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EC2 Deliverable 2.1 - Framework Document

Contents

Executive Summary

The European City2 (EC2) project uses a hybrid quantum-classical Computational Social Science (CSS) framework to advance research on democratic governance. By integrating CSS with Social Sciences and Humanities (SSH) methodologies, it aims to counter the growing threats of authoritarianism, political instability, and declining trust in democratic institutions. The project seeks innovative ways to bypass Arrow's Impossibility Theorem, a foundational result in social choice theory demonstrating that no voting system can perfectly convert individual preferences into a collective decision while satisfying all fairness conditions simultaneously. To this end, the project uses cutting-edge scientific insights—from classical agent-based modelling and active inference to quantum information theory—to rethink how democracy can be made more robust to the cited threats.

At the heart of EC2 is the development of a simulation platform that integrates synthetic and empirical data to test alternative voting systems—most notably, Quadratic Voting (QV). QV allows voters to express not just preferences but intensity, offering a more nuanced and equitable framework for public decision-making. This system will be empirically validated through small-scale experiments in the city of Aarhus, Denmark, and in QuantumBasel, a Center of Competence for Quantum Computing and Artificial Intelligence in Basel, Switzerland, renowned for hