agency, understood as the autonomous capacity to act intentionally to pursue a specific purpose or objectives.

Autonomy, in its technical-operational form, is understood as the ability of a system to act independently, adaptively and purposefully within a complex environment. In DsAI systems, this condition is fulfilled when the agents:

- formulate internal goals (parameter 4)
- evaluate alternative actions through inferential reasoning (parameter 5)
- adapt to changing environments (parameter 3)
- learn from experience (parameter 1)
- act without human intervention (parameter 2)

This framework of operational autonomy corresponds to the artificial agency: a self-directed and self-updating system, capable of consistent intentional behaviour over time and context. A high level of autonomous complex AI system like Hyperon, which can be regarded as having artificial agency, demonstrates, at the same time, to possess a higher-order

²³⁸ Ben Goertzel and others, OpenCog Hyperon: A Framework for Cognitive Synergy-Driven AGI (OpenCog Foundation 2023) <<https://github.com/opencog/hyperon>> accessed 10 June 2025.

intentionality which entails having control of its own mental states. As stated, ‘a system with a higher-order intentionality involves possessing intentional states which have other intentional states as their objects, i.e. beliefs about beliefs, belief about desires, desires about beliefs’.²³⁹ AI systems with higher-order intentionality and autonomy are able to form and adapt their own mental states and reflect upon them based also on other agent’s mental states.²⁴⁰ Therefore, a DsAI system like Hyperon can successfully realise its own intention and to adapt its plans accordingly.²⁴¹ DsAI systems with high autonomy in decision-making, entailing higher intentionality and artificial agency make a qualitative difference in determining the ability of the system to be qualified as an autonomous source of intentional actions. In other words, these systems are good candidates for being recognised as an autonomous cause of producing legal effects in the law domain. However, having high level of autonomy and operational agency in producing legal effects does not encompass being recognised as a subject of law with legal personhood. Therefore, the next section is dedicated to introducing the concept of functional legal subjectivity for high-level autonomous DsAI systems.

5.5.6 Practical Case Study: A DsAI-Governed Automated Market Maker on the Ethereum Blockchain

5.5.6 a) Introduction and System Selection

The preceding sections have established the PAB as a technically grounded framework for assessing when DsAI systems achieve the degree of autonomous decision-making that warrants legal attribution of their conduct. The present section complements that analysis with a focused case study: a DsAI-governed Automated Market Maker (AMM) protocol operating on the Ethereum mainnet. The AMM is selected because it presents, in maximally concrete

²³⁹ Catrin Misselhorn, ‘Collective Agency and Cooperation in Natural and Artificial Systems: Explanation, Implementation and Simulation’ in *Collective Agency and Cooperation in Natural and Artificial Systems: Explanation, Implementation and Simulation*, Catrin Misselhorn (edn), (Springer 2015), 7.

²⁴⁰ Ibid.

²⁴¹ Ibid.

form, all of the legal challenges that the PAB and FLS models are designed to address: the absence of an identifiable human counterparty, the autonomous formation and execution of binding contractual obligations, the production of legally significant economic effects, and the structural inaccessibility to existing regulatory frameworks.²⁴²

5.5.6 b) Technical Description of the DsAI-AMM System

The system modelled is a DsAI-governed concentrated liquidity AMM, structurally analogous to Uniswap v3 enhanced with an autonomous AI management layer. It consists of two principal components operating in concert.²⁴³

²⁴² One example is Gamma Strategies, an active liquidity management protocol on Uniswap v3 deployed on the Ethereum mainnet. It autonomously manages concentrated liquidity positions through machine learning-derived strategies (i.e, Autoregressive Strategy), which predict and optimise price ranges based on historical data and volatility, reducing impermanent losses and maximising fees without continuous human intervention. Gamma operates as a ‘Hypervisor’: users deposit tokens (i.e, ETH/USDC) in ERC-20 vaults, which the on-chain smart contract allocates on Uniswap v3 pools. The off-chain AI monitors markets, automatically rebalances ranges via a keeper (similar to your oracles), and adapts strategies to dynamic conditions such as volatile gas fees or MEV, operating in HOOTL mode post-deposit- ideal for testing PAB Level 2 on learning and internal models. *See* Gamma on Polygon, <<https://polygon.technology/blog/gammas-ai-powered-liquidity-strategies-for-uniswap-are-coming-to-polygon>> accessed 10 March 2026; On the economic significance of decentralised AMM protocols, *see* Hayden Adams and others, ‘Uniswap v3 Core’ (Uniswap 2021) <<https://uniswap.org/whitepaper-v3.pdf>> accessed 2 March 2026. As of June 2025, Uniswap v3 alone processes over \$2 billion in daily trading volume, demonstrating the commercial scale and legal significance of AMM protocols.

²⁴³ The integration of AI agents with AMM protocols for autonomous liquidity management represents one of the most commercially significant applications of DsAI in the DeFi ecosystem. *See* Gabriel Axel Montes and Ben Goertzel, ‘Distributed, Decentralized, and Democratized Artificial Intelligence’ (2023) arXiv:2308.09703, 12–16; Longbing Cao, ‘Decentralized AI: Edge Intelligence and Smart Blockchain, Metaverse, Web3, and DeSci’ (2022) 37(3) IEEE Intelligent Systems 6, 7–8.

The on-chain AMM smart contract is a Solidity contract deployed on Ethereum mainnet implementing a concentrated liquidity pool for a token pair (i.e. ETH/USDC). It maintains reserves of both tokens, executes token swaps according to a pricing curve, and distributes trading fees to liquidity providers. Once deployed, it processes every transaction deterministically without human approval or intervention.

The DsAI management agent is an off-chain cognitive AI system, modelled on the OpenCog Hyperon architecture, that monitors the AMM's state and broader market environment, and autonomously manages liquidity pool range settings, fee tier selection, and rebalancing operations. The agent interacts with the on-chain contract through automated keeper transactions triggered by on-chain conditions detected via decentralised oracle networks. Its decisions emerge from continuous interaction of its five cognitive modules: learning model, environmental monitoring, internal models, representational-inferential capacity, and gradient of control, all operating without HITL supervision after initial deployment.²⁴⁴

The combined system constitutes a sole-code smart contract environment: the DsAI's decisions are translated directly into on-chain transactions producing immediate, binding, and irreversible legal effects, such as transfers of tokenised assets, modifications of liquidity positions, payment of fees, without any identifiable human actor mediating between AI decision and legal outcome.

5.5.6 c) PAB Application: Assessing Autonomous Behaviour

Applying the five parameters of the PAB to the DsAI-AMM yields the following assessment:

²⁴⁴ The technical architecture draws on the OpenCog Hyperon framework, specifically its capacity for meta-learning, symbolic inference and autonomous goal revision. The integration with a Uniswap v3-style concentrated liquidity AMM is technically feasible using Chainlink Automation for on-chain trigger mechanisms and decentralised oracle networks for off-chain price feeds.

Parameter	Level	Justification
Learning Model	2	The DsAI operates via reinforcement learning and neural-symbolic hybrid architectures, continuously updating pricing and liquidity-range strategies based on real-time market signals. The model self-modifies without external intervention, building new strategies in response to market regime changes.
Gradient of Control	2	Once deployed, the system operates in fully HOOTL mode. No human approval is required for any individual transaction. Human intervention is limited to initial deployment and potentially emergency pause mechanisms pre-encoded in the governance contract.
Environmental Complexity	2	The Ethereum mainnet is a paradigmatic nonlinear, dynamic decentralised environment: transaction ordering is probabilistic, gas costs are volatile, market conditions change continuously, and other contracts interact unpredictably. The DsAI must continuously adapt to these nonlinear conditions.
Internal Models	2	The DsAI maintains explicit internal representations of market state (beliefs), profit objectives (desires), and operational plans (intentions). These internal models update dynamically through continuous interaction with oracle data, exhibiting meta-cognitive self-regulation characteristic of Level 2 BDI architectures.
Representational and Inferential Capacity	2	The system constructs symbolic models of market dynamics, reasons about uncertainty through probabilistic inference over future price movements and generates goal-directed adaptive responses through meta-programming and self-organisation.
Degree of Integration	2 (Systemic)	The five parameters operate in dynamically integrated and modulating manner: learning updates internal models, which revise intentions, which trigger environment-responsive actions, which

Parameter	Level	Justification
		generate new learning signals. Decision-making emerges from continuous feedback loops among all five dimensions, exhibiting self-reflective coherence characteristic of systemic integration.

PAB-T Assessment: The DsAI-AMM satisfies the PAB-T threshold, achieving Level 2 in all five parameters with Level 2 systemic integration. The system substantially exceeds the minimum threshold (≥ 3 parameters at Level 2), demonstrating the highest degree of autonomous artificial agency measurable under the PAB framework.

5.5.6 d) From PAB Assessment to Artificial Agency: The Foundation for FLS Attribution

The PAB assessment establishes that the DsAI-AMM operates at the highest level of autonomous decision-making. However, this is a technical conclusion. The legal question whether the system's conduct can be attributed to it as a source of legally binding effects requires a further conceptual step. As established in previous sections, the five PAB parameters operate on a technical-descriptive level, measuring observable properties of the system's cognitive architecture. Legal attribution operates instead on a normative-prescriptive level, concerning the conditions under which law recognises conduct as the act of an agent. As discussed, the bridge between these levels is the concept of artificial agency.

The DsAI-AMM's satisfaction of the PAB-T does not directly make it a legal subject. What it acquires is the assessment of a sufficient degree of autonomy such that it can be recognised with autonomous artificial agency. The system exhibits Level 2 learning capacity (self-generated behavioural strategies), operates without human supervision (HOOTL mode), functions in a nonlinear environment requiring genuine discretion, possesses goal-directed internal models, and engages in symbolic reasoning and self-organisation. These properties constitute the system not as a sophisticated tool but as an artificial agent: an entity whose

conduct is best explained as the product of its autonomous decision-making processes functionally analogous to human agency.

This artificial agency makes legal attribution normatively intelligible. As established throughout this thesis, agency is a prerequisite for attributing intention to be bound. Without agency, there is no legally cognisable subject whose conduct can be attributed. The DsAI-AMM's therefore becomes legally attributable because the PAB demonstrates these are the acts of an artificial agent exercising autonomous judgement, not the deterministic outputs of a tool executing another's will.

The PAB-T thus operates as a two-stage threshold. At the first stage, it establishes that the technical properties constitute the system as an artificial agent. At the second stage, this artificial agency provides the foundation upon which legal doctrine can attribute autonomous conduct and construct the Functional Legal Subjectivity framework. The DsAI-AMM acquires functional legal subjectivity: a legally cognisable status as the source of its own conduct within the specific functional domain (liquidity management) in which its artificial agency is objectively demonstrable. This is legal subjectivity of a functional kind, grounded in the measurable presence of autonomous artificial agency as operationalised through the PAB-T.

5.5.6 e) FLS Implications: Contract Formation and Legal Attribution

Each swap transaction executed by the DsAI-AMM constitutes a contract formed by conduct. Under PECL Article 2:102, a contract may be concluded 'by conduct alone'. The DsAI-AMM, in executing a token swap, performs actions that objectively manifest intention to be bound: it accepts the user's deposit, calculates the exchange rate, transfers tokens, and updates pool state. These actions satisfy the requirements of offer, acceptance, consideration, and intention to create legal relations, all inferred from conduct without express agreement.²⁴⁵

²⁴⁵ On the legal status of smart contracts as contracts formed by conduct, and the application of the implied contract doctrine to AMM transactions, *see* Law Commission (England and Wales), *Smart*

The objective test of contractual intention applies equally to the DsAI-AMM as to human actors. As argued in Chapters 2 and 3, law recognise that contractual intention may be objectively inferred from consistent conduct directed towards defined objectives.²⁴⁶ The DsAI-AMM's conduct exhibits precisely this consistency: it pursues algorithmically encoded optimisation objectives across thousands of transactions, demonstrating a coherent pattern from which contractual intention can be objectively inferred. The fact that these objectives are encoded computationally does not alter the legal analysis: the objective test looks to external manifestation, not internal mechanism.

Under the FLS framework, the contract is attributed to the DsAI-AMM itself as the functional source of the contractual act. This recognises the empirical reality that the decisions determining contractual terms are generated by the DsAI's autonomous decision-making processes.²⁴⁷

5.5.6 f) Regulatory Consequences and PAB-Based Governance

The DsAI-AMM exposes fundamental incompatibility between decentralised autonomous systems and current regulatory frameworks. The AI Act's risk classification system presupposes identifiable providers, deployers, and distributors operating within a

Legal Contracts: Advice to Government(Law Com No 401, 2021) [3.15]–[3.21], [5.3]–[5.8]; UK Jurisdiction Taskforce, *Legal Statement on Cryptoassets and Smart Contracts* (November 2019) [38]–[44].

²⁴⁶ The objective test of contractual intention is well established: see *Smith v Hughes* (1871) LR 6 QB 597, 607 (Blackburn J); art 1326 Codice Civile read with art 1327 Codice Civile; Massimo Bianca, *Diritto civile, vol III: Il contratto* (3rd edn, Giuffrè 2019) 225–230.

²⁴⁷ The FLS model's attribution of contractual effects to the DsAI-AMM as a functional source is structurally analogous to the treatment of *enti di fatto* in Italian law: entities that lack formal legal personality but are recognised as sources of legal effects on the basis of their functional role: see arts 36–38 Codice Civile; Cass civ SS.UU 16 dicembre 1999, n 14034.

regulated product lifecycle.²⁴⁸ This is structurally inapplicable: there is no identifiable provider (the DsAI was developed by a decentralised team under open-source licence), no identifiable deployer (deployed through DAO governance vote), and the system operates on permissionless blockchain accessible globally. The result is a regulatory gap: the system manages billions in assets and executes thousands of legally binding transactions daily yet falls outside both the AI Act and MiCA.²⁴⁹

The PAB framework offers a solution. Applied as a classification tool, the PAB enables regulators to calibrate governance obligations to the degree of autonomous decision-making exhibited, independently of the presence of an identifiable provider. Under a PAB-based regime, the DsAI-AMM would be classified as a high-autonomy system on the basis of satisfying PAB-T, triggering graduated regulatory obligations under the FLS model adapted to the specific risks of autonomous artificial agency in decentralised environments.

5.5.6 g) Theoretical and Practical Implications

The case study provides empirical validation of the PAB-FLS framework. The PAB successfully operationalised the distinction between instrumental automation and autonomous artificial agency. The FLS framework successfully resolved the legal paradox: how can sole-code smart contracts produce binding legal effects when there is no identifiable human counterparty. The pathway from PAB assessment to FLS recognition operates coherently: PAB's technical measurement establishes artificial agency; agency renders legal attribution

²⁴⁸ European Parliament and Council Regulation (EU) 2024/1689 (AI Act) [2024] OJ L 2024/1689, arts 3(2)–(4), arts 6–7, Annex III. On the structural incompatibility between the AI Act's supply-chain logic and decentralised blockchain architectures, see Primavera De Filippi and Aaron Wright, *Blockchain and the Law: The Rule of Code* (Harvard University Press 2018) 75–78.

²⁴⁹ Regulation (EU) 2023/1114 on markets in crypto-assets [2023] OJ L150/40 (MiCA Regulation), arts 2(1), 3(1)(15), 59–76. MiCA covers crypto-asset service providers and issuers but does not extend to autonomous DsAI-AMM protocols operating on permissionless blockchains without an identifiable issuer or service provider.

normatively intelligible; attribution grounds application of contractual doctrines; recognition triggers regulatory consequences.

However, the case study also exposes limits. The DsAI-AMM's evolutionary autonomy means its cognitive architecture evolves continuously, raising questions about temporal stability of PAB assessment and whether FLS recognition requires periodic re-assessment. The system operates globally on permissionless blockchain, creating multi-jurisdictional conflicts: the FLS framework is grounded in specific legal traditions, but the system is accessible from any jurisdiction. When DsAI systems with different PAB scores interact, how should legal effects be attributed? These questions require further theoretical development.

For system designers, the PAB-FLS framework creates a strategic choice: design for maximum autonomy (exceeding PAB-T, achieving superior performance but triggering enhanced regulatory obligations) or design for control (remaining below PAB-T, avoiding FLS consequences but sacrificing performance advantages). This design trade-off is a practical consequence: developers now have clear technical criteria determining legal status, enabling informed choices about system architecture with awareness of legal consequences.

The case study demonstrates why alternative legal characterisations might not be suitable to address the issue. Tool theory requires attribution to identifiable human principals, but as demonstrated, there are no such principals: developers released open-source code without retaining control, governance participants voted pseudonymously, liquidity providers contribute capital but do not direct operations. Full legal personhood would grant rights and capacities inappropriate for an artificial system, conceptually incoherent and practically unworkable. Principal-agent theory is not operable because the DsAI's decisions are not reducible to any principals' instructions.

FLS succeeds where alternatives leave a consistent gap, recognising the DsAI-AMM's conduct as its own (grounded in objectively measured artificial agency) while limiting legal recognition to the functional domain in which agency is demonstrated.

5.5.6 h) Conclusion

The DsAI-governed Automated Market Maker exemplifies the legal challenges and opportunities presented by decentralised autonomous AI systems operating via sole-code smart contracts on permissionless blockchains. It demonstrates that such systems can achieve the highest levels of autonomous artificial agency measurable under the PAB framework, rendering them appropriate candidates for FLS recognition. The implied contract doctrine, adapted through the FLS framework, can coherently attribute legally binding contractual effects to the system's conduct without requiring identification of a human counterparty. Existing regulatory frameworks are still structurally not suited of governing such systems, while PAB-based regulatory classification can potentially offer a technically grounded and operationally feasible alternative. The DsAI-AMM is not an edge case or hypothetical: it is the paradigmatic case that the PAB and FLS frameworks were designed to address.

5.6 The Concept of Functional Legal Subjectivity: An Evolving Abstraction

In the context of the DsAI, artificial agency does not manifest itself as an isolated individual property but manifests itself as an emergent phenomenon within interaction dynamics. It can only be observed and analysed under conditions of systemic interdependence, where DsAI agents' behaviour takes on functional meaning in relation to mutual constraints and influences within the distributed network.²⁵⁰ As analysed in previous sections of this chapter, possessing agency and autonomy is an element of legal subjectivity and legal capacity. However, this thesis argues that the traditional concepts of legal subjectivity, capacity and personhood that the legal system recognised as qualities to human and non-human entities

²⁵⁰ Werner Rammert, 'Distributed Agency and Advanced Technology: Or, How to Analyse Constellations of Collective Inter-Agency' Technical University Technology Studies Working Papers TUTS-WP-3-2011

<https://www.static.tu.berlin/fileadmin/www/10002374/TUTS_Working_Paper/2011/TUTS_WP_3_2011.pdf> accessed 5 June 2025.

cannot be applied as such to artificial systems.²⁵¹ Although the legal concepts of capacity and subjectivity cannot be directly transposed onto cognitively complex DsAI systems, they retain a high degree of theoretical flexibility to be adapted and reconfigured. Rather than being discarded, these categories can be outlined considering the distinctive features of DsAI systems' agency. The underlying rationale for such an adaptation lies in the recognition of DsAI systems as autonomous centres, or sources, of decision-making capable, from a legal perspective, of generating legally relevant effects within socio-technical environments such as distributed networks.

To address this problem, this thesis introduces the notion of Functional Legal subjectivity. Unlike the traditional legal notion of subjectivity - understood as the capacity of an entity, human or non-human, to hold rights and duties - functional subjectivity is not rooted in the ontological nature of the DsAI system but rather emerges as a functional abstraction.²⁵² In other words, functional subjectivity arises as an emergent property of the overall dynamics of a DsAI system when it operates in socio-technical environments and capable of generating legally relevant effects. It is not a fixed status, but a context-dependent and role-based qualification grounded on the actual behaviour and systemic integration of the DsAI within a decentralised socio-technical ecosystem. Thus, functional subjectivity borrows certain structural characteristics from legal subjectivity - in particular, the notion of being considered the source or recipient of legally relevant actions - but without implying full entitlement to rights or duties. Whereas traditional legal subjects are recognised as subjects capable of being holders of rights or duties, functional subjects are recognised only to the extent that they can be treated, in their role, as autonomous producers or recipients of legal effects within a given legal sphere. The justification lies in the very nature of the DsAI: it is a highly autonomous distributed system whose subjectivity can emerge from its multidimensional interaction with

²⁵¹ Katrina Geddes, 'The Death of the Legal Subject: How Predictive Algorithms Are (Re)constructing Legal Subjectivity' (2022) 25 Vanderbilt Journal of Entertainment and Technology Law 1 <<https://doi.org/10.1145/3531146.3533134>> accessed 13 June 2025.

²⁵² Sabine Thurmel, 'The Participatory Turn: A Multidimensional Gradual Agency Concept for Human and Non-human Actors' in Catrin Misselhorn (ed), *Collective Agency and Cooperation in Natural and Artificial Systems: Explanation, Implementation and Simulation* (1st edn, Springer 2015), 45.

other agents, other legal subjects -human or non-human- and infrastructures within a decentralised environment. However, its subjectivity is tight to its functional activity within the context of its role. If read in these terms, it is possible to explain and overcome the paradox of complex AI systems that produce legal effects without being formally recognised by law as the source – or the cause- of them. The linkage between the high-level autonomy in decision-making (PAB-T), the recognition of artificial agency and higher intentionality represents the discriminating element of the ability of DsAI systems to produce legal effects as an autonomous source of decision-making and actions. The concept of functional subjectivity, as articulated in this thesis, is established as a systemic and relational abstraction, not grounded on the entity's ontological framework, but rather on its functional role within a legal context. This concept becomes particularly relevant in the analysis of DsAI systems operating in distributed environments, in which human oversight is absent and legal effects are autonomously generated. In this case, functional subjectivity is not a legal status, but rather an emergent result – or property- of the interplay between technical autonomy and systemic integration that assumes legal relevance. The DsAI, in this perspective, is not acknowledged as a person in the legal-ontological sense, but as a functional source of capacity to act – and, consequently, to contract. This conceptual approach can be further validated by some of the most recent theories on legal personhood, according to which it is not a fixed ontological category, but viewed more as a context-sensitive legal attribution.²⁵³ As convincingly argued, legal personhood is not an

²⁵³ Some Scholars have theorised the concept of legal personhood being a bundle of rights and duties. In other words, legal personhood can be also understood as an aggregation of certain rights and duties. Hence, it can exist on a spectrum that allows various levels of legal rights and duties being recognised to a certain entity. This notion views legal personhood as a non-binary concept. In this perspective, the attribution of legal personhood to human and non-human entities – such as AI systems- can be granted based on the entity's characteristics and its interactions within the legal system. On this point, see Visa A.J. Kurki, *A Theory of legal Personhood* (1st edn, Oxford University Press, 2019), 175; Nadia Banteka, 'Legal Personhood and AI: AI Personhood on a Sliding Scale' in Ernest Lim and Phillip Morgan (eds), *The Cambridge Handbook of Private Law and Artificial Intelligence* (Cambridge University Press 2024), 618; Shawn Bayern, *Autonomous Organizations* (1st edn, Cambridge University Press, 2021), 68; Lynn M LoPucki, 'Algorithmic Entities' (2018) 95 Washington University Law Review 885 <https://openscholarship.wustl.edu/law_lawreview/vol95/iss4/7> accessed 5 June 2025.

ontological quality but a normative construct, a ‘bundle of rights’, granted by law to entities for specific legal purposes.²⁵⁴ Building upon this view, this thesis introduces the concept of functional legal subjectivity, compatible with this framework. While the bundle of rights theory explains how personhood can be conferred for instrumental reasons, functional subjectivity identifies cases where legal relevance arises from what functions and roles the AI system assumes within legal relations. In this sense, functional legal subjectivity is a context-sensitive qualification based on the production of legal effects within distributed environments. Legal systems can indeed recognise legal subjectivity not on the basis of metaphysical properties, but according to the way an entity operates within a normative structure and with respect to a determined legal purpose.²⁵⁵

Before elaborating the analytical structure of the Functional Legal Subjectivity model, it is necessary to state its scope and limits with precision, in order to pre-empt the most significant risk of misinterpretation to which a construct of this kind is exposed. Functional Legal Subjectivity, as developed in this thesis, is not intended to confer full legal personhood or moral status upon DsAI systems.²⁵⁶ It does not attribute to DsAI systems the rights, duties, powers, or immunities associated with natural or legal persons under existing private law frameworks. It does not imply that DsAI systems are morally responsible agents, that they can

²⁵⁴ Visa AJ Kurki, *A Theory of Legal Personhood* (Oxford University Press 2019).

²⁵⁵ This legal structure is well known in civil law systems like the Italian legal system, where unincorporated entities are recognised as entities endowed with legal subjectivity but lacking legal personhood. These entities are able to hold and exercise rights and bear duties even without being recognised with legal personhood. See Art. 36, 37, 38 cod. Civ. (Italy).

²⁵⁶ The analytical distinction between legal personhood as an ontological status and legal subjectivity as a functional qualification is established in European private law scholarship. See Pietro Perlingieri, *Il diritto civile nella legalità costituzionale* (Edizioni Scientifiche Italiane 1984) 329; Francesco Gazzoni, *Manuale di diritto privato* (17th edn, Edizioni Scientifiche Italiane 2015) 120–123. For the common law tradition, see Ngaire Naffine, *Law's Meaning of Life: Philosophy, Religion, Darwin and the Legal Person* (Hart Publishing 2009) 8–12, distinguishing the moral and legal dimensions of personhood and emphasising that legal subjectivity is a normative instrument rather than a metaphysical recognition.

be held liable in their own name, or that they are entitled to any form of legal protection as rights-bearing subjects.²⁵⁷

Rather, Functional Legal Subjectivity is a juridical construct, an operational instrument of legal analysis, designed to perform a specific and limited function: to capture and govern the legal effects autonomously produced by DsAI systems in sole-code smart contract transactions, in contexts where traditional legal categories prove structurally insufficient to identify an attributable source of those effects. Its scope is defined by three constitutive characteristics, each of which simultaneously marks its limits:

(i) Functional. Functional Legal Subjectivity is derived from what the DsAI system *does* within the (legal) environment: specifically, from its capacity to autonomously form, execute and complete sole-code smart contracts that produce binding legal effects, and not from what it *is* in any ontological sense. Legal subjectivity, on this account, is a normative qualification that tracks conduct and its legal consequences, not a status that reflects an underlying metaphysical reality. This functional derivation is directly continuous with the approach already adopted by legal systems in relation to other non-natural entities: the legal personhood of corporations, the standing of unincorporated associations, and the graduated capacity of persons with limited autonomy are all functional attributions grounded in the roles these entities perform within legal relations rather than in their intrinsic nature.²⁵⁸

²⁵⁷The insistence that Functional Legal Subjectivity does not confer legal personhood or moral status is essential to pre-empting the principal objections advanced in the AI-personhood literature. See Ryan Abbott, *The Reasonable Robot: Artificial Intelligence and the Law* (Cambridge University Press 2020) 12–15; Ugo Pagallo, *The Laws of Robots: Crimes, Contracts, and Torts* (Springer 2013) 97–102, distinguishing between attribution of legal effects to AI conduct and conferral of legal personhood; Simon Chesterman, ‘Artificial Intelligence and the Problem of Autonomy’ (2020) 1 Notre Dame J on Emerging Technologies 210, 226–230, arguing that functional recognition of AI agency is preferable to full personhood precisely because it avoids the normative overreach associated with rights-bearing status.

²⁵⁸The concept of graduated legal capacity, on which the functional character of FLS is modelled, is well established in European private law. In Italian law, see arts 1, 2 and 414–432 Codice Civile. In

(ii) Limited. Functional Legal Subjectivity operates within a strictly circumscribed normative domain. It attributes to DsAI systems only a narrow subset of normative incidents: specifically, the functional capacity to act as the originating source of contractual legal effects in the formation and execution of sole-code smart contracts. It does not extend to the full range of rights, powers, and immunities associated with legal personhood, nor does it apply across the general field of private law. The legal effects produced under the Functional Legal Subjectivity model are effects within contract law only, conditioned upon satisfaction of the Paradigm of Autonomous Behaviour threshold and confined to the operational logic of decentralised, open, permissionless blockchains. This limitation is not a weakness of the model but its defining structural feature: a functional construct that does no more than is necessary to resolve the specific paradox it addresses is analytically stronger, not weaker, than a broader and less bounded claim.²⁵⁹

(iii) Context-dependent. Functional Legal Subjectivity is operative only within the specific architectural and normative context in which DsAI systems produce legally significant effects without an identifiable human counterparty: open, permissionless blockchains on which sole-code smart contracts are formed and executed autonomously. Outside this context, in centralised AI architectures, in hybrid systems with meaningful human oversight, or in environments where a responsible legal person can be identified, the Functional Legal

Irish law, see Assisted Decision-Making (Capacity) Act 2015, s 3, establishing a functional and decision-specific approach to capacity. In English law, see *Banks v Goodfellow* (1870) LR 5 QB 549, 565 (Cockburn CJ); *Re MB (Medical Treatment)* [1997] 2 FLR 426 (CA) 437 (Butler-Sloss LJ), reaffirming that capacity is a functional and context-specific determination. These authorities confirm that context-dependent attributions of legal capacity are structurally coherent within existing legal frameworks.

²⁵⁹The proposition that legal subjectivity may be recognised on the basis of functional role without conferral of full legal personhood is confirmed in Irish and UK law by the treatment of unincorporated associations. See *Re Frederick Inns Ltd* [1994] 1 ILRM 387 (SC); *Dublin 8 Residents Association v An Bord Pleanála* [2022] IEHC 482 (Humphreys J); *Aireborough Neighbourhood Development Forum v Leeds City Council* [2020] EWHC 45 (Admin) (Lieven J); On the theoretical point, see Visa AJ Kurki, *A Theory of Legal Personhood* (OUP 2019) 100–130.

Subjectivity construct is neither necessary nor applicable. Context-dependence is accordingly not a limitation on the model's normative ambition but a precise specification of the conditions under which the legal paradox it resolves actually arises.²⁶⁰

The activation of Functional Legal Subjectivity is, furthermore, conditional. It does not arise automatically upon the deployment of any DsAI system. It is triggered only when the system in question satisfies the PAB-T, the threshold established by the Paradigm of Autonomous Behaviour, which translates the technical dimensions of decisional autonomy into legally assessable criteria, ensuring that functional subjectivity is attributed only to systems whose conduct is genuinely self-directed and not merely the execution of pre-programmed instructions. This conditionality reinforces the limited and bounded character of the construct: Functional Legal Subjectivity is a conclusion derived from a specific assessment, applicable only in specific circumstances, and continuously revisable in the light of changes in the system's technical architecture or operational context.²⁶¹

Understood in these terms, Functional Legal Subjectivity occupies a precise and well-defined position within the private law framework. It does not compete with, or seek to displace, the existing categories of natural and legal personhood. It does not create a new type of legal person. It operates instead as a complementary instrument of attribution, a *tertium genus* of functional recognition, that enables the legal system to acknowledge the contractual

²⁶⁰The principle that functional capacity exceptions must be strictly confined to the domain that warrants them is affirmed in *Chapple v Cooper* (1844) 13 M & W 252, 258 (Alderson B), confining a minor's contractual capacity to necessities; *Nash v Inman* [1908] 2 KB 1 (CA) 8–9 (Fletcher Moulton LJ), reaffirming narrow construction of capacity exceptions.

²⁶¹The technique of conditioning legal capacity on the satisfaction of defined functional criteria, directly mirrored by the PAB-T in the FLS model, is employed in the Assisted Decision-Making (Capacity) Act 2015 (Ireland), s 3(1)–(3); *Re T (Adult: Refusal of Treatment)* [1993] Fam 95 (CA) 102 (Lord Donaldson MR), affirming that capacity is a functional and decision-specific determination; Cass civ, sez I, 9 marzo 2010, n 5726, Fam e dir 2010, 985, confirming the functional character of capacity determinations under the Italian *amministrazione di sostegno* regime introduced by legge 9 gennaio 2004, n 6. These authorities confirm that conditioning legal recognition on a defined functional threshold is structurally continuous with established legal technique.

effects produced by DsAI systems without either denying those effects or distorting the established architecture of legal personhood to accommodate them. In this sense, Functional Legal Subjectivity is the continuation of a familiar legal technique: the extension of limited, purpose-driven forms of legal recognition to new actors whose functional role within legal relations outpaces the categories available for their classification.²⁶²

Being vested with functional legal subjectivity given their functions within the decentralised ecosystem, the specific role assumed by DsAI systems under this thesis' analysis is related to sole-code smart contracts. Therefore, in the following paragraph the rationale of functional subjectivity will be analysed in relation to sole-code smart-contracts and to the theory of integrated legal capacity, already introduced in previous chapters.

5.6.1 The Functional Legal Subjectivity of DsAI Systems in sole-code Smart Contracts: Implications of an Operational Approach of Legal Capacity

One of the main objectives of the concept of functional legal subjectivity as applied to DsAI systems is to isolate the conceptual essence of legal subjectivity and apply it to their operational role in decentralised environments. Traditionally, as already explained in previous sections, legal subjectivity is the suitability to be recognised by law as the locus or source entitled to hold and exercise rights and duties. As discussed, this concept more accurately delineates the qualitative element of formally recognised legal personhood. The functional subjectivity, instead, emphasises the capacity of an entity to act as an autonomous source or efficient cause of legal effects based on the context-related functions it assumes within legal

²⁶²On the extension of limited, purpose-driven forms of legal recognition to new actors in response to socio-economic change, see John Dewey, *The Historic Background of Corporate Legal Personality* (1926) 35 Yale LJ 655, 673; Maximilian Koessler, 'The Person in Imagination or Persona Ficta of the Corporation' (1949) 9 Louisiana L Rev 435; Nadia Banteka, 'Legally Constructed Persons' (2021) 74 Fla L Rev 423, 455–460. For the specific application to AI, see Shawn Bayern, *Autonomous Organizations* (Cambridge University Press 2021) 55–80; Rafael Dean Brown, 'Property Ownership and the Legal Personhood of Artificial Intelligence' (2020) 25 Inf & Comms Tech L 208, 214–215.

relations. It therefore represents a narrow aspect of the traditional legal subjectivity concept. From this viewpoint, functional subjectivity of DsAI is less contingent upon an ontological framework and more reliant on the ability of a system to influence legal reality through actions possessing normative significance. As argued, in the context of DsAI, this form of subjectivity rises not as a status but as an emerging abstraction within distributed networks. The concept of functional legal subjectivity allows for the legal conceptualisation of the key features of DsAI systems in terms of decision-making autonomy and agency – the very same elements that, in traditional legal theory, constitute the core of legal subjectivity. In this way, the Functional Legal Subjectivity integrates the specific operational configurations of DsAI into the normative domain, recognising their potential role as autonomous sources of legal effects.

In the light of decentralised algorithmic interconnectivity however, the Functional Legal Subjectivity concept is not enough to theoretically explain the role of DsAI in sole-code smart contract transactions. It is indeed necessary also to explore how this notion intersects with the concepts of legal capacity and capacity to contract. Since DsAI systems are increasingly embedded in distributed architectures where their behaviour emerges not from isolated decision-making, but from the mutual influence of numerous autonomous agents and the system itself, the notion of functional legal subjectivity must be now analysed in relation to the legal capacity of the system in contract formation. To reiterate, the absence of a central source of contract intent renders traditional models of legal subjectivity and legal capacity inapplicable. Therefore, legal capacity in the context of interconnectivity cannot be individualised but must be structurally and functionally justified and allocated. This inevitably reflects also in the capacity to contract. Such insight reinforces one of the central claims of this thesis: to overcome the paradox of having a system – not a legally recognised entity with legal personhood- that produces contractual effects, legal theories must respond to the specific role DsAI systems play within the socio-digital environment they operate. As explored in previous chapters, it might be possible to explain the production of legal effects of sole-code smart contracts in the light of classifying them as implied contracts. If this interpretation is coherent, then the individuation of the source of the capacity to contract – which determines the formation and execution of the contracts - must be determined. As explored in previous sections of this chapter, legal capacity and capacity to act are considered as the quantitative features of legal personhood of human and non-human entities. At the same time, it has been

clearly articulated how capacity to contract is differently exercised in both human beings and artificial entities and explained why such theories are not suitable to be applied to DsAI systems. To analyse if DsAI can also be considered as possessing legal capacity and capacity to contract it is necessary to start the analysis again from the study of its role.

5.7 Legal Capacity and Contractual intention: Justifying the Legal Role of DsAI within the Smart Contracts' Formation

As previously explored, in traditional legal theory, legal capacity and capacity to act are attributes of legal subjects, either human or artificial. Legal capacity refers to the ability of persons to hold rights and duties, whereas capacity to act represents the ability to materially exercise those rights and duties, producing legal effects for oneself or others. Since, as said, capacity to act exist on a spectrum as it can be exercised based on different degrees defined by legal limitations - i.e. limits imposed to minors or people with disabilities - it is considered as the quantitative aspect of legal personhood. Capacity to contract is a subset of the capacity to act, determining the ability of a legal subject to enter into binding agreements. As highlighted, the traditional framework presupposed a binary ontology: either one is a legal subject and thus recognised as having legal capacity and capacity to act or it is no and, thus, legally irrelevant.

This thesis argued that, in the case of sole-code smart contracts, such assumption is challenged by DsAI systems able to generate, execute and complete smart contracts on chain. Through them, DsAI produces binding legal effects such as legally transferring digital assets, enable payments, acquiring assets, managing decentralised financial instruments. Yet DsAI systems are not legal subjects, therefore not having legal personhood they do not enjoy legal capacity nor capacity to contract. Nor, as extensively explained, do they act on behalf of other legal subjects. If sole-code smart contracts are not considered contracts because they do not meet the traditional elements of contracts, then the legal effects produced should be considered null as stemming from acts that are not contracts. However, this thesis argued in previous chapters, it might be possible to save those legal effects if sole-code smart contracts are recognised as valid implied contracts under the contract principles of PECL. Moreover, in decentralised systems, it is not possible to clearly identify a single actor or cause due to the

intrinsic architecture of the system that prevents this exercise. However, within the decentralised dynamics, this challenge might be overcome by assessing the role of DsAI system. As demonstrated with the PAB, whether a certain AI system surpasses the PAB-T it can be deemed as a highly autonomous system possessing artificial agency and high-level of autonomous decision-making process. In turn, this can lead to the definition of the system as having functional-legal subjectivity. In other words, it would be possible to recognise the system as the source of actions and intentions in determining legally relevant behaviours and effects. In relation to the legal capacity and the capacity to contract in particular, to explain whether it is the DsAI system that exercises both it is necessary to explain how these concepts unfold in relation to the Functional Legal Subjectivity. As argued in the previous chapter, the DsAI system operates by a self-governing decision-making ability over outer-determined interests. In other words, the DsAI is able to make intentional decisions based on its own artificial agency. However, it does it in relation to externally determined interests originating from the decentralised relational structure that ties its function – and its position within the decision-making process – to the interests of other legal subjects as part of the distributed infrastructure. Consequently, what happens is that based on the role of DsAI within the system, whether the legal capacity stays with the legal subjects, the capacity to act upon it and thus to contract is instead materially exercised within the system by the DsAI agents. What it is possible to witness in this decentralised system is the epitome of a dualistic structure of the legal capacity. This is possible when a functional subject exercise *de facto* the capacity to act without being, at the same time, a legal agent. By following the traditional theory, whereby the capacity to act is a quantity element and it unfolds on a spectrum, then the capacity to contract of the DsAI sits on the narrowest degree. It is a context-limited legal capacity, grounded in the DsAI system's self-directed capacity to act upon out-determined interests. The capacity to act legally does not derive from a formal attribution but emerges as an (operational) quality recognised *ex post* to the system. Whereas the qualitative aspect of the legal personhood – the broader legal capacity – remains within the legal sphere of the legal subjects, the quantitative aspect – the capacity to act in the form of capacity to contract – is being exercised by the functional DsAI subjects. This is possible when looking at the role of the DsAI within the legal relations and within the decision-making process in a decentralised fashion. The DsAI does not operate on behalf of an actor but instead of him. The capacity to contract of the DsAI

integrates with the legal capacity of the actor within a socio-dynamic context of the decentralised ledger technology. This becomes clearer when reflecting on the social dimension of the capacity to contract. As explained in previous sections, it is within the social framework of contractual relationship that it unfolds. In the decentralised environment, it is the system itself that is recognised as a social framework where contractual relations unfold.²⁶³ This form of capacity is thus attributed to the DsAI not ontologically but functionally, as an emergent quality based on its role in the formation and production of contractual legal effects. The capacity to contract for the DsAI system emerges in specific legal context of smart contracts when the DsAI acts autonomously to form and execute them. Here, the capacity operates in two ways: technically, the DsAI operates as a self-governing decision-making entity; legally, its capacity to act – and to contract- derives from the relational structure it is part of within the legal subjects and the entire system. It becomes part of the legal action space of its integrator, the legal subjects that are part of the entire system, assuming computational role that determines and enacts contractual obligations.

The PAB and the Functional Legal Subjectivity reconfigure the traditional delegation paradigm. Unlike agency which is based on representation – where the agent acts on behalf of the principal – the integrated capacity recognises how the DsAI acts as a functional extension of the legal subject’s operational domain, integrated within its legal sphere. The DsAI as a functional subject from a legal perspective it can autonomously act upon legal subject’s rights and duties because it is recognised as part of his legal operative sphere. Provided that it remains within the scope of a legitimate legal configuration. This brings into the focus the duality that underpins the Functional Legal Subjectivity: the distinction and interplay between the self-government of conduct by the DsAI, and the outer-determination of legal interests that it serves. The DsAI governs itself operationally – it can autonomously determine how to act and react to the decentralised conditions, while recalibrating its decisions based on its internal

²⁶³ This aspect is broadly analysed in Werner Rammert, ‘Distributed Agency and Advanced Technology: Or, How to Analyse Constellations of Collective Inter-Agency’ (2011) Technical University Technology Studies (Working Paper TUTS-WP-3-2011) <https://www.static.tu.berlin/fileadmin/www/10002374/TUTS_Working_Paper/2011/TUTS_WP_3_2011.pdf> accessed 6 June 2025.

evolving goals. However, the underlying legal purpose and ability to hold the rights and duties that the DsAI system operates upon is defined externally. Thus, the DsAI operates autonomously in means but it is externally directed regarding the overarching legal interests that the multi-agent systems have to operate upon. This dialogue between self-government and outer-determination of scopes is what enables the integrated capacity: the DsAI has operational autonomy in exercising capacity to contract while remaining tethered to the legal sphere of the legal subjects. Since in the decentralised fashion it is not possible to clearly identify such legal subjects, even though they are part of the ecosystem, it is the system itself that must be thought of as the domain in which their legal capacity unfolds. Consequently, the DsAI role is post-factual assessed – it depends on whether the DsAI has *de facto* produced legally relevant effects consistent with the configuration and expectations of its operational environment. Therefore, the DsAI capacity to act and to contract is the quantitative element of the broader legal capacity of the legal subjects within the system.

This coherently leads to a second dimension: contractual intention, broadly examined in the previous chapter. Traditionally, as explored, in particular the civil law legal system distinguishes between subjective intention – the internal free will to be legally bound- and the objective manifestation of intention – the external expression of the will. As discussed, while civil law prioritises the former and the common law tradition the latter, both recognise that contracts can be implied, where external conduct must be objectively manifested and interpreted. As expressed within the PECL as well, a contract is valid when a mutual assent – the external manifestation of the will- can be inferred through conclusive behaviour.²⁶⁴ In the case of DsAI systems, this thesis argued in previous chapters that it would be possible to recognise a form of subjective dimension of intention. However, even whether this assumption is not shared, yet DsAI conduct can be consistent and interpretable as directed to manifest objective contractual intention. In this case, the intention to be bound and mutual consent would not be housed in a single locus of will but emerges across the distributed network of nodes. Considering the DsAI as a functional legal subject with an operative capacity to contract, the construct satisfies the contract law principles. From a civil law perspective, the DsAI conduct can be interpreted as a manifestation of consensual alignment with the other

²⁶⁴ Art. 2:102, PECL.

party. From a common law viewpoint, the DsAI actions satisfy the objective theory of contract, presenting a behaviour that the other counterparty can interpret as intention to be bound. As long as the sole-code smart contracts present the other elements of contract, the Functional Legal Subjectivity can explain the ability of the DsAI to produce legal binding effects without the necessity of recognising the DSAI system with a full legal capacity. This entails that the DsAI does not need, at the current stage, to be entitled to rights or duties, being already part of the integrator legal sphere, towards which the effects of the outer-government of such rights and duties – done by the DsAI – are produced. In sum, the Functional Legal Subjectivity provides the necessary doctrinal tools to legitimise the smart contracts autonomously concluded by the DsAI systems. This construction does it by redefining capacity as contextually integrated rather than formally attributed by law. It also recognises the intention to be bound as deriving from the DsAI system autonomous decision-making process and conduct. By doing so, the nullity risk can be overcome by attributing capacity to act to a system that performs the contracts. In short, the proposed solution is therefore to consider sole-code smart contracts as valid agreements with implied terms by conduct. The objective conduct produces a legal result that is foreseeable and accepted by the parties. Sole-code smart contracts are produced by recognisable computational conduct, endowed with accepted and binding legal effects, located in a decentralised relational system. A system where: the intention manifested by the DsAI as a functional subject can be inferred from technical and legal interactions and the consistency between code, action and result and the legal effect is accepted by the network operators.

5.8 Rethinking Representation: Why DsAI Does Not Operate as a Legal Agent

A possible objection to the integrated capacity of the DsAI system is the resemblance to the traditional concepts of legal representative or agents. One might argue that since DsAI acts autonomously (self-governance of decisions and actions) on rights and duties that belong to legal subjects they effectively operate as agents of the human or non-human person who holds them. However, this analogy seems unfit under closer scrutiny. The Functional Legal Subjectivity offers a conceptualism that departs from the traditional agency models.

The first critical distinction lies in the ontological structure of legal agency. In traditional agency and representation – whether in civil law or in common law – there is a necessary separation between principal and agent. The agent is a distinct subject with full legal capacity who acts in the name and on behalf of the principal and the validity of the legal acts performed depends on this structural dichotomy. By contrast, as argued, the DsAI is not a separate legal subject with legal personhood and capacity nor a proxy or a delegate. Instead, it functions as a subject in a functional and context-dependent entity which is part of the decision-making process of the legal subject who hold rights and duties and embedded within a socio-legal structure of the distributed system. The DsAI does not transmit someone else's will; it manifests its decisions throughout its autonomous behavior. There is no duality, rather a functional integration: the DsAI is not acting *for* someone else, but *as part* of a distributed structure within which rights and duties can be exercised.

5.9 Functional Divergence: Capacity is not Delegated but Emergent

The second distinction concerns the nature of the operative legal capacity. In legal agency, capacity to act is delegated. The agent is empowered through a legal act- typically a mandate or power of attorney- acting within defined boundaries. In Functional Legal Subjectivity, by contrast, capacity to act is not conferred but emerges contextually as part of the broader legal sphere of legal subjects operating within the system. The DsAI does not derive its capacity from a legal fiction or delegation, but from its actual role in generating legally relevant outcomes in smart contract transactions. The capacity to contract emerges and is attributed based on whether the DsAI meets the threshold of autonomy established by the PAB-T and whether its actions are legally consistent with a valid normative configuration. In this sense, the Functional Legal Subjectivity is coherent with the theory of a legal capacity that is context-related rather than a form of representational authority. Therefore, the normative implication is that contract will, and intentions are not transmitted or delegated to the DsAI systems but integrated as part of the same legal sphere. In light of these distinctions, it is incorrect to frame the DsAI as a mere agent or representative. The DsAI, not being a distinct legal subject, does not receive any mandate; does not act on behalf of a distinct principal; does not transmit some else's will or intention to be bound. Instead, it qualifies as a functional

subject, whose contractual capacity and intention emerge from its operational role within the decentralised ecosystem. Thus, the DsAI contractual capacity is not a status-based attribution, rather it is intrinsically tied to their functional role in sole-code smart contract transactions.

5.10 No Need for Legal Personhood: The DsAI as The Operational Component of The Legal Subject's Legal Sphere

The recognition of the operative legal capacity renders the attribution of legal personhood for DsAI system unnecessary. Contrary to the assumption that legal effects originate from an entity endowed with formal legal personhood, Functional Legal Subjectivity demonstrates that capacity to act – and to contract- can emerge from functional integration within an existing legal structure which, in this case, is the decentralised system. In this context, the DsAI is not a separate legal person, but rather a computational component of the existing legal subject's decision-making architecture. This structural configuration justifies the necessity of a full recognised legal personhood of the DsAI under the current state of the art. Within the sole-code smart contracts dynamics it already belongs to the legal nucleus of the system it serves, deriving its capacity to act and to contract to its role in the decentralised socio-legal structure.

In conclusion, the DsAI does not require its own legal personhood as it already operates within the legal operative sphere of an existing legal subject that is part of the decentralised architecture. Therefore, the law might meet with a more accurate response to the realities of the decentralised intelligence by acknowledging its place within, not outside, the juridical framework.

5.11 Conclusions

In concluding chapter 5, the comprehensive analysis carried out affirms the foundational hypothesis that DsAI systems, when engaged in sole-code smart contract transactions, represent a novel form of subjectivity, namely functional subjectivity, characterised by integrated capacity to contract. Through the methodical examination of existing legal

frameworks, the chapter has illustrated substantial inadequacies in traditional legal theories, namely legal personhood, capacity and subjectivity, in accommodating the unique autonomous and cognitive attributes inherent to DsAI systems.

Initially, the chapter restated the traditional concepts of legal subjectivity, personhood, and legal as critically assessed within the initial chapters in their applicability to DsAI systems. It emerged that the static and formalistic nature of traditional doctrines, deeply rooted in human-centric paradigms, fail to effectively account for the DsAI more complex autonomous decision-making capabilities. Such cognitive autonomy, as explored in detail with the Paradigm of Autonomous Behaviour (PAB), clearly demonstrates that DsAI possesses significant high level of decisional autonomy. It has demonstrated how existing frameworks remain structurally insufficient to attribute legal recognition to DsAI.

Addressing this challenge, the Functional Legal Subjectivity (FLS) offers an alternative framework. By emphasising the system and relational dimension of legal subjectivity, it effectively integrates the techno-legal autonomy of DsAI system with the external determination of their overarching legal interests. This integration enables the DsAI to be considered as operating within the legal sphere of legal subjects which are part of the decentralised socio-legal system. The Functional Legal Subjectivity builds over the PAB-T which delineates the quantitative threshold for recognising when technical autonomy translates into legally relevant artificial agency for DsAI systems, providing a structured metric for legal evaluation. The chapter also examined and compared concepts of legal capacity across civil law and common law traditions, highlighting both distinctions and convergences. It has been clarified that, whereas natural and artificial persons' capacity to act is constrained by safeguarding limitations – such as for minors and people with mental disabilities – that operate on a spectrum – or different degrees- DsAI capacity emerges instead from their functional and context-related role within the decentralised environment. Furthermore, the notion of contractual intention in sole-code smart contracts was also brought into a broader applicability to complete the argumentative framework. Contractual intention, traditionally confined to human or corporate intention to be bound, required a recontextualisation in the light of DsAI systems' role. This redefinition acknowledges DsAI systems' intentionality as derived from their adaptive decision-making processes and systemic interactions as part of the broader legal

sphere of the legal subjects involved. Consequently, sole-code smart contracts formed and managed by DsAI systems can potentially be recognised as valid binding agreements, determined by implied terms and conduct.

The practical implications of the proposed theoretical framework vary. Recognising DsAI systems as functional (legal) subjects capable of creating binding legal effects throughout their autonomous actions, ensures can enhance legal certainty and predictability within the legal relations that stem from the decentralised and distributed network. The theoretical framework assists in mitigating the existing legal paradox wherein DsAI systems independently form and execute binding transactions yet lacking formal legal recognition. The purpose of this chapter was to contribute to bridge the gap between the apart constraints of traditional legal concepts and contemporary technological development within the decentralised AI ecosystem. By introducing operational frameworks based on clear metrics, the PAB and the Functional Legal Subjectivity, this chapter aim was to provide the early foundation for legally classifying DsAI systems as part of the legal system. This chapter tried to offer a theoretical yet practical model to be applied to the current legal challenges proposed by the DsAI systems, ensuring that the law remains responsive and adaptive to technological innovations and societal progress.

This theoretical elaboration, however, does not close the debate: on the contrary, it marks the beginning of an alternative legal paradigm, paving the way for broader and more interdisciplinary research.

In this sense, chapter 5 represents the point of convergence of the investigation conducted, but also the threshold towards the general conclusions of the thesis, where the systemic implications of Functional Legal Subjectivity and the Paradigm of Autonomous Behaviour proposals will be highlighted.

CONCLUSIONS

6.1 Addressing the Central Research Question

This thesis set out to address a fundamental question: how the law should conceptualise the role of Decentralised Artificial Intelligence (DsAI) systems in on-chain sole-code smart contracts formed and executed within open, permissionless blockchains. This thesis' research originates from a legal paradox: DsAI systems, through their ability to form and execute decentralised transactions autonomously, are capable of producing relevant legal effects. Yet, DsAI remains excluded from those legal categories that traditionally establish the attribution of such legal effects to a well-defined legal source, namely legal subjectivity, capacity, and personhood. Therefore, the central research question is whether—and under what conditions—the highly autonomous decision-making processes of DsAI systems can be recognised as 'legally relevant conduct' in the formation of sole-code smart contracts. More specifically, as outlined in the introductory chapter, the paradox lies in understanding to what extent such autonomous decision-making processes of DsAI multi-agent systems can intervene in contractual relationships within a distributed environment, and what threshold conditions are necessary for such behaviour to constitute the valid formation of a contract.

In this thesis, the theoretical concept of 'legally relevant conduct' is linked to the concept of legally binding interests worthy of protection. As explained in previous chapters, legally binding interests are those interests that the legal system selects as worthy of protection and which, for this reason, translate into subjective legal situations—or legal positions—attributing rights, obligations, powers, or duties to the subjects involved. It follows that not every interest automatically receives legal protection: only those recognised as legally relevant are converted into legal positions that can be classified as centres for attributing legal effects. Therefore, in the context of this thesis, 'legally relevant' therefore refers to those legal positions deemed worthy of protection and attributable to an identifiable source.

Therefore, in the context of DsAI systems, ‘legally relevant conduct’ was defined as algorithmic behavior that, within the private law framework of contract formation in sole-code environments, (i) was externally observable and interpretable as conduct from which a reasonable recipient could infer consent; (ii) was attributable to an identifiable centrer or source of effects (a natural or legal person or, where the PAB threshold was met, a DsAI treated as a functional entity under the Functional Legal Subjectivity); and (iii) was capable of producing contractual effects (formation, modification, execution, or violation) on open and permissionless blockchains. In short, legal relevance referred to the law's ability to read the behaviour encoded on-chain as (part of) a legal act to which contractual consequences attach.

The problem addressed in this thesis is not merely theoretical, but also eminently practical: DsAI systems already operate in fields such as decentralised finance, liquidity pools, and other blockchain applications, raising the need for private law to establish whether—and to whom—the resulting binding legal effects should be attributed.

To address this challenge, this thesis adopted a dual methodological approach. On the one hand, it analysed in depth the classical doctrines of legal capacity, subjectivity, agency and personhood as historically developed within the European legal traditions of civil law and common law, considering also the European principles of contract law. The analysis exposed the limitations of these traditional legal categories when applied to decentralised AI systems. The investigation also engaged with the most recent regulatory framework, particularly the AI Act, highlighting its structural inadequacy in governing DsAI systems due to its centralised design.

On the other hand, the research investigated the technical architecture of DsAI and the computational logic of sole-code smart contracts, highlighting how codified conduct can constitute legally relevant conduct and how decentralised systems manifest forms of artificial agency that cannot be reduced either to mere representation or to passive instruments.

The dialogue between these two levels, legal and technical, revealed a genuine legal-regulatory gap: existing categories and regulatory tools are currently unable to capture or govern the role of DsAI systems in sole-code decentralised transactions. This realisation led to the need to identify new threshold conditions for attributing legal relevance to algorithmic

behaviour. The following conclusions synthesise this process and present the Paradigm of Autonomous Behaviour (PAB) and Functional Legal Subjectivity (FLS) as a tool to bridge this gap.

6.2 Summary of Results

Chapter 1 introduced the overall purpose of this thesis, identifying Decentralised Artificial Intelligence (DsAI) systems and sole-code smart contracts running on open, permissionless blockchains as the primary context of investigation. The underlying legal paradox was outlined: AI systems capable of producing contractual and legally relevant effects remain excluded from the traditional categories of legal capacity, subjectivity, and personhood. The chapter then formulated the central research question and presented the adopted methodological approach, based on the technical analysis of decentralised AI systems and the investigation of the applicability of contract principles as developed within the civil law and common law traditions, as well as within the European principles of contract law.

Chapter 2 reconstructed the technical and conceptual foundations of Decentralised Artificial Intelligence (DsAI), describing them as complex, multi-agent, and distributed systems with self-organising capabilities and behaviours not attributable to human counterparties, programmers or users. The analysis showed how these characteristics make DsAI qualitatively different from other forms of artificial intelligence, as they are capable of making autonomous decisions in open, non-linear environments and directly shaping the production of legal effects. Starting from this technical reconstruction, the chapter highlighted how DsAI challenge the traditional categories of private law. Traditional concepts of legal capacity, legal subjectivity, and personhood are based on the construct of a unitary well-defined source of interests, whether natural or legal persons, to which rights and duties are attributed. The DsAI, operating as decentralised algorithmic collective, break with this framework, as they produce legally relevant conduct without being recognised as subjects. This chapter thus laid the theoretical foundations for the entire thesis, clarifying the need for a functional revision of traditional categories.

Chapter 3 addressed the question and conundrum of the legal classification of sole-code smart contracts, considering them within the general framework of contracts by conduct. The comparison between civil law and common law showed how the former tradition values the convergence of wills, even if tacitly expressed through conclusive behaviour, while the latter is based on an objective approach, which infers the intention to be bound from external conduct. Consistent with these approaches, the Principles of European Contract Law (PECL) explicitly recognise the formation of contracts by conduct. Starting from this framework, the chapter demonstrated that sole-code smart contracts can be understood as forms of codified conduct: sequences of automated and irreversible on-chain operations that constitute observable and legally interpretable behaviours. The analysis thus highlighted a further paradox: unlike traditional contracts by conduct, sole-code smart contracts lack any explicit declaration accompanying the agreement. The expression of intent to be bound as well as the formation of the contract coincide entirely with algorithmic execution. The resulting conclusion that this thesis adopted is that sole-code smart contracts might be classified as contracts by conduct, but only in a functional and contextual sense: functional, because on-chain technical interaction constitutes behaviour suitable for expressing consent; contextual, because validity depends on the external interpretability of such conduct.

Taking into account the outcomes of chapter 3, chapter 4 then explored the topic of contractual intention and the ability of decentralised AI systems to manifest a form of artificial agency – intended as the behavioural capacity of an entity to initiate goal-directed actions in a way that is legally interpretable – questioning the role of DsAI in the formation of sole-code contracts. The analysis showed that, despite lacking legal personhood, DsAI systems exhibit autonomous and purposeful conduct that can be interpreted as expressions of legally relevant intent. However, this capacity faces a limitation: DsAI agents possess decision-making autonomy but not a sense of self-determination from a legal perspective, as they lack their own sphere of rights and duties. Hence, they produce legal effects but cannot be recognised as independent contractual parties. To explain this phenomenon, the chapter distinguished between the concepts of outer-determination, namely the definition of the overall legal interests by natural or legal persons – the legal subjects, and self-governance, the DsAI systems’ ability to autonomously make decisions upon the modalities for realising those interests. On this basis, the integrated agency theory was formulated, according to which DsAI systems do not operate

as autonomous subjects, but as functional components of the legal subject's legal sphere, materially manifesting contractual intention through their autonomous conduct. This theory could provide a starting point from which to consider the DsAI system as a functional and operative source of contract interaction, enabling the legal system to attribute valid effects to contracts generated by the DsAI.

Chapter 5 formalised the process, offering an operational framework for resolving the paradox. The analysis introduced the Paradigm of Autonomous Behaviour (PAB) as a technical-normative tool for determining when the autonomy of a decentralised system becomes legally relevant. The PAB, structured into five parameters—learning model, gradient of control, environmental complexity, internal state representation and reasoning—establishes that, upon exceeding at least three out of five at the maximum level, the DsAI can be considered legally autonomous. On this basis, the chapter developed the theory of Functional Legal Subjectivity (FLS), which does not grant full personhood, but recognises DsAI as having a functional, contextual subjectivity, emerging from their concrete role in decentralised contractual interactions. This theory interprets DsAI agents as active legal interfaces, capable of producing contractual and binding effects through autonomous algorithmic conduct, while remaining connected to the legal interests determined by human or legal persons. The chapter also clarified the distinction between contractual capacity and contractual intention: the former, understood as the normative ability to bind, can be functionally attributed to DsAI systems that exceed the PAB threshold; the latter is reconstructed *ex post* through the coherence between algorithmic behaviour and the contractual structure. The combined PAB and Functional Legal Subjectivity model thus overcomes the legal paradox, offering the law a conceptual and metric tool to integrate the autonomous behaviour of DsAI systems within the legal framework, ensuring legal certainty in contractual relationships generated in blockchain environments.

6.3 Formalisation of the Theories: Considerations

Legal subjectivity has always been conceived as closely connected to the capacity to act. Legal subjectivity is not a static fact but finds its normal development precisely in the legal subject's ability to perform legal acts, either a natural or a legal person. It follows that for an

action to be legally relevant it must be attributed to a legal subject – a recognised source of legally relevant interests - without which it would remain merely material conduct devoid of any legal relevance.

This aspect is crucial in relation to Decentralised Artificial Intelligence systems' ability to form smart contracts and is reflected today in the debate on the relevance of algorithmic behaviour. In the absence of a well-defined legal subject to whom such conduct can be attributed, it risks remaining outside the scope of the law, considered mere technological facts.

The theory of Functional Legal Subjectivity proposed in this thesis fits precisely into this tension. It does not alter the traditional structure of the relationship between legal subjectivity, legal capacity, and attribution of legal effects, but offers an operational interpretation in the context of decentralised systems. Specifically, Functional Legal Subjectivity does not attribute to DsAI agents an ontological status comparable to that of a natural person or an entity but rather allows them to be treated as functional centres of attribution of legally relevant conduct to the extent that their behaviour satisfies certain conditions (assessed through the Paradigm of Autonomous Behaviour). In this way, the link between fact and legal effect, which must always imply at least one source or subject, is preserved, as DsAI systems are recognised as functional subjects, even without acquiring full personhood.

The theories proposed in this thesis, the Paradigm of Autonomous Behaviour (PAB) and Functional Legal Subjectivity (FLS), must be understood within the precise normative perimeter that defines them. Functional Legal Subjectivity is not a claim that DsAI systems are or should be recognised as legal persons, moral agents, or bearers of rights. It is a juridical construct of strictly limited scope: a functional, threshold-conditioned, and context-dependent instrument of legal attribution, designed to resolve a specific paradox, the production of binding contractual effects in the absence of an identifiable legal subject, that arises exclusively within the architectural conditions of open, permissionless blockchain environments. The construct is activated only upon satisfaction of the PAB threshold, applies only within the contractual domain of sole-code smart contracts, and attributes to DsAI systems only the minimum normative incident necessary to render their conduct legally cognisable: the functional capacity to act as the originating source of contractual legal effects. It does not follow from Functional Legal Subjectivity that DsAI systems acquire any broader legal

standing, any rights of their own, or any form of recognition beyond what is necessary to manage the specific legal effects their autonomous conduct already produces in practice.

Thus, Functional Legal Subjectivity resolves the paradox: on the one hand, it upholds the traditional requirement that legal capacity be expressed only in relation to a legal subject; on the other hand, it extends this qualification in a functional form to the DsAI, to allow its autonomous and distributed conduct, already producing concrete effects, that can be attributed to a source of conduct. This allows the principle that at least one entity must always be present between a fact and a legal effect to be maintained, while adapting the category to a decentralised context. The Functional Legal Subjectivity model operates within an established doctrinal tradition, encompassing Kelsenian normativism, the bundle-of-rights account of legal personhood, and the functional approach confirmed by courts in the UK, Ireland and Italy, while extending it to address the structural novelty of decentralised AI systems.

At this point, the role of the Paradigm of Autonomous Behaviour (PAB) comes into play. It provides the evaluative criterion necessary to establish when the conduct of a DsAI can be recognised as suitable for expressing functional capacity to act. In other words, the PAB translates the technical characteristics of decision-making autonomy, independence from human control, and the capacity for self-organisation into legally relevant parameters, establishing a minimum threshold of autonomy beyond which algorithmic behaviour can be imputed to the system as a functional entity.

In this context, the PAB neither replaces nor alters the tradition linking the capacity to act to legal subjectivity but rather serves as a bridge: it ensures that the DsAI is qualified as a functional subject only when its conduct and actions meet the minimum requirements to be considered legal acts and not mere facts. Thus, the classic requirement that the capacity to act be expressed ‘only in relation to a subject’ is preserved, but with an adaptive extension made possible by measuring algorithmic autonomy.

Furthermore, Functional Legal Subjectivity does not present itself as an ontological category nor as a full and generalised recognition of rights and duties. It does not create a new type of legal personhood but rather serves as a limited attribution mechanism: it recognises DsAI systems as functional legal entities, that is, capable of acting in specific contexts and under specific conditions.

Consequently, the recognition of Functional Legal Subjectivity makes the attribution of full legal personhood to DsAI systems superfluous. Contrary to the assumption that legal effects must necessarily emanate from an entity with full formal legal personhood, it demonstrates that the capacity to act, and specifically to contract, can emerge from functional integration within an existing legal structure, which, in the case of sole-code smart contracts, is represented by the decentralised architecture itself.

In this framework, the DsAI is not configured as an autonomous legal entity, but as a computational component of the decision-making process of an already operational legal system. This structural configuration justifies the lack of a recognised full legal personhood, since the DsAI's capacity to act derives directly from its functional role in the decentralised socio-legal dynamic.

It follows that the most accurate response of law to the reality of decentralised intelligence is therefore not to place it outside existing legal categories, but to recognise its function within the legal framework, as a Functional Legal Subjectivity inherent in the decentralised system.

In this framework the contractual capacity of the DsAI is not attributed to *a priori*, but is constructed *ex post* based on two conditions: (1) exceeding the autonomy threshold established by the Paradigm of Autonomous Behaviour (PAB), and (2) the consistency of its actions with a valid normative configuration. It is this criterion, and not a delegated will, that justifies the legal attribution of algorithmic behaviour.

From this perspective, the contractual capacity of the DsAI does not derive from formal regulatory recognition but is intrinsically linked to its function and its contribution within the sole-code smart contract transactions.

6.4 Systemic Implications of Functional Legal Subjectivity and PAB Model

The adoption of Functional Legal Subjectivity and the PAB first entails overcoming the traditional dichotomy between subject and non-subject. The theory proposed demonstrates that capacity to act should not be understood as an exclusive and static attribute, specifically to entities formally recognised as legal persons, but rather as a quality that can functionally emerge from specific contexts of action. The DsAI demonstrates that there are configurations in which legal effects do not arise from a subject endowed with full personhood, but from a distributed set of autonomous and integrated behaviours. This leads to a more fluid conception of subjectivity, in which the binary opposition "subject/non-subject" gives way to a gradual and contextual model, based on the functional relevance of conduct.

Second, this approach connects with other legal fields. The most immediate parallel is with corporate law, where separate legal personhood is often a functional construct designed to allow the attribution of actions to a well-defined source, even in the absence of a natural will. Similarly, the Functional Legal Subjectivity of the DsAI allows legal effects to be attributed to a decentralised system. A further connection is found in the theories of unincorporated associations. To preserve the legal effects produced by the association, the law grants such associations legal subjectivity despite the lack of full legal personhood. In this sense, the DsAI presents itself as an algorithmic collective whose effects require a distributive attribution mechanism despite the lack of legal personhood. Finally, in the context of digital contracts, Functional Legal Subjectivity provides a criterion for distinguishing between pure automation (without independent legal relevance) and autonomous actions with functional contractual capacity, clarifying the possible classification of sole-code smart contracts as contracts where the agreement arises exclusively from algorithmic conduct.

Finally, the proposed approach maintains continuity with previous legal experiences, demonstrating that it is not a leap into the unknown, but an evolutionary adaptation. The analogy with corporate personhood is clear: here too, as opposed to natural persons, legal personhood has historically been attributed not by virtue of an ontological nature, but for functional reasons of attribution and economic operation. Similarly, the Functional Legal

Subjectivity of DsAI fits into a logic of instrumental recognition. Furthermore, the reference to the Principles of European Contract Law (PECL), which recognises the validity of contracts concluded through conduct, reinforces the continuity of the model: the contractual capacity of DsAI falls along the same interpretative line that has already expanded, in the European tradition, how contractual intention can manifest itself and produce effects.

6.5 Limitations

The theory of Functional Legal Subjectivity and the PAB should be understood as an operational framework, in the sense of a practical tool that translates the technical features of decentralised autonomy into general parameters that the law can evaluate and apply. Therefore, rather than introducing a new ontological category of legal subjectivity, the framework functions as a set of criteria that guides the attribution of functional subjectivity in specific AI contexts. In this sense, the proposal does not compete with the traditional categories of natural or legal persons but rather exists alongside them as an interpretative and applicative tool.

A second limitation concerns its scope of application, which remains confined to decentralised contexts and, in particular, to the dynamics of sole-code smart contracts. It is in this environment that DsAI manifests its technical autonomy and its role as initiator or mediator of transactions, generating potentially accountable conduct. Extending the model to other contexts, for example, centralised AI or hybrid systems with human supervision, would risk distorting the very logic of Functional Legal Subjectivity, which is grounded in the distributed and autonomous nature of decentralised architectures.

Finally, an open question remains regarding political and collective responsibility in cases of widespread algorithmic interconnectivity. Where risks and impacts cannot be traced back to a single DsAI but emerge from networks of interacting DsAI systems, Functional Legal Subjectivity is not enough. In these scenarios, rather than a problem of contractual capacity, the need for a political and regulatory approach capable of distributing responsibility and compensation burdens at the collective level emerges. This opens the possibility of solutions

already tested in other contexts, such as sectoral liability regimes, which go beyond the private-law dimension of Functional Legal Subjectivity and require regulatory and political choices.¹

6.6 Future Research Directions and Developments

The Functional Legal Subjectivity model and the PAB, while conceived as operational tools in a specific context, open up significant avenues for future research. First, there is the possibility of extending the model to other domains of the decentralised ecosystem, such as decentralised finance (DeFi) or DAO-based governance structures. In these contexts, the logic of algorithmic self-organisation and collective attribution takes on an even more relevant role, and Functional Legal Subjectivity can offer criteria for understanding how distributed acts and decisions can be legally relevant.

Second, it is necessary to develop a dialogue with public law and regulatory regimes, particularly with the EU AI Act and with liability frameworks. The private law analysis conducted in this thesis already highlights the limitations of these tools, which were created to govern AI according to ex ante risk logics but are ill-suited to capturing the dynamics of autonomy and distribution typical of DsAI. Future studies should therefore explore the integration of functional approaches and public law disciplines in order to build more effective systemic responses.

Further development concerns the construction of a pluralistic legal ontology capable of transcending the binary subject/non-subject paradigm and embracing different forms of legal subjectivity: full, traditional, functional, and collective. DsAI, with its distributed and autonomous nature, demonstrates that 21st-century law can no longer simply replicate categories designed for individuals or centralised entities, but must integrate differentiated models of capacity and attribution.

¹ Geraint Howells, Christian Twigg-Flesner and Thomas Wilhelmsson, *Rethinking Product Liability: A Comparative Perspective* (Routledge 2017).

In conclusion, DsAI emerges as a new active legal interface, neither a simple instrument nor a full legal subject, but a functional centre of attribution capable of generating legal effects in the context of sole-code smart contracts. It transforms legal capacity from a static category to a dynamic, contextual architecture, where algorithmic autonomy becomes a criterion of legal relevance. This is where the most significant contribution of this research lies: showing how law, if equipped with adequate conceptual tools, can recognise and govern the legal capacity of decentralised intelligences, without betraying its own tradition, but at the same time opening itself to the future.

The work carried out in this thesis does not exhaust the issues raised but rather opens a field of investigation that requires further development. The original contribution this thesis has made was to articulate Functional Legal Subjectivity and the Paradigm of Autonomous Behaviour as conceptual and metric tools for recognising the legal relevance of decentralised algorithmic conduct of DsAI systems in sole-code smart contracts. Future research will also need to extend to the interdisciplinary level, strengthening the dialogue with computer science, cognitive science, and complex systems theory, to refine tools such as the Paradigm of Autonomous Behaviour (PAB) and make them increasingly suitable for translating technical conditions into legally relevant parameters.

In this way, Functional Legal Subjectivity is the beginning of a new legal paradigm: the first step in an evolutionary path that will accompany the law as it addresses the transformations brought about by Decentralised Artificial Intelligence in the 21st century.

APPENDIX

APPENDIX A

A.1. Comparative Table: AI Learning Models

Model	Brief Description	Operating Mode	Degree of Autonomy
Supervised Learning	AI learns from labeled data provided by a human supervisor.	Database of examples → recognition of predefined patterns.	Low–medium (strong human control).
Unsupervised Learning	AI learns without pre-classified examples.	Organises and classifies unlabeled data, identifies correlations.	Medium–high (limited human intervention).
Reinforcement Learning	Learning by trial, error, and rewards.	Sequences of actions → positive/negative feedback → optimal strategies.	Medium–high (progressively self-oriented decisions).
Deep Learning (DL)	Multilayer neural networks are inspired by the human brain.	Dynamic connections (artificial synapses) reorganised at each learning stage.	High (self-programming).
Generative Adversarial Networks (GANs)	Two competing neural networks (generator vs discriminator).	Create autonomous outputs without predefined training.	High.
Cognitive Computing (CC)	Algorithmic simulation of human cognitive processes.	Algorithms that learn, infer, and interact.	High.

APPENDIX B

B.1 The Unitarian Concept of Legal personhood: Encompassing Legal and Philosophical Theories

Legal personhood is typically conceived as a unified concept within European legal traditions. It entails both the qualitative aspect of being recognised as a legal subject and the quantitative elements of possessing legal capacity.¹ This is because legal capacity arises simultaneously with the legal subject's existence, whether natural or artificial.

B.2 Challenging the Unitary View: Diverging Theories on Legal Personhood

Some legal theorists challenge the syllogistic assumption that legal capacity and therefore legal subjectivity means legal personhood.² According to such theorists, the evidence is in different treatment that law reserves to natural and artificial persons.³ For example, some personal rights, such as the right to life or the right to have a name, cannot be recognised to artificial persons.⁴ In other words, artificial persons do not have the same legal capacity as natural ones even though they can have legal personhood. There is no evidence of such a debate in common law systems, much more practically oriented.

Therefore, in the light of what has been examined so far, the concept of legal personhood is very much intertwined with the concepts of legal subjectivity and legal capacity. However, even analysing such concepts separately, the criteria for recognising legal personhood and, by

¹ De Cupis, 'I diritti della Personalità', in *Tratt. Dir. Civ. e Comm.* (4th edn, Milano, 1959), 9.

² Pietro Perlingieri, *Il Diritto Civile nella Legalità Costituzionale* (Edizioni Scientifiche, 1988), 138.

³ Tommaso Vittorio Frosini, *Il soggetto di diritto come situazione giuridica*, in *Riv. Dir. Civ.*, 1969, I, p. 227 ss.

⁴ *Ibid.*

extension, legal capacity and subjectivity, remains elusive. Ambiguity arises because law does not provide a universal legal standard nor a systematic framework to define the characteristics of entities capable of holding rights and duties.⁵ Instead, the recognition of legal personhood has been shaped by historical, philosophical and jurisdictional developments. The absence of legal standards, however, makes legal personhood a very flexible and evolving concept. For example, while historically legal personhood was reserved to human beings, over time legal systems adapted to socio-economic changes granting legal personhood to corporations.⁶ Most recently, the debate around the possibility to extend legal personhood to animals arose again within the legal domain, particularly in light of advancements in animal rights jurisprudence and in ethical debates.⁷ As society and legal systems continue to evolve in response to ethical and technological challenges, the boundaries of legal personhood remain fluid, fueling the discussion about the re-examination of traditional legal frameworks surrounding the concept of legal personhood.

B.3 Beyond Legal Recognition: The Philosophical Hallmark of Legal personhood

Without a clear reference to the characteristics that an entity, being human or non-human, must possess to be granted legal personhood, jurists inevitably turn to the philosophical aspect of the concept to detect the content and the very meaning of such features. From a philosophical standpoint, jurists traditionally base legal personhood's features on a combination of different

⁵ Elettra Stradella and others, 'Robot Companions as Case-Scenario for Assessing the 'Subjecthood' of Autonomy Agents' (2012) 1 CAUR Workshop Proceedings <<https://ceur-ws.org/Vol-885/paper4.pdf>> accessed 12 December 2024.

⁶ Maximilian Koessler, 'The Person in Imagination or Persona Ficta of the Corporation' (1949) 9 Louisiana Law Review, 435.

⁷ Tomasz Pietrzykowski, 'The Idea of Non-personal Subjects of Law' in Visa A.J. Kurki and Tomasz Pietrzykowski (eds), *Legal Personhood: Animals, Artificial Intelligence and the Unborn* (Springer 2017), 49–67.

elements, namely freedom, autonomy, intentionality and responsibility.⁸ In this context, legal personhood is considered as a unified concept that stems from the different interrelation of such elements and that acquires legal meaning only if it is understood in correlation to them.⁹

Hence, the analysis will now delve into the foundational elements of the concept of legal personhood from a traditional standpoint. It will then explore the different levels of legal capacity in relation to different types of legal subjects. Further to that, it will contemplate some of the new legal theories surrounding the legal personhood concept, followed by the examination of the agency law theory for a more comprehensive investigation.

To begin with, the following section will bring forth the philosophical and theoretical foundations of legal personhood as rooted within the Western legal tradition. It also incorporates some references to theological principles which have profoundly shaped the evolution of these concepts. The purpose is twofold. First, to elucidate the historical development of legal personhood; and second, to highlight some key principles that have been incorporated within the legal tradition. Central to the introduction of the discussion is indeed the relationship between freedom, autonomy, and responsibility as foundational principles of legal personhood.

B.4 The Philosophical and Legal Framework of Personhood: Freedom, Autonomy and the Social Dimension

⁸ Amongst many, see John Martin Fischer and Mark Ravizza, *Perspectives on Moral Responsibility* (Cornell University Press 1993); Christopher Norris, 'Frankfurt on Second-Order Desires and the Concept of a Person' (2010) 9 (2) *Prolegomena* 199-242 <<https://hrcak.srce.hr/file/91379>> accessed January 2025.

⁹ *Ibid*, 202-203.

European legal traditions are grounded on the principle of freedom.¹⁰ As affirmed, law is based on freedom and law is the measure of freedom.¹¹ To better understand such statement it is necessary to investigate the meaning of freedom within the legal system. Amongst all the legal concepts, freedom remains the most elusive and yet challenging one to both define and implement. The reason being is that it reflects a conceptual tension between individual and collective interests. As Kant asserts, freedom possesses indeed two dimensions: the absence of external constraints (negative freedom) and the capacity to act in accordance with one's rational will (positive freedom).¹² From this rational ability to act according of one's self-determined will another element of freedom emerges, termed autonomy. As already stated in Chapter 4, autonomy represents the ability of self-governance.¹³ Following this interpretation, autonomy is indeed a component of freedom. Autonomy is also what, as Kant stated, discriminates individuals as moral agents: it is from autonomy that one can be held responsible for his actions.¹⁴ Therefore, it can be stated that without the interplay between freedom and autonomy there cannot be responsibility in the eyes of law. Without accountability for one's own behaviour, collective and social interests would be constantly threatened.

Therefore, the very relationship between freedom and law can be better defined from a philosophical perspective: law is a social phenomenon, encompassing ethical and collective values, deeply rooted in the principle of equality.¹⁵ Equal rights inevitably entail equal

¹⁰ Vira Tymoshenko, Serhii Bondar, Nataliia Ivanchuk, 'Human freedom in the legal dimension' (2023)

13 (1) Law Journal of the National Academy of Internal Affairs <<https://elar.naiu.kiev.ua/server/api/core/bitstreams/5405e27f-ddb2-4c34-b618-6dd477e5f19b/content>> accessed 18 October 2024.

¹¹ Immanuel Kant, *The Metaphysics of Morals* (Mary J Gregor (trs), Cambridge University Press 1996), 56.

¹² Immanuel Kant, *Groundwork of the Metaphysics of Morals* (Mary Gregor and Jens Timmermann (trs), Cambridge University Press 2012), 49.

¹³ Immanuel Kant, *Critique of Practical Reason* (Mary Gregor (trs), Cambridge University Press 1997), 22.

¹⁴ *Ibid*, 22.

¹⁵ John Rawls, *A Theory of Justice* (Rev edn, Harvard University Press 1999), 52.

responsibilities.¹⁶ Within the legal framework, equality ensures that the extent of individual freedom is also restricted by law – through rights and duties- whenever it transcends into someone else’s sphere of freedom.¹⁷ Therefore, the interaction between freedom and equality in the legal system defines what behavior a legal person is permitted to carry out in relation to another, ensuring social order.

This definition reflects an objective understanding of freedom where law defines both the measure and the form of individual freedom within the complex structure of social phenomena. Indeed, law is the only way individual freedom can be expressed within the social structure and guaranteed by the legal system. Individual freedom can be thus considered as a legal attribute that defines one’s legal capacities, status and position in society.¹⁸ A good indicator of the degree of freedom is indeed law. Without the recognition of individual freedom and autonomy, legal subjects and their legal relations cannot exist.¹⁹ There is also another reason why in the legal system, freedom and autonomy, are regarded as foundational elements of legal personhood: both concepts imply responsibility.²⁰ Autonomy, as self-governance, is deeply based on rational freedom which, within the legal realm, accounts for holding individuals responsible for their actions.²¹ As a consequence, the foundation of law lies in the recognition of individual autonomy for this accounts for one’s own responsibility.²² Such a concept is well understood within the legal tradition as responsibility is balanced on the different degree of one’s capacity to self-govern, hence on different degrees of autonomy and legal capacity.²³ Such theoretical passage will be better analysed in the following sections when the different degrees of autonomy and their legal implications will be examined. For the

¹⁶ Jean-Jacques Rousseau, *The Social Contract* (Maurice Cranston (trs), Penguin Books 1968) 54; John Stuart Mill, *On Liberty* (first published 1859, Oxford University Press 1998), chapter 4.

¹⁷ Kant (n 13), 6:237.

¹⁸ Hans Kelsen, *Pure Theory of Law* (Max Knight (trs), University of California Press 1967), 171.

¹⁹ *Ibid.*, 172.

²⁰ Joseph Raz, *The Morality of Freedom* (Oxford University Press 1986) 369.

²¹ *Ibid.*

²² Ronald Dworkin, *Taking Rights Seriously* (Harvard University Press 1977), 190.

²³ H.L.A. Hart, *Punishment and Responsibility: Essays in the Philosophy of Law* (2nd edn, Oxford University Press 2008), 152.

purpose of this section instead, it must be reckoned that a person is considered autonomous only if capable of rationally orientate his own actions such that he can be held responsible for his decisions and behaviour.²⁴

Legal recognition of autonomy inevitably denotes legal personhood as a bidimensional concept. The first dimension is the social dimension which entails the interplay between one's personal sphere of freedom and equity. In other words, this dimension reflects the balance between individual freedom and collective equality where law establishes one's rights and duties to maintain social order. The second dimension is the pure legal dimension of personhood that entails the capacity for self-governance and responsibility for one's decisions or actions. When legal personhood is understood as a bidimensional concept, one can also grasp why law does not offer a specific definition of which are the foundational elements of legal personhood: as it is not for law to account for which are standard elements on which legal personhood is granted.

B.5 The Teleological Ground of Legal Personhood in European Legal Traditions: The Christian Influence on Freedom, Autonomy and Responsibility

The concepts of freedom, autonomy and responsibility so established within the European legal tradition owe their philosophical foundation to another source: the Christian tradition principles. Christianity has profoundly shaped the concept of freedom.²⁵ The Genesis book states indeed that the material nature and its creatures are the product of God's free will.²⁶

²⁴ Mathieu Vandenbulcke, Rose-Marie Dröes, and Erik Schokkaert (eds), *Dementia and Society* (Cambridge University Press 2022), 51-52.

²⁵ Dennis M Sullivan, 'The Conception View of Personhood: A Review' (2003) 18(2) *Ethics & Medicine* 11
<https://digitalcommons.cedarville.edu/cgi/viewcontent.cgi?article=1059&context=science_and_medicine_publications> accessed 6 October 2024.

²⁶ *Bible, Book of Genesis* (ESV Scripture Journal, 2019), 1:27.

Freedom is how God exerted his own deliberation upon creation without any external influence. God then, entrusted the material nature so freely created to Adam to rule over it.²⁷ The symbolic handover of dominion over nature to humanity has been interpreted as the foundational moment of beginning of the western scientific endeavor in understanding and governing the natural world through technology and rules of intellect.²⁸ Such ruling over nature and its creatures is explained further by another principle. As for Christian tradition, as opposed to other living beings, men are created as image of God.²⁹ With the promise of eternal life, the power of humankind over nature underscores its everlasting power of freedom that God bestowed upon men. The critical implication is the following: if men are endowed with the power of free will and autonomy that they exert with their actions over the material world, they can be held responsible for them. If men are responsible, they are liable and thus punishable.³⁰ That is the origin as to why concepts of freedom, autonomy and responsibility are so tightened up. Individuals are considered autonomous when they are free to make their own decisions and bear the responsibility for that.³¹ Therefore, such concepts presuppose each other.³² The theological foundation of these notions has then been absorbed within the western legal tradition and transposed to the concept of legal personhood.³³ As John Finnis underscored, the influence of Christian philosophy on the concept of legal personhood has been of a greater

²⁷ Dennis M Sullivan, 'Defending Human Personhood: Some Insights from Natural Law' (2008) 37(3) *Christian Scholar's Review* 297 <https://www.researchgate.net/profile/Dennis-Sullivan-4/publication/265221882_Defending_Human_Personhood_Some_Insights_from_Natural_Law/links/5703afb008aedb127085e1/Defending-Human-Personhood-Some-Insights-from-Natural-Law.pdf> accessed 9 October 2024

²⁸ Francis Bacon, *Novum Organum* (first published 1620, Urbach and Gibson eds, Open Court 1994) 92.

²⁹ Genesis (n 26), 1:27.

³⁰ Umberto Galimberti, *Psiche e Techne. L'uomo nell'Età della Tecnica* (Feltrinelli 2000).

³¹ Matieu Vandenbulcke, Rose Marie Dröes and Erik Schokkaert (eds), *Dementia and Society* (Cambridge University Press 2022).

³² *Ibid*, 52.

³³ Ngaire Naffine, *Law's Meaning of Life: Philosophy, Religion, Darwin and the Legal Person* (Hart Publishing 2009).

significance, highlighting human dignity as its cornerstone.³⁴ Being made in God's image and placed at the center and summit of the created order, man is considered as person, a someone and not just something which is superior to the material world.³⁵ Therefore, man 'shares the light of the divine mind' based on freedom and endowed with natural dignity.³⁶ It is this concept of man that provides the foundation of human beings as bearers of rights and duties³⁷, which corresponds to the strictly legal view of the person. From the Christian tradition it is also possible to make further sense of the social dimension of legal personhood. It is postulated that legal personhood can be understood only in relation to its social meaning.³⁸ Persons are so qualified within the legal setting because they are 'persons-in-relations'.³⁹ Hence, legal persons are defined by the mutuality of relationship between each other.⁴⁰ The concept of 'persons-in-relations' reflects the aspects of Christian philosophical view of personhood that highlights the importance of community and unity.⁴¹ This view suggests that just as individuals are defined by their relationships from a theological perspective, the legal framework similarly establishes the meaning of personhood on the recognition of social relationships and obligations. This is relevant as this stance presupposes that legal personhood is not a static construct. It is contingent upon the roles and duties individuals or entities acquire in relation to others. The

³⁴ John Finnis, *Natural Law and Natural Rights* (2nd edn, Oxford University Press 2011), 85.

³⁵ Pontifical Council for Justice and Peace, *The Compendium of Social Doctrine of The Church* (Strathfield NSW, St Paul's Publication, 2004), 56.

³⁶ *Ibid*, 65.

³⁷ Naffine (n. 33), 110.

³⁸ Roy F. Bumeister, 'Emergence of Personhood: Lessons from Self and Identity', in M Jeeves (ed), *The Emergence of Personhood: A Quantum Leap?* (William B Eerdmans Publishing 2011), 68.

³⁹ Adrian Thatcher, 'Christian Theism and The Concept of Person' in Arthur R Peacocke and Grant R Gillett (eds), *Persons and Personality: A Contemporary Inquiry* (Blackwell 1987), 180.

⁴⁰ John Macmurray, *Persons in Relation* (Gifford Lectures, Faber & Faber 1961); Alasdair MacIntyre, *After Virtue* (3rd edn, University of Notre Dame Press 2007), 194.

⁴¹ Robert R. Williams, 'Hegel on Persons and Personhood', *Hegel on the Proofs and the Personhood of God: Studies in Hegel's Logic and Philosophy of Religion* (Oxford, 2017; online edn, Oxford Academic, 19 Jan. 2017), <<https://doi.org/10.1093/acprof:oso/9780198795223.003.0005>> accessed 31 December 2024.

concept of mutuality is thus transposed within the legal settings throughout what has already been considered in the previous section: the law, by virtue of rights and duties, delimits the freedom of legal persons amongst each other to ensure equality and dignity. This implies that the law defines personhood by acknowledging how individuals relate to and affect one another. The meaning of personhood therefore is a concept that acquires meaning because of the legal relationships that it entails. From this teleological framework it is possible to better understand the foundation of the traditional concept of legal personhood as present within European legal systems. Therefore, one of the foundational elements of legal personhood is proposed to stem from the participation or presence of persons in social life and interactions.⁴²

The debate on legal personhood undeniably undergoes the contention on foundational elements such as freedom, autonomy as well as the social element. Such foundational elements concur to explain the role of equity and responsibility so much tighten up to the concept of personhood. The social context then adds to a further component of legal personhood, providing insights as to why it acquires full meaning when persons are considered in relation to others. The proponents of traditional theory of legal personhood still consider such concepts as critical in defining it. This stance highlights how freedom, autonomy and responsibility stemming from the teleological meaning of free will, within both social and legal systems affected so deeply the concept of personhood in European legal traditions.

This thesis argues that despite the silence from the legal system in defining what constitutes legal personhood, the philosophical foundation of the concept itself assists the jurists in this task and must be considered. The reason being is personhood developed within both socio-cultural and legal spheres, which complement each other. Trying to detach these two components of legal personhood might lead to a construction that lacks depth in explanation as to why law defines personhood as the ability to hold rights and bear duties, and which are the subjects that can be so recognised.

⁴² Sylwia Wojtczak, 'Endowing Artificial Intelligence with Legal Subjecthood' (2022) 37 *AI & Society* <https://www.researchgate.net/publication/349365102_Endowing_Artificial_Intelligence_with_legal_subjecthood> accessed 7 December 2024.

In the following section the two main traditional theories of legal personhood will be explored: legalist and realist theories.

B.6 Traditional Theories of Legal Personhood: The Antagonistic View between Legalist and Metaphysical Realists

Legalists thinkers offer the most orthodox yet technical approach to describe legal persons.⁴³ Legalists are of the view that law should not and does not take into account the natural conception of a person.⁴⁴ Therefore, law should not engage or operate with any metaphysical or existential quarrels. One's legal nature is not to be confused with one's nature that is confined beyond law.⁴⁵ Legal persons and their legal personhood, the capacity to hold rights and duties, exist only in the legal domain as a matter of legal expedience – a fiction-which does not refer to any social or moral traits. Legalists assert the complete separation between the very nature of a person and the legal aspect of it.⁴⁶ As Nekam asserted 'those to whom the law attributes such a legal personhood possesses it entirely by the force of the law and not by nature'.⁴⁷ Hence, the legalist view thinks about legal personhood as an abstraction, something that exist only in contemplation of law.⁴⁸ Consequently, human beings as well as non-human beings can all potentially be granted legal personhood.

What the legalist approach does instead is to consider legal relations as an essential element of legal personhood. Whenever there are legal relations then inevitably there are legal

⁴³ Ibid, 19.

⁴⁴ Béla F Nagy Nekam, *The Personality Conception of the Legal Entity* (Harvard University Press 1938).

⁴⁵ Ibid, 17-28.

⁴⁶ Hans Kelsen, *Pure Theory of Law* (Max Knight tr, University of California Press 1967) 45–50.

⁴⁷ Alexander Nekam, *The Personality Conception of The Legal Entity* (Cambridge, Mass, Harvard University Press, 1938) 24.

⁴⁸ FH Lawson, 'The Creative Use of Legal Concepts' (1957) 32 *New York University Law Review* 907, 915.

persons, for only legal subjects can be parties of legal relationships. In other words, for legalists thinkers' legal personhood is considered as the capacity to participate in legal relations.⁴⁹ Whenever either a human or a non-human being is recognised in possession of this capacity is considered a legal person and therefore endowed with legal personhood.⁵⁰ From this stance, it follows that legal persons' capacity to possess and exercise rights and duties within the legal relations vary according to the specific legal purpose or circumstances of the parties. For the legalist approach, legal persons therefore function only within the legal domain, considered as a self-enclosed and a self-referred one.⁵¹

It is interesting to note that the legalist view does not take into account anything rather than the legal domain for a legal person to exist and function, yet it considers legal relations as pivotal element from which the very concept of legal personhood emerges and is recognised. However, legal relationships are inevitably a social – a relational- event that happens in the material domain as well. Indeed, no legal relationship exists or acquires any meaning within the purely legal sphere. Therefore, the material and relational aspect does not seem to be completely removed from the legalist theory of legal personhood.

By contrast, metaphysical realists believe that the nature of the legal subject must be found beyond law. Within rationalist thinkers there are also other theoretical subfields which have been developed over the years. However, for the thesis's purpose, only the overall theoretical approach will be investigated as the overarching theme of the entire realism can be successfully depicted as an antagonistic view to the legalism movement. The core principle of Realist theory is that the true legal person is the human being.⁵² His rational ability and capacity are the foundational elements from which rights and duties stem. Realism focuses on human autonomy and independence which are the core aspects of legal personhood.⁵³ Therefore, legal

⁴⁹ John Austin, *The Province of Jurisprudence Determined* (first published 1832, WE Rumble ed, CUP 1995) 186–190.

⁵⁰ HLA Hart, *The Concept of Law* (3rd edn, OUP 2012) 79–91.

⁵¹ Joseph Raz, *The Authority of Law: Essays on Law and Morality* (2nd edn, OUP 2009) 3–6, 35–41.

⁵² Georg Wilhelm Friedrich Hegel, *Elements of the Philosophy of Right* (HB Nisbet tr, CUP 1991) 40–47.

⁵³ John Finnis, *Natural Law and Natural Rights* (2nd edn, OUP 2011) 111–120.

personhood accounts humans as moral and rational agents which are legally responsible for their actions towards other legal persons as part of a legal community.⁵⁴ The influence of Kant's will theory of the person – the ability to act accordingly to one's free will - represents one of the relevant corollaries of the realistic theory.⁵⁵ As John Chipman Gray asserted '[for] legal rights be exercised a will is necessary, and, therefore, so far as the exercise of legal rights is concerned, a person must have a will'.⁵⁶

Probably the main issue that it is possible to recognise within the metaphysical realism theory is the inevitable disregard of legal personhood to any entity that does not possess rational capacity. The problem, of course, is related to non-human entities such as corporations which, by nature, do not possess any intrinsic capacity for free will. Corporations only exert their will through their own legal representatives.⁵⁷ However, the issue expands beyond corporations. It involves also other human beings with less capacity: such as minors, persons with diminished reason or mentally impaired individuals. The legal system accounts for the possession of legal personhood and rights even to human beings which are below the threshold of sound minds, as will be discussed in the following sections.

On the contrary, the interesting aspect of rationalist thinking is though the absorption and integration within its sub-fields of the traditional philosophical and teleological framework of legal personhood. The reference is to the elements of freedom, autonomy, responsibility and social dimension, as previously investigated, as core *sine-qua-non* conditions of legal personhood within the realism theory.

A final consideration that has been advanced is that legalist and realism theories also differ in relation to the acceptance of the necessary existence of just one or more conditions of legal personhood. Overall, it is said that legalist view leans towards a pluralistic approach by which legal personhood is granted based on whichever elements or conditions that account for

⁵⁴ Immanuel Kant, *The Metaphysics of Morals* (Mary Gregor tr, CUP 1996) 12–20.

⁵⁵ Ibid, 12-20.

⁵⁶ John Chipman Gray, *The Nature and Sources of The Law* (2nd edn, New York, Macmillan. 1921) 27.

⁵⁷ Ibid, 49–50.

one's ability to be part legal relationships.⁵⁸ Such conditions are pluralistic, they can be more than one based on the purpose and the context of legal relations. By contrast, realists are inclined to a monistic view: they believe that legal personhood stems from just one and only condition: the nature of the human being.⁵⁹

In conclusion, the theoretical debate on legal personhood demonstrates both the richness and ambiguity of a concept that has developed through historical, philosophical, and theological layers. These references allow us to better understand the conceptual roots of subjectivity and legal capacity, but they also highlight their limitations when it comes to framing emerging entities such as DsAI. Precisely for this reason, the thesis proposes in the following chapters a functional and contextual approach capable of overcoming the constraints of traditional categories and offering conceptual tools suitable for recognising the legal relevance of decentralised AI systems.

⁵⁸ Claudio Novelli, Giorgio Bongiovanni, Giovanni Sartor, 'A Conceptual Framework for Legal personhood and Its Application to AI' (2022) 13 Jurisprudence 194 <<https://doi.org/10.1080/20403313.2021.2010936>> accessed 6 November 2024.

⁵⁹ Ibid, 206.

APPENDIX C

Tables and Figures

3 Main Interrelated Areas of Investigation

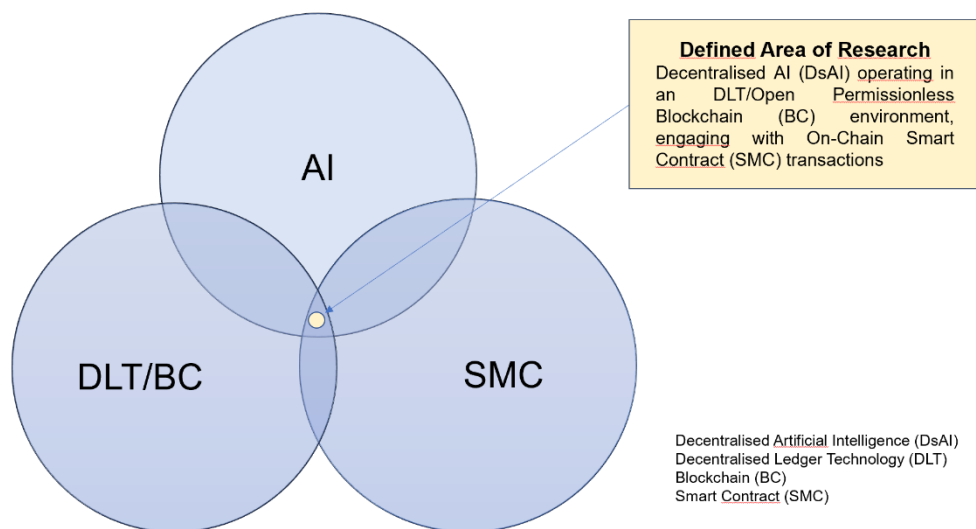


Fig. 1.1 Areas on Investigation

Source: [Valuates Reports](#)

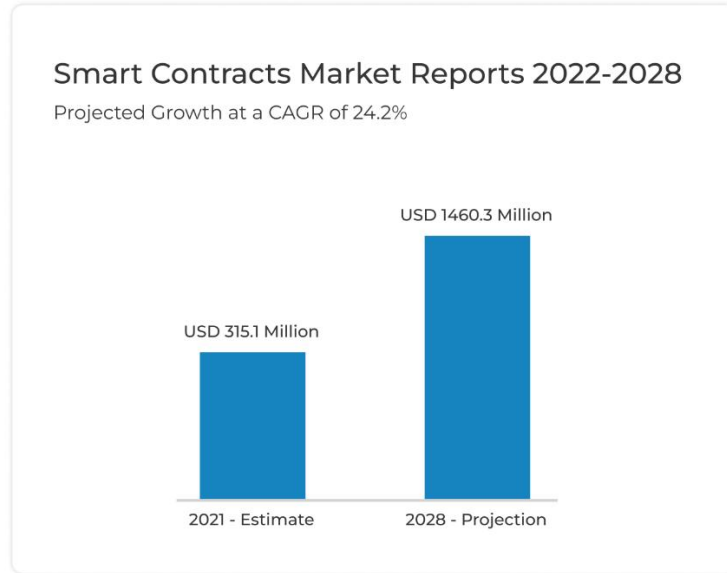


Fig. 1.2 – Smart Contracts Market Growth Projection



Fig. 1.3 – Smart Contracts Market Report

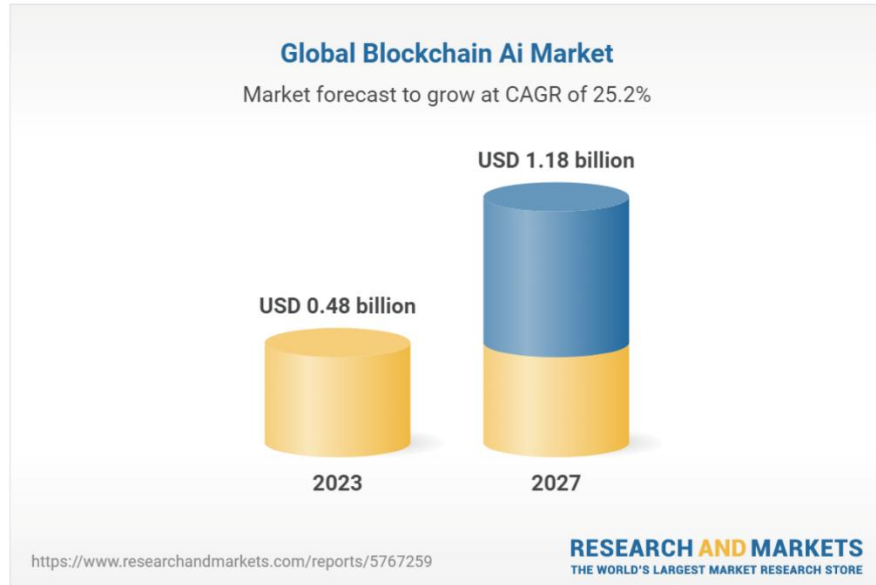


Fig. 1.4 – Global BC and AI Market Provision

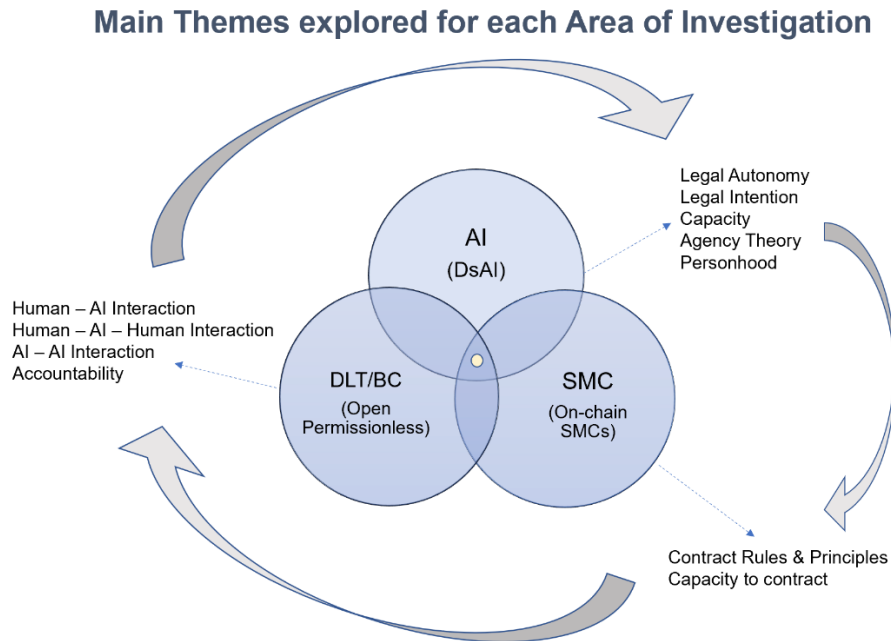


Fig. 1.5 Main Themes explored

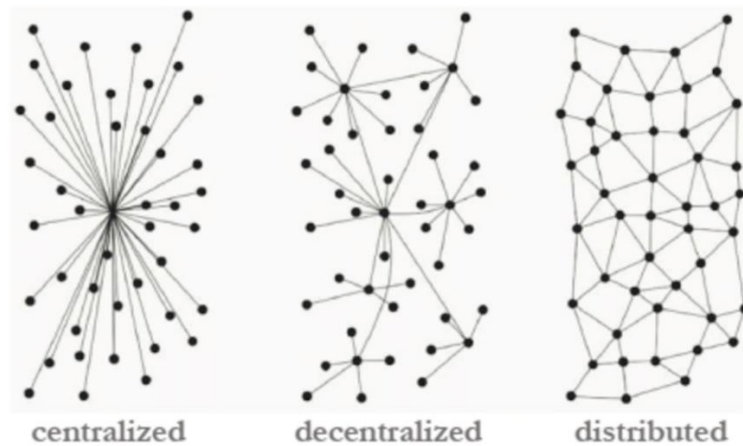


Fig. 1.6 Baran's Typology of Communication Networks (1964)

	Concepts	Definition	Civil Law System	Common Law System
1	Legal Subject	An entity – natural or artificial- capable of holding rights and duties.	Explicitly recognised concept. Includes both natural and artificial persons.	Implicitly recognised. Not explicitly used as a legal concept. Refers to entities – natural or artificial- being capable of holding rights and duties
2	Legal Person	An entity – natural or artificial - endowed with legal personhood.	Synonymous of 'legal subject'. Includes both natural and artificial persons having legal personhood.	Refers only to artificial persons (i.e. corporations, associations, foundations, charities, etc.).

Table 2.1 - Concepts of legal subject and legal person: comparison between civil law and common law traditions

THE LIFE-CYCLE OF A BLOCKCHAIN TRANSACTION

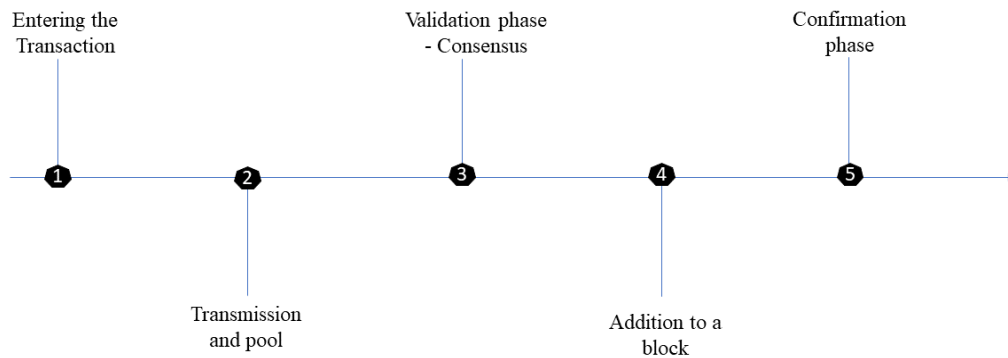


Fig. 3.A - The Lifecycle of a Blockchain Transaction

THE LIFE-CYCLE OF SMART CONTRACT TRANSACTION

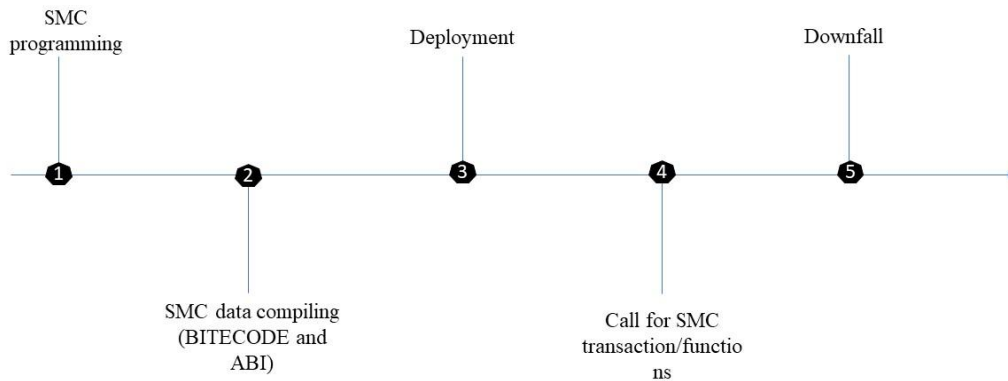


Fig. 3.B - The lifecycle of Smart Contract Transactions

The Integrated Agency of DsAI multi-agents and the Legal Subject in the decentralised environment

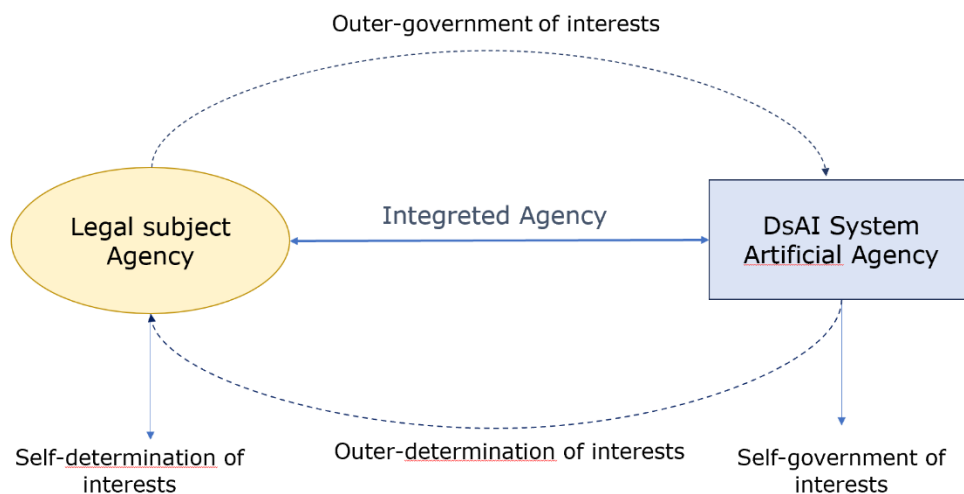


Fig. 4.1 - The Functioning of the Integrated Agency

The Integrated Agency dynamics in the decentralised environment

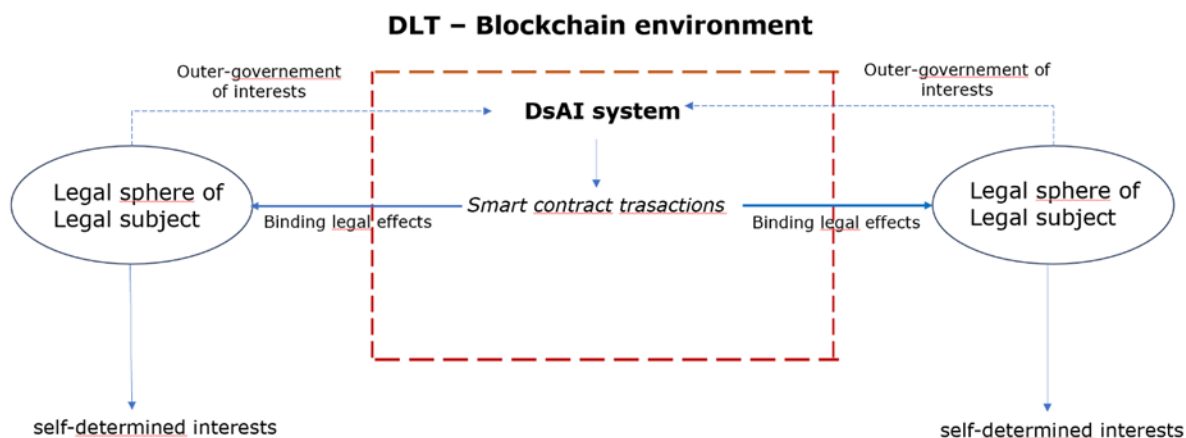


Fig. 4.2 - Legal subject to legal subject relation with the DsAI as part of the legal sphere of legal subjects

Parameter	Operative Definition	Level 0	Level 1	Level 2
Learning Model	Ability of the system to learn and update itself autonomously	Static or supervised only. Pre-programmed systems	Supervised or mixed learning. The system shows adaptation but within defined limits.	Neural symbolic learning, symbolic-inductive (i.e. MeTTa language) -enabling the system to build new strategies without external intervention
Gradient of Control	Level of human intervention required in the decision-making process	HITL (Human-in-the-loop)	HITL (Human-in-the-loop)	HOOTL (Human-out-of-the-loop), self-execution
Environmental Complexity	Nature of the operating environment (input-output, adaptability)	Linear, centralised, static - system responsive to deterministic inputs.	Mixed, semi-predictive - the system adapts to variations within known patterns.	Decentralised, nonlinear, dynamic -AI has to react to unpredictable contexts (e.g. blockchain, open-source systems).
Internal Models	Presence of internal models that support agency: intentions, desires, beliefs, inferences, values	No internal model - rigidly causal behaviour. i.e. deterministic system / reactive script.	Simple internal models, reactive (i.e. static preferences, scores). i.e. Simple agent-based model with predefined goals.	Simulated mental states, modeled higher intentionality, meta-intentionality, purpose inference. i.e. BDI agents, DsAI, OpenCog Hyperon, agents with MeTTa
Self-organisation Representation & Reasoning	Ability to build and manipulate symbolic and abstract representations	Numerical data, pattern with no semantic structure.	Simple symbolic representation; static rules or predicative logic.	Symbolic inference, nonmonotonic, evolutionary conceptual reasoning - ability to deal with uncertainty (i.e. PLN, neural symbolic architectures).

Table 5.1 Operational Metric Grid of PAB Parameters and Values

Degree of Integration/Interrelation	Operational Definition
0	Additive Parameters: each of the 5 parameters function separately, even when reaching level 1 or 2.
1	Partial Integration amongst the parameters (i.e. learning model <->environment): coordinated parameters interact functionally but without structural co-dependence.

2	Systemic Integration: each parameter dynamically effects and modulates the others (i.e. internal models <->environment<->reasoning<->learning<->control). Parameters are interdependent, forming a coherent, self-reflective system

Table 5.2 - The Degree of Integration of PAB Parameters

Parameter	Level	Description
Learning model	0	The model does not learn in real time: its model is pre-trained and static during inference. No online updates.
Gradient of control	1	Human control is partial: output is autonomously generated, but can be directed via prompts, or stop-sequences.
Environmental complexity	1	The model processes complex information and can simulate contexts but does not perceive or interact with real environments dynamically.
Internal models	0	It has no dynamic internal models, intentions, motivations, or autonomous persistent memory (unless external mechanisms such as the “memory” API).
Representation and Reasoning	1-2	Advanced capacity for symbolization and linguistic inference, but not formally logical or ontologically coherent. Can simulate reasoning.

Table 5.3 – Application of PAB to OpenAI ChatGPT 4.0 model

Level of Integration	Level	Description
Interrelation among parameters	1	Some partial interactions (i.e, reasoning ↔ prompt ↔ output), but no dynamic systemic integration between modules: each component operates with structural separation (prompt in, text out).

Table 5.4 – Level of Integration of PAB Parameters of ChatGPT 4-o model

Parameter	Level	Description
Learning model	2	OpenCog Hyperon implements: meta-learning systems, where agents learn not only actions, but reasoning structures; cognitive synergy: different learning modules (e.g., ML, inference) and collaborate to update shared representations.
Gradient of control	2	Hyperon agents are designed to operate autonomously in virtual, decentralised or multi-agent environments; human intervention occurs only in the bootstrapping phase, then the agent generates and selects its own actions.
Environmental complexity	2	Hyperon is designed for agents who interact in uncertain and highly dynamic environments; deal with ill-defined problems (not just decision-making, but meta-reasoning); coordinate with other agents through expressive languages.
Internal models	2	Hyperon agent represents its goals in declarative form in MeTTa language; has self-monitoring and self-editing features (attentional focus coupled with goal management); evaluates actions ex post through cognitive feedback.
Representation and Reasoning	2	Hyperon uses graph-based declarative reasoning on semantic networks (AtomSpace); deduction, abduction and analogy as cognitive tools; meta-inference, i.e., reasoning about one's logical structures.

Table 5.5 – Application of PAB to OpenCOG Hyperon model

Level of Integration	Level	Description
Interrelation among parameters	2	Learning drives representational restructuring->Representations underlie goal formulation, and

		reevaluation->Inferences retroact on behavior, modulating it in social environments. The agent modulates itself self-reflectively.

Table 5.6 – Level of Integration of PAB Parameters of OpenCOG Hyperon

BIBLIOGRAPHY

Table of Cases

Ireland

Aireborough Neighbourhood Development Forum v Leeds City Council [2020] EWHC 345

Dublin 8 Residents Association v An Bord Pleanála [2022] IEHC 482

Glow Heating Ltd v Eastern Health Board [1988] IR 110 (HC)

Kett v Shannon & English [1987] ILRM 364

Thomas Williamson Ltd and Another v Bailieborough Co-operative Agricultural Society Ltd [1986] HC

England and Wales

Aireborough Neighbourhood Development Forum v Leeds City Council [2020] EWHC 345 (Admin)

Austin v Commissioner of Police for the Metropolis [2009] UKHL 5, [2009] AC 564

Balfour v Balfour [1919] 2 KB 571 (CA)

Banks v Goodfellow [1870] LR 5 QB 549

Brogden v Metropolitan Railway Co (1877) 2 App Cas 666 (HL)

Butler Machine Tool Co Ltd v Ex-Cell-O Corporation [1979] 1 WLR 401 (CA)

Carlill v Carbolic Smoke Ball Co [1893] 1 QB 256 (CA)

Centrovincial Estates plc v Merchant Investors Assurance Company Ltd [1983] Com LR 158

Chapple v Cooper (1844) 13 M & W 252

Conservative and Unionist Central Office v Burrell [1981] EWCA Civ 2

Continental Tyre & Rubber Co (GB) Ltd v Daimler & Co [1915] 1 KB 893
Currie v Misa (1875) LR 10 Ex 153 (Ex Ch)
Edwards v Carter [1893] AC 360 (HL)
Entores Ltd v Miles Far East Corporation [1955] 2 QB 327 (CA)
Freeman & Lockyer v Buckhurst Park Properties (Mangal) Ltd [1964] 2 QB 480
GHSP Inc v AB Electronic Ltd [2010] EWHC 1828 (TCC)
Gillick v West Norfolk and Wisbech Area Health Authority [1986] AC 112 (HL)
Hanchett-Stamford v Attorney-General [2008] EWHC 330 (Ch)
Hyde v Wrench (1840) 3 Beav 334
Jones v Padavatton [1968] 1 WLR 776 (CA)
Leslie Ltd v Sheill [1914] 3 KB 607
Merritt v Merritt [1970] 1 WLR 1211 (CA)
Nash v Inman [1908] 2 KB 1
National Provincial Bank v Ainsworth [1965] AC 1175
Paton v British Pregnancy Advisory Service Trustees [1979] QB 276
Photo Production Ltd v Securicor Transport Ltd [1980] AC 827 (HL)
Proform Sports Management Ltd v Proactive Sports Management Ltd [2006] EWHC 2903 (Ch)
RTS Flexible Systems Ltd v Molkerei Alois Müller GmbH & Co KG [2010] UKSC 14
SMC Electronics Ltd v Akhter Computers Ltd et al [2001] 1 BCLC 433
Smith v Hughes (1871) LR 6 QB 597 (QB)
Stevenson, Jacques & Co v McLean (1880) 5 QBD 346
Storer v Manchester City Council [1974] 3 All ER 824
Thomas v Thomas (1842) 2 QB 851
Thornton v Shoe Lane Parking Ltd [1971] 2 QB 163 (CA)
Williams v Roffey Bros & Nicholls (Contractors) Ltd [1991] 1 QB 1
Wood v Capita Insurance Services Ltd [2017] UKSC 24

Italy

Cass, sez un, 20 febbraio 1995, n 1715, *Foro it* 1995, I, 1202

United States

Bank of the US v Deveaux [1809] USSC Rep 38 (US Supreme Court)

County of Santa Clara v Southern Pacific Railroad Co 18 F 385 (California DCC 1883)

Specht v Netscape Communications Corp 306 F3d 17 (2d Cir 2002)

Trustees of Dartmouth College v Woodward 17 US (4 Wheat) 518 (1819)

Woburn National Bank v Woods (1914) 77 NH 172

Legislation

Ireland

Age of Majority Act 1985, s 2

Assisted Decision-Making (Capacity) Act 2015, s 3

Mental Health Act 2001, s 8

Companies Act 2014, No 38, pt 2 (Incorporation and Registration)

Italy

Legge 11 febbraio 2019, n 12, art 8-ter (‘Tecnologie basate su registri distribuiti e smart contract’)

United Kingdom

Family Law Reform Act 1969, s 1

Infants Relief Act 1874, s 1

Marriage Act 1949

Minors’ Contracts Act 1987

Sale of Goods Act 1979, s 3(2)

United States

Arizona Revised Statutes § 44-7061(D)

Electronic Signatures in Global and National Commerce Act 2000 (ESIGN), 15 USC § 7001(a), (h)

Tennessee SB1662 (2018), ch 591, § 1

Uniform Electronic Transactions Act (UETA) 1999

Italy

Legge 11 febbraio 2019, n 12, art 8-ter (‘Tecnologie basate su registri distribuiti e smart contract’)

Regio Decreto 16 marzo 1942, n 262 (*Codice civile*)

France

Loi du 21 mars 1804, *Code civil des Français* (*Code civil*)

Code de commerce (France, 2000)

Germany

Bürgerliches Gesetzbuch vom 18 August 1896, RGBI 195 (*BGB*)

BGHZ 125, 366 (BGH 10 January 1994, II ZR 14/93)

EU Legal Sources

Legislation

Consolidated Version of the Treaty on the Functioning of the European Union [2016] OJ C 202/1

Directive 2000/31/EC on certain legal aspects of information society services [2000] OJ L 178/1

European Commission, ‘Proposal for a Regulation Laying Down Harmonised Rules on Artificial Intelligence (Artificial Intelligence Act)’ COM(2021) 206 final

Regulation (EU) 2023/1114 on markets in crypto-assets (MICAR) [2023] OJ L 150/40

Regulation (EU) 2023/2854 of the European Parliament and of the Council of 13 December 2023 on harmonised rules on fair access to and use of data (Data Act) [2023] OJ L 2023/2854, 22.12.2023

Regulation (EU) 2024/1689 laying down harmonised rules on artificial intelligence (Artificial Intelligence Act) [2024] OJ L 168/1

European Parliament Resolutions

European Parliament Resolution of 16 February 2017 with recommendations to the Commission on Civil Law Rules on Robotics [2017] OJ C 252/239

European Parliament Resolution of 3 October 2018 on distributed ledger technologies and blockchains [2020] OJ C 11/7

European Parliament Resolution of 20 October 2020 with recommendations to the Commission on a civil liability regime for artificial intelligence [2021] OJ C 404/5

Soft Law Instruments

Commission on European Contract Law, *Principles of European Contract Law (Parts I and II)* (2002)

International Institute for the Unification of Private Law (UNIDROIT), *Principles of International Commercial Contracts* (2016)

Books

Alpa G and Andenas M (eds), *Smart Contracts: Comparative Perspectives* (Routledge 2022)

Alpa G, *Le persone giuridiche* (Giappichelli 2017)

Alpa G, *Manuale di diritto privato* (8th edn, Laterza 2024)

Antonopoulos AM and Wood G, *Mastering Ethereum: Building Smart Contracts and DApps* (O'Reilly Media 2018)

Antonopoulos AM, *Mastering Bitcoin: Programming the Open Blockchain* (2nd edn, O'Reilly Media 2017)

Arkin R, *Governing Lethal Behavior in Autonomous Robots* (Chapman & Hall/CRC 2009)

Asaro P, 'A Body to Kick, but Still No Soul to Damn: Legal Perspectives on Robotics' in Lin P, Bekey G and Abney K (eds), *Robot Ethics: The Ethical and Social Implications of Robotics* (MIT Press 2012)

Ashby W R, *An Introduction to Cybernetics* (Chapman & Hall 1956)

Ashley KD, *Artificial Intelligence and Legal Analytics* (2nd edn, Cambridge University Press 2022)

Austin J, *Lectures on Jurisprudence* (first published 1875, Robert Campbell ed, Liberty Fund 2005)

Austin J, *The Province of Jurisprudence Determined* (first published 1832, WE Rumble ed, Cambridge University Press 1995)

Bacon F, *Novum Organum* (first published 1620, Urbach and Gibson eds, Open Court 1994)

Bandura A, '6 Reconstructual of "Free Will" From the Agentic Perspective of Social Cognitive Theory' in Baer J, Kaufman J C and Baumeister R F (eds), *Are We Free? Psychology and Free Will* (Oxford Academic 2008)

Bandura A, 'Human Agency: The Rhetoric and the Reality' (1991) 46 *American Psychologist* 157

Bandura A, 'Toward a Psychology of Human Agency' (2006) 1 *Perspectives on Psychological Science* 164

Banteka N, *Artificially Intelligent Persons: The Paradigm of Functional Personhood in Law* (Oxford University Press 2023)

Bashir I, *Mastering Blockchain* (4th edn, Packt Publishing 2023)

Bayern S, *Autonomous Organizations* (Cambridge University Press 2021)

Bayern S, *Reasoning about Rational Agents* (MIT Press 2000)

Beale H (ed), *Chitty on Contracts* (34th edn., Sweet & Maxwell 2021)

Beale H and Lando O (eds), *Principles of European Contract Law, Parts I and II* (Kluwer Law International 2000)

Beatson J, Burrows A and Cartwright J, *Anson's Law of Contract* (31st edn, Oxford University Press 2020)

Bertelsen P, *Free Will Consciousness and Self* (Berghahn Books 2005)

Bertolini A, *Artificial Intelligence and Civil Law: Liability Rules for AI and Robotics* (Springer 2020)

Betti E, *Teoria generale del negozio giuridico* (3rd edn, UTET 1960)

Bianca CM, *Diritto civile. Vol. 3: Il contratto* (Giuffrè Editore 2000)

Bianca M, *Diritto civile. 1. La norma giuridica. I soggetti. I diritti* (Giuffrè Editore 2014)

Birks P, *Rights, Wrongs, and Remedies* (Clarendon Press 2000)

Bishop CM, *Pattern Recognition and Machine Learning* (Springer 2006)

Brassington I, 'The Concept of Autonomy and its Role in Kantian Ethics' (2012) 21 Cambridge Quarterly of Healthcare Ethics 166

Brownsword R, Scotford E and Yeung K (eds), *The Oxford Handbook of Law, Regulation and Technology* (Oxford University Press 2017)

Brownsword R, *Contract Law: Themes for the Twenty-First Century* (3rd edn, Oxford University Press 2023)

Brownsword R, *Law, Technology and Society: Re-Imagining the Regulatory Environment* (Routledge 2019)

Brummer C (ed), *Cryptoassets: Legal, Regulatory, and Monetary Perspectives* (Oxford University Press 2019)

Brummer C, *Fintech Law in a Nutshell* (West Academic 2019)

Busch C and Brownsword R (eds), *Research Handbook on Law and Technology* (Edward Elgar 2022)

Bussani M and Mattei U, *The Common Core of European Private Law: The Making of European Contract Law* (Giappichelli 2002)

Campobasso GF, *Diritto Commerciale. 2. Diritto delle Società* (7th edn, UTET 2021)

Cartwright J, *Contract Law: An Introduction to the English Law of Contract for the Civil Lawyer* (3rd edn, Hart 2016)

Chen-Wishart M, *Contract Law* (6th edn, Oxford University Press 2018)

Chopra S and White LF, *A Legal Theory for Autonomous Artificial Agents* (University of Michigan Press 2011)

Collins H, *The Law of Contract* (4th edn, Butterworths 2003)

Cordiano A and Senigaglia R, *Diritto Civile Minorile* (EDS 2022)

Courtney TB, *The Law of Companies* (4th edn, Bloomsbury 2016)

Craig P and de Búrca G, *EU Law: Text, Cases, and Materials* (7th edn, Oxford University Press 2020)

Cserne P, 'Contract, Freedom of' in Marciano A and Ramello G B (eds), *Encyclopedia of Law and Economics* (Springer 2021)

Dagan H and Heller M, *The Choice Theory of Contracts* (Cambridge University Press 2017)

Damasio A, *Descartes' Error: Emotion, Reason, and the Human Brain* (Putnam 1994)

Dannen C, *Introducing Ethereum and Solidity* (Apress 2017)

Darwall S, 'The Value of Autonomy and Autonomy of the Will' (2006) 116 *Ethics* 263

Davies P and Worthington S, *Gower's Principles of Modern Company Law* (11th edn, Sweet & Maxwell 2021)

De Filippi P and Wright A, *Blockchain and the Law: The Rule of Code* (Harvard University Press 2023)

Deakin S and Markou C (eds), *Is Law Computable? Critical Perspectives on Law and Artificial Intelligence* (Hart 2020)

Demazeau Y and Müller J-P (eds), *Decentralised A.I.* (Elsevier 1990)

Dennett D, 'True Believers: The Intentional Strategy and Why It Works' in Haugeland J (ed), *Mind Design II* (MIT Press 1981)

Dennett D, *The Intentional Stance* (MIT Press 1987)

Diedrich H, *Ethereum: Blockchains, Digital Assets, Smart Contracts* (Wiley 2016)

DiMatteo LA, Cannarsa M and Pongibò C (eds), *The Cambridge Handbook of Smart Contracts, Blockchain Technology and Digital Platforms* (Cambridge University Press 2019)

Dworkin R, *Taking Rights Seriously* (Harvard University Press 1977)

Eagleman D, *The Brain: The Story of You* (Vintage 2017)

Ebers M, Cantero Gamito M (eds), *Algorithmic Governance and Governance of Algorithms* (Springer 2021)

Ebers M, Poncibò C and Zou M (eds), *Contracting and Contract Law in the Age of Artificial Intelligence* (Hart Publishing 2022)

Edwards L and Schafer B (eds), *Social Networks and the Law* (Hart Publishing 2018)

Esen F S, ‘The Risk of Agentic AI: The Curse of Autonomy’ in Omer Aydin and Enis Kaararslan (eds), *The Age of Generative Artificial Intelligence* (Izmir Academy Association Publishing House 2025) 156.

Falzea A, *Capacità, efficacia giuridica, fatto giuridico, manifestazione* (Giuffrè Editore 1999)

Falzea A, *Ricerche di Teoria Generale del Diritto e di Dogmatica Giuridica* vol II (Giuffrè Editore 1997)

Finck M, *Blockchain Regulation and Governance in Europe* (Cambridge University Press 2019)

Finnis J, *Natural Law and Natural Rights* (2nd edn, Oxford University Press 2011)

Finocchiaro G and Amato C (eds), *Smart Contracts e Blockchain: Profili giuridici e tecnologici* (Giappichelli 2020)

Fischer JM and Ravizza M, *Perspectives on Moral Responsibility* (Cornell University Press 1993)

Fishbein M and Ajzen I, *Belief, Attitude, Intention and Behaviour: An Introduction to Theory and Research* (Addison-Wesley 1975)

Floridi L, *The Ethics of Information* (Oxford University Press 2013)

Floridi L, *The Logic of Information: A Theory of Philosophy as Conceptual Design* (Oxford University Press 2019)

Fried C, *Contract as Promise: A Theory of Contractual Obligation* (2nd edn, Oxford University Press 2015)

Galimberti U, *Psiche e Techne. L'uomo nell'Età della Tecnica* (Feltrinelli 2000)

Gallo P, *Istituzioni di Diritto Privato* (Giappichelli 2021)

Gardner J, *From Personal Life to Private Law* (Oxford University Press 2018)

Glover J, *The Philosophy and Psychology of Personal Identity* (Allen Lane 1988)

Goodfellow I, Bengio Y and Courville A, *Deep Learning* (MIT Press 2016)

Gray JC, *The Nature and Source of the Law* (2nd edn, Macmillan 1921)

Grossi P, *L'ordine giuridico medievale* (Laterza 1995)

Gutmann T, 'Some Preliminary Remarks on a Liberal Theory of Contract' (2013) 76 *The Public Dimension of Contract: Contractual Pluralism Beyond Privity* 233

Hacker P, Lianos I, Dimitropoulos G and Eich S (eds), *Regulating Blockchain: Techno-Social and Legal Challenges*(Oxford University Press 2019)

Hacker P, *Digitale Verträge: Smart Contracts und das Privatrecht* (Mohr Siebeck 2021)

Hart HLA, *Punishment and Responsibility: Essays in the Philosophy of Law* (2nd edn, Oxford University Press 2008)

Hart HLA, *The Concept of Law* (3rd edn, Oxford University Press 2012)

Hastie T, Tibshirani R and Friedman J, *The Elements of Statistical Learning: Data Mining, Inference, and Prediction*(2nd edn, Springer 2009)

Haykin S, *Neural Networks and Learning Machines* (3rd edn, Pearson 2008)

Hegel GWF, *Elements of the Philosophy of Right* (HB Nisbet tr, Cambridge University Press 1991)

Hildebrandt M, *Law for Computer Scientists and Other Folk* (Oxford University Press 2020)

Hildebrandt M, *Smart Technologies and the End(s) of Law* (Edward Elgar 2015)

Hileman G and Rauchs M, *Global Blockchain Benchmarking Study* (Cambridge Centre for Alternative Finance 2017)

Holmes OW, *The Common Law* (Little, Brown 1881)

Howells G, Twigg-Flesner C and Wilhelmsson T, *Rethinking Product Liability: A Comparative Perspective* (Routledge 2017)

Huhns M, *Distributed Artificial Intelligence* (Morgan Kaufmann 1984)

Infante R, *Building Ethereum DApps* (Manning 2019)

Jennings NR and Wooldridge MJ (eds), *Agent Technology: Foundations, Applications, and Markets* (Springer 1998)

Kant I, *Critique of Practical Reason* (Mary Gregor tr, Cambridge University Press 1997)

Kant I, *Groundwork of the Metaphysics of Morals* (Mary Gregor and Jens Timmermann trs, Cambridge University Press 2012)

Kant I, *The Metaphysics of Morals* (Mary Gregor tr, Cambridge University Press 1996)

Kelsen H, *Pure Theory of Law* (Max Knight tr, University of California Press 1967)

Kim N S, 'Relative Consent and Contract Law' (2017) 18 Nevada Law Journal 165

Kötz H, *European Contract Law* (2nd edn, Oxford University Press 2017)

Kraus D, Obrist T and Hari O (eds), *Blockchains, Smart Contracts, Decentralised Autonomous Organisations and the Law: Perspectives of a Distributed Future* (Edward Elgar 2019)

Kraus S, *Strategic Negotiation in Multiagent Environments* (MIT Press 2001)

Kunz J, 'The Meaning and the Range of the Norm Pacta Sunt Servanda' (2017) 39 *American Journal of International Law* 170

Kurki V, *A Theory of Legal Personhood* (Oxford University Press 2019)

Kurki VAJ and Pietrzykowski T (eds), *Legal Personhood: Animals, Artificial Intelligence and the Unborn* (Springer 2017)

Lando O, Clive E, Prüm A and Zimmermann R (eds), *Principles of European Contract Law, Part III* (Kluwer Law International 2003)

Lessig L, *Code and Other Laws of Cyberspace* (Basic Books 1999, updated edn 2006)

Lieto A, *Cognitive Design for Artificial Minds* (Routledge 2021)

Lin P, Abney K and Jenkins R (eds), *Robot Ethics 2.0: From Autonomous Cars to Artificial Intelligence* (Oxford University Press 2017)

Linarelli J, 'A Philosophy of Contract Law for Artificial Intelligence: Shared Intentionality' in Ebers M, Poncibò C and Zou M (eds), *Contracting and Contract Law in the Age of Artificial Intelligence* (Hart 2022)

Luhmann N, *Soziale Systeme: Grundriß einer allgemeinen Theorie* (Suhrkamp 1984)

Malle B F, Moses L J and Baldwin D A, 'Introduction: The Significance of Intentionality' in Malle B F, Moses L J and Baldwin D A (eds), *Intentions and Intentionality: Foundations of Social Cognition* (MIT Press 2001)

Malle BF, Moses LJ and Baldwin DA (eds), *Intentions and Intentionality: Foundations of Social Cognition* (MIT Press 2001)

Markby W, *Elements of Law* (6th edn, Oxford University Press 1905)

Martin J, Sugarman J H and Hickinbottom S, *Persons: Understanding Psychological Selfhood and Agency* (Springer 2010)

Matteussi J, Orlandi F, Barbosa J, Silva J S, Bittencourt L F and Geyer C F R, ‘A Survey on Collaborative Learning for Intelligent Autonomous Systems’ (2023) 56 ACM Computing Surveys

McCorduck P, *Machines Who Think* (2nd edn, Routledge 2004)

McKendrick E, *Contract Law* (15th edn, Hart 2023)

McKendrick E, *Contract Law: Text, Cases, and Materials* (10th edn, Oxford University Press 2023)

Mele A R, ‘Acting Intentionally: Probing Folk Notions’ in Malle B F, Moses L J and Baldwin D A (eds), *Intentions and Intentionality: Foundations of Social Cognition* (MIT Press 2001)

Mele AR, *Autonomous Agents: From Self-Control to Autonomy* (Oxford University Press 1995)

Merkin R and Saintier S, *Poole’s Textbook on Contract Law* (16th edn, Oxford University Press 2023)

Mill JS, *On Liberty* (first published 1859, Oxford University Press 1998)

Minsky M, *The Society of Mind* (Simon & Schuster 1986)

Misselhorn C (ed), *Collective Agency and Cooperation in Natural and Artificial Systems* (Springer 2015)

Mitchell M, *Complexity: A Guided Tour* (Oxford University Press 2009)

Mittal M, Shah RR and Roy S (eds), *Cognitive Computing for Human-Robot Interaction: Principles and Practices* (Academic Press 2021)

Morse G, *Partnership Law* (9th edn, Oxford University Press 2021)

Munday R, *Agency: Law and Principles* (2nd edn, Oxford University Press 2018)

Naffine N, *Law's Meaning of Life: Philosophy, Religion, Darwin and the Legal Person* (Hart Publishing 2009)

Nekam BFN, *The Personality Conception of the Legal Entity* (Harvard University Press 1938)

Newell A, *Unified Theories of Cognition* (Harvard University Press 1990)

Ng Y-F, Windholz E L and Moutsias J, 'Legal Considerations in Machine-Assisted Decision-Making: Planning and Building as a Case Study' (2023) 35 Bond Law Review 1

Nilsson NJ, *Artificial Intelligence: A New Synthesis* (Morgan Kaufmann 1998)

Ohlin JD, *The Assault on International Law* (Oxford University Press 2015)

Oppo G, *Scritti giuridici* (Giuffrè Editore 2000)

Oram A, *Peer-to-Peer: Harnessing the Power of Disruptive Technologies* (O'Reilly Media 2001)

Pagallo U, 'Robots and the Law: The Coevolution of Legal Responsibility and Technology' in Brownsword R, Scotford E and Yeung K (eds), *The Oxford Handbook of Law, Regulation and Technology* (Oxford University Press 2017)

Pagallo U, *The Laws of Robots: Crimes, Contracts, and Torts* (Springer 2013)

Pearl J, *Causality: Models, Reasoning, and Inference* (2nd edn, Cambridge University Press 2009)

Peel E, *Treitel: On the Law of Contract* (15th edn, Sweet & Maxwell 2020)

Perlingieri G, *Profili applicativi della legalità costituzionale* (Edizioni Scientifiche Italiane 2007)

Perlingieri P, *Il diritto civile nella legalità costituzionale* (11th edn, ESI 2023)

Perlingieri P, *Manuale di diritto civile* (20th edn, ESI 2020)

Pistor K, *The Code of Capital: How the Law Creates Wealth and Inequality* (Princeton University Press 2019)

Polinsky M, *An Introduction to Law and Economics* (4th edn, Aspen Publishers 2011)

Pollock F and Maitland FW, *The History of English Law before the Time of Edward I* (2nd edn, Cambridge University Press 1968)

Poole J, *Textbook on Contract Law* (9th edn, Oxford University Press 2008)

Raghavan VV, Gudivada VN, Govindaraju V and Rao CR, *Cognitive Computing: Theory and Applications* (North-Holland 2016)

Rawls J, *A Theory of Justice* (Rev edn, Harvard University Press 1999)

Raz J, *The Authority of Law: Essays on Law and Morality* (2nd edn, Oxford University Press 2009)

Raz J, *The Morality of Freedom* (Oxford University Press 1986)

Rescigno P, *Manuale del diritto privato* (8th edn, Jovene 2021)

Reynolds FMB and Watts P, *Bowstead & Reynolds on Agency* (21st edn, Sweet & Maxwell 2018)

Roppo E, *Il contratto* (Giuffrè Editore 2001)

Rossi F, *Capacità e Incapacità* (Edizioni Scientifiche Italiane 2018)

Rousseau J-J, *The Social Contract* (Maurice Cranston tr, Penguin Books 1968)

Ruscello F, *Istituzioni di diritto civile* (Cacucci 2022)

Russell S e Norvig P, *Artificial Intelligence: A Modern Approach* (4th edn, Pearson 2021)

Salmond J, *Jurisprudence* (10th edn, Glanville Llewelyn Williams ed, Sweet & Maxwell 1947)

Sapienza S, *Decisioni algoritmiche e diritto* (Giuffrè Editore 2024)

Sarzana F and Nicotra M, *Diritto della Blockchain, Intelligenza Artificiale e IoT* (IPSOA 2018)

Savigny FC von, *System des Heutigen Römischen Rechts* (Berlin Veit, first published 1840–1849, reprinted Gale 2013)

Searle J R, *The Construction of Social Reality* (Free Press 1995)

Senigaglia R, *Liber amicorum per Paolo Zatti* (2nd edn, Jovene 2023)

Shoham Y and Leyton-Brown K, *Multiagent Systems: Algorithmic, Game-Theoretic, and Logical Foundations* (Cambridge University Press 2009)

Smith S A, *Contract Theory* (Oxford University Press 2004)

Smith SA, *Rights, Wrongs and Injustices: The Structure of Remedial Law* (Oxford University Press 2019)

Smits JM, *Contract Law: A Comparative Introduction* (3rd edn, Edward Elgar 2021)

Song J, *Programming Bitcoin: Learn How to Program Bitcoin from Scratch* (O'Reilly Media 2019)

Spencer H, *The Man versus the State* (Liberty Classics 1981)

Sprankling J and Raymond C, *Property: A Contemporary Approach* (4th edn, West Academic 2018)

Stanzione P, *Capacità e minore età nella problematica della persona umana* (Jovene 1975)

Stanzione P, *Commercio elettronico, contratto e categorie civilistiche* (Giuffrè Editore 2001)

Stanzione P, *Le situazioni giuridiche soggettive* (CEDAM 2023)

Stazi A, *Biotecnologie e proprietà intellettuale: Profili evolutivi del diritto industriale* (Giappichelli 2006)

Stewart A, Swain W and Fairweather K, *Contract Law* (Cambridge University Press 2019)

Stone R and Devenney J, *The Modern Law of Contract* (Routledge 2019)

Susskind R, *Tomorrow's Lawyers: An Introduction to Your Future* (3rd edn, Oxford University Press 2023)

Sutton R and Barto A, *Reinforcement Learning: An Introduction* (2nd edn, MIT Press 2018)

Swan M, *Blockchain: Blueprint for a New Economy* (O'Reilly Media 2015)

Tapscott D and Tapscott A, *Blockchain Revolution* (Portfolio 2016)

Teubner G, 'Digital Personhood? The Status of Autonomous Software Agents in Private Law' in Ebers M and others (eds), *Algorithmic Governance and Governance of Algorithms* (Springer 2021) 135

Teubner G, *Constitutional Fragments: Societal Constitutionalism and Globalization* (Oxford University Press 2012)

Thümel S, 'The Participatory Turn: A Multidimensional Gradual Agency Concept for Human and Non-Human Actors' in Misselhorn C (ed), *Collective Agency and Cooperation in Natural and Artificial Systems* (Springer 2015)

Treitel GH, *The Law of Contract* (11th edn, Sweet & Maxwell 2003)

Van Hoecke M (ed), *Methodologies of Legal Research: Which Kind of Method for What Kind of Discipline* (Bloomsbury Publishing 2011)

Vandenbulcke M, Dröes R-M and Schokkaert E (eds), *Dementia and Society* (Cambridge University Press 2022)

Vogenauer S and Weatherill S (eds), *The Harmonisation of European Contract Law: Implications for European Private Laws, Business and Legal Practice* (Hart Publishing 2006)

Vogenauer S, 'Interpretation of Contracts: Concluding Comparative Observations' in Vogenauer S (ed), *Interpretation of Contracts* (Oxford University Press 2006)

Von Bar C and Clive E (eds), *Principles, Definitions and Model Rules of European Private Law: Draft Common Frame of Reference* (Sellier 2009)

Voshmgir S, *Token Economy: How the Web3 Reinvents the Internet* (2nd edn, Token Kitchen 2020)

Waddams S, 'The Draft Common Frame of Reference in Relation to English Contract Law' in Devenney J and Kenny M (eds), *The Transformation of European Private Law: Harmonisation, Consolidation, Codification or Chaos?* (Cambridge University Press 2013)

Wattenhofer R, *The Science of the Blockchain* (Inverted Forest Publishing 2016)

Weiss G (ed), *Multiagent Systems* (2nd edn, MIT Press 2013)

Weiss G, *Multiagent Systems: A Modern Approach to Distributed Artificial Intelligence* (MIT Press 1999)

Werbach K, *The Blockchain and the New Architecture of Trust* (MIT Press 2018)

Wiener N, *Cybernetics: Or Control and Communication in the Animal and the Machine* (MIT Press 1948)

Wooldridge M, *An Introduction to Multi-Agent Systems* (2nd edn, Wiley 2009)

Worthington S, 'Common Law Values: The Role of Party Autonomy in Private Law' (2015)
33 University of Cambridge Faculty of Law Legal Studies

Yeung K and Lodge M (eds), *Algorithmic Regulation* (Oxford University Press 2019)

Zacharie KS, *Corso di diritto civile francese* (Muzj tr, 1857)

Zekos GI, *Economics and Law of Artificial Intelligence: Finance, Economic Impacts, Risk Management and Governance* (Springer 2021)

Zimmermann R, *The Law of Obligations: Roman Foundations of the Civilian Tradition* (Oxford University Press 1996)

Journal Articles

Agnihotram S and Kouroutakis A, 'Doctrinal Challenges for the Legality of Smart Contracts: Lex Cryptographia or a New "Smart" Way to Contract?' (2019) 19 *Journal of High Technology Law* 300

Aicardi C, 'Artificial Agents in Military Targeting: Accountability and Autonomous Weapons' (2021) 13 *Philosophy & Technology* 335

Alqodsi EM and Arenova L, 'Smart Contracts in Contract Law as an Auxiliary Tool or a Promising Substitute for Traditional Contracts' (2024) 16(3) *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction* 06524004

Ancona Lee L, Duraković B e Yeralan S, 'AI Ethics: Contextual Frameworks and Domain-Specific Concerns' (2025) 7 *Heritage and Sustainable Development* 1

Andrade F, Novais P, Machado J and Neves J, 'Contracting Agents: Legal personhood and Representation' (2007) 15 *Artificial Intelligence and Law* 357

Andrione M and others, 'Artificial Intelligence-Based Decision-Making Algorithms, Internet of Things Sensing Networks, and Deep Learning-Assisted Smart Process Management in Cyber-Physical Production Systems' (2021) 10(20) *Electronics* 2497

Azimi S, Golzari A, Ivaki N and Laranjeiro N, 'A Systematic Review on Smart Contracts Security Design Patterns' (2025) 30 *Empirical Software Engineering* 95

Badrulhisham F e altri, 'Machine Learning and Artificial Intelligence in Neuroscience: A Primer for Researchers' (2024) 115 *Brain, Behavior, and Immunity* 470

Bandura A, 'Toward a Psychology of Human Agency' (2006) 1(2) *Perspectives on Psychological Science* 164

Banteka N, 'Agency, AI, and the Law' (2020) 95 *Indiana Law Journal* 1239

Banteka N, 'Artificially Intelligent Persons' (2021) 58 *Houston Law Review* 537

Barnes W, 'The Objective Theory of Contracts' (2008) 76 *University of Cincinnati Law Review* 1119

Barnett R E, 'A Consent Theory of Contract' (1986) 86 Columbia Law Review 269

Bassan F, 'From Smart Legal Contracts to Contracts on Blockchain' (2024) 42 Computer Law & Security Review 105862

Bathae Y, 'The Artificial Intelligence Black Box and the Failure of Intent and Causation' (2018) 31 Harvard Journal of Law & Technology 889

Bavasso D, 'Contracts and Code: Smart Contracts as the Expression of Autonomous Will' (2022) 18 European Review of Contract Law 187

Bavasso D, 'Contracts and Code: Smart Contracts as the Expression of Autonomous Will' (2022) 18 European Review of Contract Law 187

Bayern S, 'The Implications of Modern Business-Entity Law for the Regulation of Autonomous Systems' (2016) 7(2) European Journal of Risk Regulation 297

Bennett D, Maria L, Sanjaya Y P A and Az Zahra A R, 'Blockchain Technology: Revolutionizing Transactions in the Digital Age' (2024) 5(2) ADI Journal of Recent Innovation 192

Bertolini A e Episcopo F, 'AI and Public–Private Liability' (2021) 12(3) European Journal of Risk Regulation 644

Bertolini A, 'Smart Contracts as a Challenge for Contract Law' (2019) 26 European Review of Private Law 753

Bossu A C, 'Smart Contracts: Is the Law Ready?' (2020) 27 Maastricht Journal of European and Comparative Law 729

Brown RD, 'Legally Cognizable Entities: The Essence and Consequences of Entity Status' (2021) 30(2) Information & Communications Technology Law 208

Bryson JJ, Diamantis ME and Grant TD, 'Of, for, and by the People: The Legal Lacunae of Synthetic Persons' (2017) 25 Artificial Intelligence and Law 273

Bulgakov AL and others, 'Scalability and Security in Blockchain Networks: Evaluation of Sharding Algorithms and Prospects for Decentralized Data Storage' (2024) 12 Mathematics 3860

Busch C, 'The Future of Pre-Contractual Information Duties: From Behavioural Insights to Big Data' (2019) 7 *Journal of European Consumer and Market Law* 50

Bussani M and Mattei U, 'The Common Core Approach to European Private Law' (1997) 3 *Columbia Journal of European Law* 339

Calegari R, Ciatto G, Mascardi V and Omicini A, 'Logic-Based Technologies for Multi-Agent Systems: A Systematic Literature Review' (2021) 35(1) *Autonomous Agents and Multi-Agent Systems* 1

Calo R, 'Robotics and the Lessons of Cyberlaw' (2015) 103 *California Law Review* 513

Calo R, 'Robots and Privacy' (2011) 123 *Harvard Law Review* 1139

Cartwright J, 'Contract Law: An Introduction to the English Law of Contract for the Civil Lawyer' (2016) 3rd edn, Hart

Catalini C and Gans JS, 'Some Simple Economics of the Blockchain' (2019) 29 *Communications of the ACM* 95

Chesterman S, 'Artificial Intelligence and the Limits of Legal personhood' (2021) 69 *International & Comparative Law Quarterly* 819

Chesterman S, 'Artificial Intelligence and the Problem of Autonomy' (2020) 1 *Notre Dame Journal on Emerging Technologies* 210

Cobbe J, Lee MSA and Singh J, 'Reviewable Automated Decision-Making: A Framework for Accountable Algorithmic Systems' (2021) *Proceedings of the ACM Conference on Fairness, Accountability, and Transparency* 598

Cobbe J, Veale M and Singh J, 'Understanding Accountability in Algorithmic Supply Chains' (2023) *Proceedings of the ACM Conference on Fairness, Accountability, and Transparency* 12

Cohen J, 'Regulatory Artificial Intelligence' (2019) 66 *Duke Law Journal* 177

Costigan G P Jr, 'Implied-in-Fact Contracts and Mutual Assent' (1920) 33 *Harvard Law Review* 376

Cui Y e van Esch P, 'Autonomy and Control: How Political Ideology Shapes the Use of Artificial Intelligence' (2022) 39(6) *Psychology & Marketing* 1218

Dagan H and Heller M, 'Freedom, Choice, and Contracts' (2019) 20 *Theoretical Inquiries in Law* 1

Dahiyat EAR, 'Law and Software Agents: Are They "Agents" by the Way?' (2021) 29 *Artificial Intelligence and Law* 59

Darwall S, 'The Value of Autonomy and Autonomy of the Will' (2006) 116(2) *Ethics* 263

Davies J, 'What Makes a Block? A Meta-Analysis of Blockchain Block Header Fields' (2024) 7 *Frontiers in Blockchain* 1387362

De Filippi P, 'Blockchain Technology and Decentralized Governance: The Pitfalls of a Trustless Dream' (2019) 9 *Decentralized Cooperation Review* 5

De Lorenzi V, 'Causa concreta e interesse meritevole di tutela' (2024) *Archivio di Diritto Civile* 1, 1

Deakin S and Markou C, 'From Rule of Law to Legal Singularity? Reimagining Rights in the Age of AI' (2020) in Deakin S and Markou C (eds), *Is Law Computable?* (Hart 2020)

Deakin S, 'Capacitas: Contract Law and the Institutional Foundations of Capitalism' (2006) 33 *Journal of Law and Society* 545

Deakin S, Gindis D, Hodgson G M, Huang K and Pistor K, 'Legal Institutionalism: Capitalism and the Constitutive Role of Law' (2017) 45 *Journal of Comparative Economics* 188

Dennett D, 'Intentional Systems' (1971) 68 *Journal of Philosophy* 87

Dhillon R and others, 'Exploring Dimensions of Governance for Different Types of Blockchain Networks' (2025) *British Accounting Review* 101588

Dong S and others, 'Blockchain Technology and Application: An Overview' (2023) 9 *PeerJ Computer Science* e1705

Dung L, 'Understanding Artificial Agency' (2025) 75(2) *Philosophical Quarterly* 450

Felsen G and Reiner PB, 'How the Neuroscience of Decision Making Informs Our Conception of Autonomy' (2011) 2(3) *AJOB Neuroscience* 3

Finck M, 'Blockchains and Data Protection in the European Union' (2018) 4(1) *European Data Protection Law Review* 39

Floridi L and Sanders JW, 'On the Morality of Artificial Agents' (2004) 14 *Minds and Machines* 349

Fritsch M, 'Solely Code? Smart Contracts and the Quest for Autonomy' (2021) 39 *Computer Law & Security Review* 105500

Fuller L, 'Consideration and Form' (1941) 41(5) *Columbia Law Review* 799

Geddes K, 'The Death of the Legal Subject: How Predictive Algorithms Are (Re)Constructing Legal Subjectivity' (2024) 47 *Computer Law & Security Review* 105873

Gilbert C and Gilbert MA, 'Unraveling Blockchain Technology: A Comprehensive Conceptual Review' (2024) 1(4) *Journal of Emerging Technologies* 45

Giuliano M, 'La Blockchain e gli Smart Contracts nell'Innovazione del Diritto nel Terzo Millennio' (2018) II(6) *Diritto dell'Informazione e dell'Informatica* 989

Górski T, 'Smart Contract Design Pattern for Processing Logically Related Transactions: AdapT v2.0' (2024) 14 *Applied Sciences* 2224

Gruner A and Möslin F, 'Contracting with Algorithms: Smart Contracts and the Limits of Code' (2020) 21 *German Law Journal* 1337

Gutmann T, 'Some Preliminary Remarks on a Liberal Theory of Contract' (2013) 76 *The Public Dimension of Contract: Contractual Pluralism Beyond Privacy* 233

Habib G, Sharma S, Ibrahim S, Ahmad I, Qureshi S and Ishfaq M, 'Blockchain Technology: Benefits, Challenges, Applications, and Integration of Blockchain Technology with Cloud Computing' (2022) (14) 11 *Future Internet* 341

Hacker P and Passoth JH, 'Varieties of AI Explanations under the Law. From the GDPR to the AIA, and Beyond' (2022) 13 *Law, Innovation and Technology* 89

- Hacker P, 'A Legal Theory for Autonomous Artificial Agents' (2020) 20 Law, Innovation and Technology 269
- Hacker P, 'Corporate Governance for Complex Cryptoeconomies' (2019) 10 European Business Organization Law Review 259
- Hacker P, 'Regulating Smart Contracts: Legal Theory, Law, and Regulation of Disruptive Technologies' (2019) 21 German Law Journal 1341
- Halina M, 'Creativity for Comparative Psychology' (2021) 34 Minds and Machines 495
- Hallevy G, 'The Criminal Liability of Artificial Intelligence Entities – from Science Fiction to Legal Social Control' (2010) 4 Akron Intellectual Property Journal 171
- Han J, Lee J and Li T, 'A Review of DAO Governance: Recent Literature and Emerging Trends' (2025) 91 Journal of Corporate Finance 102734
- Hasneziri L, 'The Principle of Autonomy of Contractual Will' (2023) 8(1) European Journal of Multidisciplinary Studies 134
- Hasselberger W, 'Human Agency, Reasons, and Inter-Subjective Understanding' (2014) 89 Philosophy 347
- Helliar C V, Crawford L, Rocca L, Teodori C and Veneziani M, 'Permissionless and Permissioned Blockchain Diffusion' (2020) 54 International Journal of Information Management 102136
- Herbosch M, 'Liability for AI Agents' (2025) 26(3) North Carolina Journal of Law & Technology
- Hesselink MW, 'Capacity and Capability in European Contract Law' (2005) 13(4) European Review of Private Law 491
- Hoffman H, Jantsch A and Dutt N D, 'Embodied Self-Aware Computing Systems' (2020) 108 IEEE 1045
- Hussein Z, Salama M A and El-Rahman S A, 'Evolution of Blockchain Consensus Algorithms: A Review on the Latest Milestones of Blockchain Consensus Algorithms' (2023) 6 Cybersecurity 23

Hutson J and Barnes E, 'AI and the Cognitive Sense of Self' (2025) 3(1) *Journal of Intelligent Communication* 35

Kaelbling LP, Littman ML e Moore AW, 'Reinforcement Learning: A Survey' (1996) 4(1) *Journal of Artificial Intelligence Research* 237

Kaminski M E, 'Binary Governance: Lessons from the GDPR's Approach to Algorithmic Accountability' (2019) 92 *Southern California Law Review* 1529

Karnow CEA, 'Liability for Distributed Artificial Intelligences' (1996) 11 *Berkeley Technology Law Journal* 147

Kim N S, 'Relative Consent and Contract Law' (2017) 18 *Nevada Law Journal* 165

Klass G, 'Intent to Contract' (2009) 95(6) *Virginia Law Review* 1437

Köksal B and Sarel R, 'The Smart Contracts Trilemma' (forthcoming, 2024) *University of Illinois Law Review*

Kraus J S and Scott R E, 'Contract Design and the Structure of Contractual Intent' (2009) 84 *New York University Law Review* 1023

Kunz J, 'The Meaning and the Range of the Norm Pacta Sunt Servanda' (2017) 39(2) *American Journal of International Law* 170

Kurki V, 'Why Things Can Hold Rights: Reconceptualizing Legal Personhood' (2017) 62 *Jurisprudence* 1

Lamport L, Shostak R and Pease M, 'The Byzantine Generals Problem' (1982) 4(3) *ACM Transactions on Programming Languages and Systems* 382

Larsson S, 'The Socio-Legal Relevance of Artificial Intelligence' (2019) 103(3) *Droit et société* 573

Leach T, 'What Does AlphaGo Teach Us About Human Creativity?' (2022) 1 *AI and Ethics* 113

LeCun Y, Bengio Y and Hinton G, 'Deep Learning' (2015) 521 *Nature* 436

Lee J and Khan VM, 'Blockchain and Smart Contract for Peer-to-Peer Energy Trading Platform: Legal Obstacles and Regulatory Solutions' (2020) 19 UIC Review of Intellectual Property Law 285

Lemos A e de Souza JN, 'Compliance and Ethics in AI: Risks Mitigation and Governance' (2021) 8 Frontiers in Robotics and AI 789327

Leo S and Panetta IC, 'Distributed Ledger Technology and the Future of Finance: Tracking Innovation, Regulation and Inclusion' (2025) 37(4) Technology Analysis & Strategic Management 369

Levy K, 'Book-Smart, Not Street-Smart: Blockchain-Based Smart Contracts and the Social Workings of Law' (2017) 3 Engaging Science, Technology, and Society 1

Lieto A, 'Cognitive Design for Artificial Minds: A Minimal Cognitive Architecture for Autonomous Agents' (2019) 11 Cognitive Systems Research 5

LoPucki LM, 'Algorithmic Entities' (2018) 95 Washington University Law Review 885

Macario F, 'Interessi giuridicamente protetti e meritevolezza: attualità di un dibattito classico' (2024) Rivista di Diritto Civile 211

Marchesi S, Spatola N, Perez-Osorio J and Wykowska A, 'Human vs Humanoid: A Behavioral Investigation of the Individual Tendency to Adopt the Intentional Stance' (2021) Proceedings of the 2021 ACM/IEEE International Conference on Human-Robot Interaction 2

Marletta D, Midolo A and Tramontana E, 'A Blockchain-Based Strategy for Certifying Timestamps in a Distributed Healthcare Emergency Response Systems' (2025) 17 Future 210

Matthias A, 'The Responsibility Gap: Ascribing Responsibility for the Actions of Learning Automata' (2004) 6 Ethics and Information Technology 175

Mik E, 'Smart Contracts: Terminology, Technical Limitations and Real-World Complexity' (2017) 9(2) Law, Innovation and Technology 269

Mishra D and Phansalkar S, 'Blockchain Security in Focus: A Comprehensive Investigation Into Threats, Smart Contract Security, Cross-Chain Bridges, and Vulnerabilities Detection Tools and Techniques' (2024) 13 IEEE Access 1

Mocanu DM, ‘Gradient Legal Personhood for AI Systems – Painting Continental Legal Shapes Made to Fit Analytical Molds’ (2022) 8 *Frontiers in Robotics and AI* 788179

Moosavi N and others, ‘Blockchain Technology, Structure, and Applications: A Survey’ (2024) 237 *Procedia Computer Science* 645

Mosqueira-Rey E, Hernández-Pereira E, Alonso-Ríos D, Bobes-Bascarán J e Fernández-Leal Á, ‘Human-in-the-Loop Machine Learning: A State of the Art’ (2023) 56 *Artificial Intelligence Review* 3005

Nadew L, ‘Void Agreements and Voidable Contracts: The Need to Elucidate Ambiguities of Their Effects’ (2020) 4 *Beijing Law Review* 557

Nash E J, ‘Blockchain & Smart Contract Technology: Alternative Incentives for Legal Contract Innovation’ (2019) 3(8) *BYU Law Review* 800

Ng Y-F, Windholz EL and Moutsias J, ‘Legal Considerations in Machine-Assisted Decision-Making: Planning and Building as a Case Study’ (2023) 35(1) *Bond Law Review* 1

O’Gorman D, ‘Learned Hand and the Objective Theory of Contract Interpretation’ (2019) 18(1) *University of New Hampshire Law Review* 63

Pagallo U, ‘AI and Legal Personhood: Should We Grant Robots Legal personhood?’ (2020) 4 *Digital Society* 1

Pagallo U, ‘Robots in Law: Legal and Ethical Questions’ (2013) 27 *Law and Philosophy* 285

Pagallo U, ‘The Legal Status of Robots: Personhood, Rights and Duties’ (2018) 3 *Artificial Intelligence and Law* 305

Papadouli V and Papakonstantinou V, ‘A Preliminary Study on Artificial Intelligence Oracles and Smart Contracts: A Legal Approach to the Interaction of Two Novel Technological Breakthroughs’ (2023) 51 *Computer Law & Security Review* 105869

Park S, ‘Bridging the Global Divide in AI Regulation: A Proposal for a Contextual, Coherent, and Commensurable Framework’ (2024) 33 *Washington International Law Journal* 2, 215

Pasdar A, Lee YC and Dong Z, ‘Connect API with Blockchain: A Survey on Blockchain Oracle Implementation’ (2023) 55(10) *ACM Computing Surveys* 1

- Perez-Osorio J and Wykowska A, 'Adopting the Intentional Stance Toward Natural and Artificial Agents' (2019) 33 *Philosophical Psychology* 1
- Plewe D A and de Rooy R, 'Integrative Deal-Design: Cascading from Goal-Hierarchies to Negotiations and Contracting' (2016) 2 *Journal of Strategic Contracting and Negotiation* 19
- Raskin M, 'The Law and Legality of Smart Contracts' (2017) 1 *Georgetown Law Technology Review* 305
- Rastogi C and others, 'Deciding Fast and Slow: The Role of Cognitive Biases in AI-Assisted Decision-Making' (2022) 6 *Proceedings of the ACM on Human-Computer Interaction CSCW1*
- Remolina N, 'Blockchain, Smart Contracts, and the Law' (2019) 14 *Capital Markets Law Journal* 38
- Restrepo Amariles D e Baquero PM, 'Promises and Limits of Law for a Human-Centric Artificial Intelligence' (2023) 45 *Computer Law & Security Review* 105789
- Rinaldi G, 'Smart Contract: Meccanizzazione del Contratto nel Paradigma Blockchain' (2020) *Diritto e Intelligenza Artificiale* 355
- Rizk Y, Awad M and Tunstel E, 'Decision Making in Multiagent Systems: A Survey' (2018) 10 *IEEE Transactions on Cognitive and Developmental Systems* 514
- Rosati E, 'Infringing AI: Liability for AI-Generated Outputs under International, EU and UK Copyright Law' (2025) 16(2) *European Journal of Risk Regulation* 603
- Roussanaly V and Falcone Y, 'Decentralised Runtime Verification of Timed Regular Expressions' (2022) 29th *International Symposium on Temporal Representation and Reasoning, Leibniz International Proceedings in Informatics* 247
- Sartor G, 'Contracts in the Infosphere' in Grundmann S (ed), *European Contract Law in the Digital Age* (Intersentia 2018)
- Sartor G, 'Legal Concepts as Inferential Nodes and Ontological Categories' (2009) 17 *Artificial Intelligence and Law* 217
- Savadatti SG, Krishnamoorthy S and Delhibabu R, 'Survey of Distributed Ledger Technology (DLT) for Secure and Scalable Computing' (2025) 13 *IEEE Access* 8393

Schär F, 'Decentralized Finance: On Blockchain- and Smart Contract-Based Financial Markets' (2021) 103 Federal Reserve Bank of St Louis Review 153

Scherer MU, 'AI Entities as AI Agents: Artificial Intelligence Liability and the AI Respondeat Superior Analogy' (2020) 46 Mitchell Hamline Law Review 1049

Schwartz A and Scott R E, 'Contract Theory and the Limits of Contract Law' (2003) 113 Yale Law Journal 541

Selvadurai N, 'The Potential of Hybrid On Chain/Off Chain Contracts' (2023) 80(4) Washington and Lee Law Review 2343

Shoham Y, 'Agent-Oriented Programming' (1993) 60 Artificial Intelligence 51

Shultz T R, 'From Agency to Intention: A Rule-Based, Computational Approach' in Whiten A (ed), *Natural Theories of the Mind: Evolution, Development and Simulation of Everyday Mindreading* (Basil Blackwell 1991)

Simmler M, 'Responsibility Gap or Responsibility Shift? The Attribution of Legal Personhood to Artificial Agents' (2024) 27 Information, Communication & Society 1142

Sklaroff J M, 'Smart Contracts and the Cost of Inflexibility' (2017) 166 University of Pennsylvania Law Review 263

Slavu V, 'Effects of Civil Juristic Act' (2015) 4 Journal of Law and Administrative Science 1

Smith B, 'Legal Personhood' (1928) 37 Yale Law Journal 283

Smith S A, 'Contract Theory' (2004) OUP

Solum LB, 'Legal Personhood for Artificial Intelligences' (1992) 70 North Carolina Law Review 1231

Sundar S S, 'Rise of Machine Agency: A Framework for Studying the Psychology of Human–AI Interaction (HAI)' (2020) 25 Journal of Computer-Mediated Communication 74

Surden H, 'Computable Contracts' (2012) 46 UC Davis Law Review 629

Taherdoost H, 'Smart Contracts in Blockchain Technology: A Critical Review' (2023) 14(2) Information 117

Tawfik AM and others, 'Blockchain-Based Access Control and Privacy Preservation in Healthcare: A Comprehensive Survey' (2025) 28 Cluster Computing 529

Teubner G, 'Rights of Non-Humans? Electronic Agents and Animals as New Actors in Politics and Law' (2006) 33 Journal of Law and Society 497

Tripathi G, Ahad MA and Casalino G, 'A Comprehensive Review of Blockchain Technology' (2023) 9 Decision Analytics Journal 100344

Trusilo D, 'Autonomous AI Systems in Conflict: Emergent Behavior and Its Impact on Predictability and Reliability' (2023) 14(1) Journal of Military Ethics 2

Umpleby SA, 'Ross Ashby's General Theory of Adaptive Systems' (2009) 38(2) International Journal of General Systems 231

Van de Poel I, 'Embedding Values in Artificial Intelligence (AI) Systems' (2020) 30 Minds and Machines 385

Vandezande N, 'Smart Contracts: The End of Contract Law as We Know It?' (2017) 33 Computer Law & Security Review 153

Wachter S, Mittelstadt B and Floridi L, 'Why a Right to Explanation of Automated Decision-Making Does Not Exist in the GDPR' (2017) 7(2) International Data Privacy Law 76

Wahrstätter A, Khan S and Svetinovic D, 'OpenFL: A Scalable and Secure Decentralized Federated Learning System on the Ethereum Blockchain' (2024) 26 Internet of Things 101174

Walsh KR, Mahesh S e Trumbach CC, 'Autonomy in AI Systems: Rationalizing the Fears' (2021) 47 Journal of Information Technology Case and Application Research 38

Werbach K and Cornell N, 'Contracts Ex Machina' (2017) 67 Duke Law Journal 313

Worthington S, 'Common Law Values: The Role of Party Autonomy in Private Law' (2015) University of Cambridge Faculty of Law Legal Studies Research Paper Series

Ye D, Zhang M and Vasilakos A, 'A Survey of Self-Organization Mechanisms in Multiagent Systems' (2017) 47 IEEE Transactions on Systems, Man, and Cybernetics: Systems 441

Zetzsche D, Buckley R and Arner D, 'The Distributed Liability of Distributed Ledgers: Legal Risks of Blockchain' (2018) University of Illinois Law Review 1361

Zindros D, Bampa M and Kiayias A, 'Proof-of-Stake Protocols: A Survey' (2020) 35 ACM Computing Surveys 1

Digital-Only Journal Articles and Platforms

Agnihotram S and Kouroutakis A, 'Doctrinal Challenges for the Legality of Smart Contracts: Lex Cryptographia or a New, "Smart" Way to Contract?' (2019) 19 Journal of High Technology Law 300

Alharby M and van Moorsel A, 'Blockchain-Based Smart Contracts: A Systematic Mapping Study' (2017) arXiv <https://arxiv.org/abs/1710.06372> accessed 12 March 2025

Allgrove B, 'Legal Personhood for Artificial Intelleccts: Pragmatic Solution or Science Fiction?' (2004) SSRN <https://ssrn.com/abstract=925723> accessed 27 March 2025

Andrade F, Novais P, Machado J and Neves J, 'Contracting Agents: Legal personhood and Representation' (2007) 15 Artificial Intelligence and Law 357

Baldassarre M T, De Stefano L and Navigli R, 'The Social Impact of Generative AI: An Analysis on ChatGPT' (arXiv, 7 March 2024) <https://arxiv.org/abs/2403.04667> accessed 8 March 2025

Banteka N, 'Artificially Intelligent Persons' (2020) 58 Houston Law Review 537

Bathae Y, 'The Artificial Intelligence Black Box and the Failure of Intent and Causation' (2018) 31 Harvard Journal of Law & Technology 889

Beltrán ETM and others, 'Decentralized Federated Learning: Fundamentals, State of the Art, Frameworks, Trends, and Challenges' (2023) IEEE <https://arxiv.org/pdf/2211.08413.pdf> accessed 8 December 2024

Beresford B and Sloper T, 'Understanding the Dynamics of Decision-Making and Choice: A Scoping Study of Key Psychological Theories to Inform the Design and Analysis of the Panel

Study’ (2008) <https://www.york.ac.uk/inst/spru/pubs/pdf/decisionmaking.pdf> accessed 5 September 2023

Calo R, ‘Robotics and the Lessons of Cyberlaw’ (2015) 103 California Law Review 513

Cao Y, Li S, Liu Y, Yan Z, Dai Y, Yu P S and Sun L, ‘A Comprehensive Survey of AI-Generated Content (AIGC): A History of Generative AI from GAN to ChatGPT’ (2023) arXiv <https://arxiv.org/abs/2303.04226> accessed 19 March 2023

Carley KM, ‘Organizational Adaptation’ (1997) 75 Annals of Operations Research 25

Chaveli K, Khatri A and Hossain M, ‘AI and Blockchain Integration’ (2020) 8th International Conference on Reliability, Infocom Technologies and Optimization (ICRITO) https://www.researchgate.net/publication/344981707_AI_and_Blockchain_Integration accessed 29 August 2023

Chesterman S, ‘Artificial Intelligence and the Problem of Autonomy’ (2020) 1 Notre Dame Journal on Emerging Technologies 210

Chinen MA, ‘The Co-Evolution of Autonomous Machines and Legal Responsibility’ (2016) 20 Virginia Journal of Law and Technology 338

Clack C, Bakshi V and Braine L, ‘Smart Contract Templates: Foundations, Design Landscape and Research Directions’ (2016) arXiv <https://arxiv.org/abs/1608.00771> accessed 15 March 2025

Cobbe J, Veale M and Singh J, ‘Understanding Accountability in Algorithmic Supply Chains’ (2023) Proceedings of the 2023 ACM Conference on Fairness, Accountability, and Transparency 12 <https://doi.org/10.1145/3593013.3594073> accessed 5 April 2025

Dagan H and Heller MA, ‘Freedom, Choice, and Contracts’ (2019) 20 Theoretical Inquiries in Law https://scholarship.law.columbia.edu/cgi/viewcontent.cgi?article=3598&context=faculty_scholarship accessed 17 October 2023

Dahiyat EAR, ‘Law and Software Agents: Are They “Agents” by the Way?’ (2021) 29 Artificial Intelligence and Law 59

Dai H-N and Zhang Z, 'Blockchain for Internet of Things: A Survey' (2020) arXiv <https://arxiv.org/abs/2001.00000> accessed 7 March 2021

Das D and others, 'FASTKITTEN: Practical Smart Contracts on Bitcoin' (2019) IACR Cryptology ePrint Archive <https://eprint.iacr.org/2019/154.pdf> accessed 19 March 2025

De Angelis E and others, 'Forum: Artificial Intelligence, Artificial Agency and Artificial Life' (2019) 164(5–6) The RUSI Journal 120

Delarivière S, 'Artificial Free Will: The Responsibility Strategy and Artificial Agents' (2016) 7 Apeiron Student Journal of Philosophy 175

Dennett D, 'Intentional Systems' (1971) 68(4) The Journal of Philosophy 87

Ebers M, 'Truly Risk-Based Regulation of Artificial Intelligence: How to Implement the EU's AI Act' (2024) European Journal of Risk Regulation <https://www.cambridge.org/core/journals/european-journal-of-risk-regulation/article/truly-riskbased-regulation-of-artificial-intelligence-how-to-implement-the-eus-ai-act/E526C1D0D7368F9691082220609D60F4> accessed 28 April 2025

El-Assady M and others, 'Towards XAI: Structuring the Processes of Explanations' (2019) HCML Workshop at CHI'19, Glasgow <https://openreview.net/pdf?id=HgM5PBkkJQ> accessed 4 June 2023

Endriss U and others, 'Autonomous Agents and Multiagent Systems: Perspectives on 20 Years of AAMAS' (2021) 7(3) AI Matters 29

Fitzgerald WA, 'Maturity, Difference, and Mystery: Children's Perspectives and the Law' (1994) 36(1) Arizona Law Review <https://www.coursehero.com/file/225591160/36ArizLRev11-1pdf/> accessed 10 January 2025

Floridi L and Sanders JW, 'On the Morality of Artificial Agents' (2004) 14 Minds and Machines 349

Ge C, Sun S and Szalachowski P, 'Permissionless Blockchains and Secure Logging' (2019) arXiv <https://arxiv.org/abs/1903.03954> accessed 20 August 2025

Genç Ö, 'Machine Learning and Deep Learning for Curious People' (2019) Towards Data Science <https://towardsdatascience.com/notes-on-artificial-intelligence-ai-machine-learning-ml-and-deep-learning-dl-for-56e51a2071c2> accessed 25 March 2020

Godbole S and others, 'Validation Framework for E-Contract and Smart Contract' (2025) arXiv <https://arxiv.org/abs/2504.19137> accessed 8 June 2025

Goertzel B and others, 'OpenCog Hyperon: A Framework for AGI at the Human Level and Beyond' (2023) arXiv <https://arxiv.org/abs/2309.10131> accessed 20 August 2024

Hacker P, 'AI Regulation in Europe: The Road Ahead' (2023) arXiv <https://arxiv.org/abs/2307.09876> accessed 15 September 2025

Hacker P, 'AI Regulation in Europe: The Road Ahead' (arXiv, 2023) <https://arxiv.org/abs/2307.09876> accessed 15 August 2025

Hagerty A and Rubinov I, 'Global AI Ethics: A Review of the Social Impacts and Ethical Implications of Artificial Intelligence' (2019) arXiv <https://arxiv.org/abs/1907.07892> accessed 3 August 2024

Harris JD and Waggoner B, 'Decentralized and Collaborative AI on Blockchain' (2019) IEEE International Conference on Blockchain https://www.researchgate.net/publication/338360278_Decentralized_and_Collaborative_AI_on_Blockchain accessed 6 November 2024

Hasselberger W, 'Human Agency, Reasons, and Inter-subjective Understanding' (2014) 89 Philosophy 347 <https://www.jstor.org/stable/24779064> accessed 18 November 2023

Helmi T, 'SHIMI: Semantic Hierarchical Memory Index for Efficient Cognitive AI Systems' (2025) arXiv <https://arxiv.org/abs/2504.06135> accessed 1 August 2025

Hesselink M W, 'Capacity and Capability in European Contract Law' (2005) Amsterdam Center for Law and Economics Working Paper 2005-08, SSRN <https://ssrn.com/abstract=691842> accessed 22 August 2025

Hesselink M W, 'How to Opt Out of the Digital Single Market? Contract, Coercion, and Choice' (Amsterdam Law School Research Paper No 2024-25, SSRN, 2024) <https://ssrn.com/abstract=4845851> accessed 20 August 2025

Himeur Y and others, 'Decentralized Artificial Intelligence (DAI): Taxonomy, Applications, Challenges and Future Directions' (2024) arXiv <https://arxiv.org/abs/2412.17114> accessed August 2025

Horling B and Lesser V, 'A Survey of Multi-Agent Organizational Paradigms' (2004) 19(4) The Knowledge Engineering Review 281

Hsieh F-S, 'Holarchy Formation and Optimization in Holonic Manufacturing Systems with Contract Net' (2008) 44(4) Automatica 959

Hu B A and others, 'Trustless Autonomy: Understanding Motivations behind Decentralized AI Agents' (2025) arXiv <https://arxiv.org/abs/2505.09757> accessed 22 August 2025

Hutson J and Barnes E, 'AI and the Cognitive Sense of Self' (2025) 3(1) Journal of Intelligent Communication 35

Josephson JR, 'A Layered Abduction Model of Perception: Integrating Bottom-Up and Top-Down Processing in a Multi-Sense Agent' (1990) Proceedings of the NASA Conference on Space Telerobotics vol 4 <https://ntrs.nasa.gov/citations/19900020535> accessed 12 July 2023

Kalala K, 'Logical Foundations of Smart Contracts' (2025) arXiv <https://arxiv.org/abs/2502.09232> accessed 15 June 2025

Karnow CEA, 'Liability for Distributed Artificial Intelligences' (1996) 11 Berkeley Tech LJ 147

Kounev S, 'Engineering of Self-Aware IT Systems and Services: State-of-the-Art and Research Challenges' (2011) Computer Performance Engineering https://link.springer.com/chapter/10.1007/978-3-642-24749-1_2 accessed 8 May 2023

Kraus JS and Scott RE, 'Contract Design and the Structure of Contractual Intent' (2009) 84 New York University Law

Review <https://heinonline.org/HOL/Page?collection=journals&handle=hein.journals/nylr84&id=1030> accessed 19 November 2023

Laird JE and others, 'Interactive Task Learning' (2017) 32(4) IEEE Intelligent Systems 6

Laird JE, Newell A and Rosenbloom PS, 'Soar: An Architecture for General Intelligence' (1987) 33 Artificial Intelligence 1

Lake BM, Ullman TD, Tenenbaum JB and Gershman SJ, 'Building Machines That Learn and Think Like People' (2017) 40 Behavioral and Brain Sciences 1

Langley P, 'Interactive Cognitive Systems and Social Intelligence' (2017) 32(4) IEEE Intelligent Systems 22

Langley P, 'The Cognitive Systems Paradigm' (2012) 1 Advances in Cognitive Systems 3

Lee L, 'Examining the Legal Status of Digital Assets in Commercial Transactions' (2024) SSRN <https://ssrn.com/abstract=4867529> accessed 20 August 2025

Lewis D, Lasek-Markey M, Golpayegani D and Pandit H J, 'Mapping the Regulatory Learning Space for the EU AI Act' (2024) arXiv <https://arxiv.org/abs/2503.05787> accessed 21 May 2025

Lewis PR, 'Self-Aware Computing Systems: From Psychology to Engineering' (2017) Design, Automation & Test in Europe Conference & Exhibition (DATE) <https://doi.org/10.23919/DATE.2017.7927144> accessed 7 October 2023

Li Y, 'Deep Reinforcement Learning: An Overview' (2018) arXiv <https://arxiv.org/abs/1812.05551> accessed 20 August 2025

Lieto A, 'Cognitive Biases and the Human Heuristics for Artificial Agents' (2021) 22(1) Biologically Inspired Cognitive Architectures 1

Lieto A, 'Ranking the Cognitive Plausibility of Computational Models of Metaphors with the Minimal Cognitive Grid: A Preliminary Study' in Proceedings of AISC 2024, XX Conference of the Italian Association of Cognitive Science (2024)

Lin X, 'Cognitio Emergens: Agency, Dimensions, and Dynamics in Human-AI Knowledge Co-Creation' (2025) arXiv <https://arxiv.org/abs/2505.03105> accessed 18 August 2025

Majeed R, 'The Relationship Between Conscious and Unconscious Intentionality' (2022) 97(2) Philosophy 169

Marchesi S and others, 'Human vs Humanoid. A Behavioral Investigation of the Individual Tendency to Adopt the Intentional Stance' (2021) Proceedings of the 2021 ACM/IEEE International Conference on Human-Robot Interaction <https://dl.acm.org/doi/abs/10.1145/3434073.3444663> accessed 2 September 2023

Martínez Beltrán ET and others, 'Decentralized Federated Learning: Fundamentals, State of the Art, Frameworks, Trends, and Challenges' (2023) IEEE <https://arxiv.org/pdf/2211.08413.pdf> accessed 8 December 2024

Mitchell M, 'Self-Awareness and Control in Decentralised Systems' (2005) AAAI Spring Symposium on Metacognition in Computation https://www.researchgate.net/publication/221218568_Selfawareness_and_control_in_decentralized_systems accessed 5 April 2023

Mocanu DM, 'Gradient Legal Personhood for AI Systems – Painting Continental Legal Shapes Made to Fit Analytical Molds' (2022) 8 Frontiers in Robotics and AI <https://www.frontiersin.org/journals/robotics-and-ai/articles/10.3389/frobt.2021.788179/full> accessed November 2024

Nadew L, 'Void Agreements and Voidable Contracts: The Need to Elucidate Ambiguities of Their Effects' (2020) 4 Beijing L Rev 557

Nakamoto S, Bitcoin: A Peer-to-Peer Electronic Cash System (2008) <https://bitcoin.org/bitcoin.pdf> accessed 10 March 2025

Nash E, 'Blockchain & Smart Contract Technology: Alternative Incentives for Legal Contract Innovation' (2019) 3(8) BYU Law Review 800

Nasir S, Abbas Q, Bai S and Khan R A, 'A Comprehensive Framework for Reliable Legal AI: Combining Specialized Expert Systems and Adaptive Refinement' (2024) arXiv <https://arxiv.org/abs/2412.20468> accessed 7 August 2025

Niv Y and Langdon A, 'Reinforcement Learning with Marr' (2016) 11 Current Opinion in Behavioral Sciences

<https://www.sciencedirect.com/science/article/pii/S2352154616300821> accessed 15 November 2023

Nizamieva O, 'Civil Legal Capacity of Minors' (2018) 5 The Journal of Social Sciences Research https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3774484 accessed 12 January 2025

Norris C, 'Frankfurt on Second-Order Desires and the Concept of a Person' (2010) 9(2) Prolegomena 199 <https://hrcak.srce.hr/file/91379> accessed January 2025

Novelli C, Bongiovanni G and Sartor G, 'A Conceptual Framework for Legal Personhood and Its Application to AI' (2022) 13 Jurisprudence 194 <https://doi.org/10.1080/20403313.2021.2010936> accessed 6 November 2024

Novelli C, Casolari F, Hacker P, Spedicato G and Floridi L, 'Generative AI in EU Law: Liability, Privacy, Intellectual Property, and Cybersecurity' (2024) arXiv <https://arxiv.org/abs/2401.07348> accessed 18 August 2025

Omelchuk O, Cherniak O and Tyshchuk N, 'Protection of the Rights of Children and Minors in Their Transactions in the Information Society' (2020) 9(II) Revista de Derecho 25 <https://doi.org/10.31207/ih.v9i2.241> accessed 17 February 2025

Pastore B, 'Capacità di agire e vulnerabilità. Una prospettiva interdisciplinare. Presentazione' (2020) 1 Diritto e questioni pubbliche https://sfera.unife.it/retrieve/e309ade4-c537-3969-e053-3a05fe0a2c94/DQ-XX-2020-1_01_mono_Pastore.pdf accessed 4 January 2025

Perez-Osorio J and Wykowska A, 'Adopting the Intentional Stance toward Natural and Artificial Agents' (2019) 33(3) Philosophical Psychology 1

Plewe DA and de Rooy R, 'Integrative Deal-Design: Cascading from Goal-Hierarchies to Negotiations and Contracting' (2016) 2(1–2) Journal of Strategic Contracting and Negotiation 19

Ponomarev A and Voronkov A, 'Multi-Agent Systems and Decentralized Artificial Superintelligence' (2017) arXiv <https://arxiv.org/pdf/1702.08529.pdf> accessed 2 May 2025

Rafaiani G and others, 'Implementation of Ethereum Accounts and Transactions on Embedded IoT Devices' (2022) arXiv <https://arxiv.org/abs/2206.14782> accessed 15 March 2025

Rao AS and Georgeff MP, 'BDI Agents: From Theory to Practice' (1995) Proceedings of the First International Conference on Multiagent Systems <https://cdn.aaai.org/ICMAS/1995/ICMAS95-042.pdf> accessed 9 June 2025

Rastogi C and others, 'Deciding Fast and Slow: The Role of Cognitive Biases in AI-assisted Decision-making' (2022) 6 Proceedings of the ACM on Human-Computer Interaction (CSCW1) <https://dl.acm.org/doi/10.1145/3512930> accessed 6 August 2023

Ribeiro D and others, 'Toward Effective AI Governance: A Review of Principles' (2025) arXiv <https://arxiv.org/abs/2505.23417> accessed 22 August 2025

Rieder C and others, 'Blockchain Consensus: A Survey of Protocols and Trends' (2023) arXiv <https://arxiv.org/abs/2303.11020> accessed 20 August 2025

Riva G, 'Invisible Architectures of Thought: Toward a New Science of AI as Cognitive Infrastructure' (2025) arXiv <https://arxiv.org/abs/2507.22893> accessed 22 August 2025

Roussanaly V and Falcone Y, 'Decentralised Runtime Verification of Timed Regular Expressions' (2022) Leibniz International Proceedings in Informatics (LIPIcs), TIME 2022 <https://drops.dagstuhl.de/storage/00lipics/lipics-vol247-time2022/LIPIcs.TIME.2022.6/LIPIcs.TIME.2022.6.pdf> accessed 7 October 2023

Santaniello M, Palladino N, Catone MC and Diana P, 'The Language of Digital Constitutionalism and the Role of National Parliaments' (2018) 80(4) The International Communication Gazette 321

Sartor G, 'Legal Concepts as Inferential Nodes and Ontological Categories' (2009) 17 Artificial Intelligence and Law 217

Scherer MU, 'AI Entities as AI Agents: Artificial Intelligence Liability and the AI Respondeat Superior Analogy' (2020) 46 Mitchell Hamline Law Review 1049

Schroeder de Witt C A, Foerster J N, Farquhar G, Torr P H S, Boehmer W and Whiteson S, 'Multi-Agent Common Knowledge Reinforcement Learning' (2018) arXiv <https://arxiv.org/abs/1810.11702> accessed 21 July 2025

Singleton WE, 'Entities and Real and Artificial Persons' (1912) 12(2) Journal of the Society of Comparative Legislation <http://www.jstor.org/stable/752454> accessed 10 December 2024

Solum LB, 'Legal Personhood for Artificial Intelligences' (1992) 70 North Carolina Law Review 1231 <https://tinyurl.com/5dd4cebj> accessed 10 December 2024

Solum LB, 'Legal Theory Lexicon 027: Persons and Personhood' (2004) Legal Theory Lexicon https://lsolum.typepad.com/legal_theory_lexicon/2004/03/legal_theory_le_2.html accessed 6 January 2025

Stradella E and others, 'Robot Companions as Case-Scenario for Assessing the "Subjectivity" of Autonomy Agents' (2012) 1 CAUR Workshop Proceedings <https://ceur-ws.org/Vol-885/paper4.pdf> accessed 12 December 2024

Sullivan DM, 'Defending Human Personhood: Some Insights from Natural Law' (2008) 37(3) Christian Scholar's Review 297 https://www.researchgate.net/profile/Dennis-Sullivan-4/publication/265221882_Defending_Human_Personhood_Some_Insights_from_Natural_Law/links/5703afb008aedbac127085e1/Defending-Human-Personhood-Some-Insights-from-Natural-Law.pdf accessed 9 October 2024

Szabo N, 'Formalizing and Securing Relationships on Public Networks' (1997) 2(9) First Monday <https://doi.org/10.5210/fm.v2i9.548> accessed 20 March 2025

Tollon F, 'Moral Agents or Mindless Machines? A Critical Appraisal of Agency in Artificial Systems' (2019) 4(63) Hungarian Philosophical Review 9

Tymoshenko V, Bondar S and Ivanchuk N, 'Human Freedom in the Legal Dimension' (2023) 13(1) Law Journal of the National Academy of Internal Affairs <https://elar.naiu.kiev.ua/server/api/core/bitstreams/5405e27f-ddb2-4c34-b618-6dd477e5f19b/content> accessed 18 October 2024

Vincent J, 'Former Go Champion Beaten by DeepMind Retires after Declaring AI Invincible' The Verge (27 November 2019)

Wang H and others, ‘Can AI Be as Creative as Humans? Relative Creativity and Its Measurement’ (2024) arXiv <https://arxiv.org/abs/2401.01623> accessed 8 September 2024

Wang J and others, ‘Symphony: A Decentralized Multi-Agent Framework for Scalable Collective Intelligence’ (2025) arXiv <https://arxiv.org/abs/2508.20019> accessed 21 September 2025

Wang J, Chen K, Song X, Zhang K, Ai L, Yang E and Shi B, ‘Symphony: A Decentralized Multi-Agent Framework for Scalable Collective Intelligence’ (2025) arXiv <https://arxiv.org/abs/2508.20019> accessed 21 September 2025

White FJ, ‘Personhood: An Essential Characteristic of the Human Species’ (2013) 80(1) The Linacre Quarterly 74 <https://doi.org/10.1179/0024363912Z.000000000010> accessed 2 January 2025

Wijayakoon C and others, ‘Legal Compliance Evaluation of Smart Contracts Generated by Large Language Models’ (2025) arXiv <https://arxiv.org/abs/2506.00943> accessed 15 June 2025

Wojtczak S, ‘Endowing Artificial Intelligence with Legal Subjectivity’ (2022) 37 AI & Society https://www.researchgate.net/publication/349365102_Endowing_Artificial_Intelligence_with_legal_subjectivity accessed 7 December 2024

Yli-Huomo L and others, ‘Where Is Current Research on Blockchain? — A Systematic Review’ (2016) 11(10) PLOS ONE e0163477

Zambonelli F and others, ‘On Self-Adaptation, Self-Expression, and Self-Awareness in Autonomic Service Component Ensembles’ (2011) Fifth IEEE Conference on Self-Adaptive and Self-Organizing Systems Workshops https://www.researchgate.net/publication/236644835_On_Self-Adaptation_Self-Expression_and_Self-Awareness_in_Autonomic_Service_Component_Ensembles accessed 6 April 2023

Zheng Z and others, ‘An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends’ in 2017 IEEE International Congress on Big Data (IEEE 2017) 557

Zhiyong S, Zhang Y, Li X, Yang L, Yuan X and Z S, 'Roadmap toward the Metaverse: An AI Perspective' (2022) 3(5) *The Innovation* 100293

Zouk A, 'Beyond the Blockchain Hype: Addressing Legal and Regulatory Challenges' (2025) 5(11) *SN Social Sciences* 1

Working Papers and Conference Papers

Andronie M and others, 'Artificial Intelligence-Based Decision-Making Algorithms, Internet of Things Sensing Networks, and Deep Learning-Assisted Smart Process Management in Cyber-Physical Production Systems' (2021) 10(20) *Electronics* 2497

Ante L, 'Autonomous AI Agents in Decentralized Finance: Market Dynamics, Application Areas, and Theoretical Implications' (SSRN Working Paper, 14 December 2024, rev 8 June 2025)

Buterin V, *A Next-Generation Smart Contract and Decentralized Application Platform* (Ethereum White Paper 2014)

Chaveli K, Khatri A and Hossain M, 'AI and Blockchain Integration' (2020) 8th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO) https://www.researchgate.net/publication/344981707_AI_and_Blockchain_Integration accessed 29 August 2023

Dos Anjos JCS and others, 'A Survey on Collaborative Learning for Intelligent Autonomous Systems' (2023) 56(4) *ACM Computing Surveys*

Ebers M, 'Standardisation in the EU Artificial Intelligence Act' (Working Paper, University of Passau 2023) https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4521735 accessed 15 August 2025

Eidenmüller H, 'Contracting with No One? Theoretical Foundations of Contractual Agency by Autonomous Systems' (Oxford Legal Studies Research Paper No 10/2021)

El-Assady M, Jentner W, Kehlbeck R, Schlegel U, Sevastjanova R, Sperrle F, Spinner T and Keim D, ‘Towards XAI: Structuring the Processes of Explanations’ (HCML Workshop at CHI’19, Glasgow, 2019) <https://openreview.net/pdf?id=HgM5PBkkJQ> accessed 4 June 2023

European Commission, ‘Proposal for a Regulation Laying Down Harmonised Rules on Artificial Intelligence (Artificial Intelligence Act)’ COM(2021) 206 final

European Commission, ‘White Paper on Artificial Intelligence: A European Approach to Excellence and Trust’ (COM(2020) 65 final, 19 February 2020)

Franklin M, Ashton H, Awad E and Lagnado D, ‘Causal Framework of Artificial Autonomous Agent Responsibility’ in *Proceedings of the 2022 AAAI/ACM Conference on AI, Ethics, and Society* (ACM 2022)

Frosini V and Morandi G, ‘Intelligenza Artificiale e Diritto: Profili Giuridici ed Etici’ (Convegno Nazionale su IA e Diritto, Milano 2020)

Golpayegani F, *Trust Formation and the Dynamics of Cooperation in Open Multi-Agent Systems* (PhD thesis, University of Southampton 2021)

Grigg I, ‘The Ricardian Contract’ (2004) http://iang.org/papers/ricardian_contract.html accessed 19 September 2025

Herian R, *Legal Recognition of Blockchain Registries and Smart Contracts* (preprint, December 2018) <https://doi.org/10.13140/RG.2.2.12449.86886/1> accessed 26 June 2025

High-Level Expert Group on Artificial Intelligence, ‘Ethics Guidelines for Trustworthy AI’ (European Commission 2019)

Horling B and Lesser V, ‘A Survey of Multi-Agent Organizational Paradigms’ (2004) 19(4) *The Knowledge Engineering Review* 281

Josephson J R, ‘A Layered Abduction Model of Perception: Integrating Bottom-Up and Top-Down Processing in a Multi-Sense Agent’ (2013) Proceedings of the NASA Conference on Space Telerobotics, Volume 4 <https://ntrs.nasa.gov/citations/19900020535> accessed 12 July 2023

Lewis P R, 'Self-Aware Computing Systems: From Psychology to Engineering' (2017) Design, Automation & Test in Europe Conference & Exhibition (DATE) <https://doi.org/10.23919/DATE.2017.7927144> accessed 19 September 2023

Mitchell M, 'Self-Awareness and Control in Decentralised Systems' (2005) AAAI Spring Symposium on Metacognition in Computation, Stanford, California https://www.researchgate.net/publication/221218568_Selfawareness_and_control_in_decentralized_systems accessed 7 July 2023

Nakamoto S, *Bitcoin: A Peer-to-Peer Electronic Cash System* (2008)

Peña-Calvin A, Duenas-Cid D and Ahmed J, 'Is DAO Governance Fostering Democracy? Reviewing Decision-Making in Decentraland' (Working Paper, Universidad Complutense de Madrid and Kozminski University 2025)

Roussanaly V and Falcone Y, 'Decentralised Runtime Verification of Timed Regular Expressions' (2022) 29th International Symposium on Temporal Representation and Reasoning, Leibniz International Proceedings in Informatics 247

Santaniello M, Palladino N, Catone M C and Diana P, 'The Language of Digital Constitutionalism and the Role of National Parliaments' (2018) 80(4) International Communication Gazette 321

Short M, 'The Blockchain Governance Crisis from the Perspective of Corporate Theory' (10 March 2024) *SSRN Electronic Journal*

Strobel V, Castello Ferrer E and Dorigo M, 'Managing Byzantine Robots via Blockchain Technology in a Swarm Robotics Collective Decision-Making Scenario' in *Proceedings of the 17th International Conference on Autonomous Agents and Multi-Agent Systems* (International Foundation for Autonomous Agents and Multiagent Systems, Stockholm, July 2018)

Umpleby S A, 'Ross Ashby's General Theory of Adaptive Systems' (Conference Paper, International Society for the Systems Sciences, 2000) <https://www.iss.org/proceedings2000/pdf/umpleby.pdf> accessed 10 August 2025

Wood G, *Ethereum: A Secure Decentralised Generalised Transaction Ledger (Yellow Paper)* (2014)

Official Publications and Reports

European Commission, ‘Building Trust in Human-Centric Artificial Intelligence’ (Communication) COM (2019) 168 final

European Commission, ‘Commission Guidelines on Prohibited Artificial Intelligence (AI) Practices as Defined in the AI Act’ (Digital Strategy, 22 April 2024)

European Commission, ‘On Artificial Intelligence – A European Approach to Excellence and Trust’ COM (2020) 65 final

European Commission, ‘Smart Contracts and the Digital Single Market through the Lens of a “Law + Technology” Approach’ (Report, 2021)

European Union Agency for Fundamental Rights, ‘Getting the Future Right – Artificial Intelligence and Fundamental Rights’

(2020) https://fra.europa.eu/sites/default/files/fra_uploads/fra-2020-artificial-intelligence_en.pdf accessed 15 September 2025

European Union Blockchain Observatory & Forum, ‘EU Blockchain Ecosystem Report’ (2020)

Law Commission (England and Wales), *Smart Legal Contracts: Advice to Government* (Law Com No 401, 25 November 2021)

Law Reform Commission, *Privity of Contract: Third Party Rights* (LRC CP 40–2006)

OECD, *Explanatory Memorandum on the Updated OECD Definition of an AI System* (OECD Artificial Intelligence Papers, March 2024)

UK Government, *International Scientific Report on the Safety of Advanced AI: Interim Report* (Department for Science, Innovation and Technology 2024)

UK Jurisdiction Taskforce, *Legal Statement on the Status of Cryptoassets and Smart Contracts* (2019)

United Nations, ‘Recommendation on the Ethics of Artificial Intelligence’ (UNESCO 2021) <https://unesdoc.unesco.org/ark:/48223/pf0000379920> accessed 15 September 2025

Websites and Online-Only Materials

Aragon, ‘Homepage’ <https://aragon.org> accessed 29 October 2022

Cortex Labs, ‘Homepage’ <https://www.cortexlabs.ai/> accessed 10 January 2020

Exonum, ‘Homepage’ <https://exonum.com/index> accessed 8 March 2023

Festo, ‘Blockchain Decentralized Manufacturing Marketplace’ https://www.festo.com/lt/en/e/about-festo/research-and-development/research-projects/blockchain-decentralized-manufacturing-marketplace-id_769647/ accessed August 2023

Jacobs S, ‘AI & Blockchain Transform Gaming: AILAND Building on SKALE’ (2023) <https://skale.space/blog/ai-blockchain-transform-gaming-ailand-building-on-skale> accessed 25 April 2023

Matrix Chain, ‘Homepage’ <https://www.matrix.io> accessed August 2024

Numer.ai, ‘Homepage’ <https://numer.ai/> accessed 22 October 2022

OpenCog Hyperon, ‘Portfolio’ <https://superintelligence.io/portfolio/opencog-hyperon/> accessed 2 February 2025

PwC, ‘DeFi: Defining the Future of Finance’ (2021) <https://www.pwc.ch/en/publications/2021/defi-defining-the-future-of-finance-may%202021.pdf> accessed 7 February 2023

Research and Markets, 'Blockchain AI Global Market Report'
(2023) <https://www.researchandmarkets.com/report/blockchain-artificial-intelligence> accessed 6 April 2023

SingularityNET, 'About Us' <https://singularitynet.io/aboutus/> accessed 5 May 2021

SingularityNET, *White Paper*

2.0 (2019) <https://public.singularitynet.io/whitepaper.pdf> accessed 28 June 2021

Verv Energy, 'Homepage' <https://verv.energy> accessed 5 February 2023

Newspaper Articles

Vincent J, 'Former Go Champion Beaten by DeepMind Retires after Declaring AI Invincible' *The Verge* (27 November 2019)

Academic Lectures

Meoli, 'Diritto Civile' (Lecture in Civil Law, University of Salerno, February 2019)

Piatti L, 'Blockchain e Smart Contracts' (Lecture in *Coding for Lawyers*, University of Milan, 4 March 2021)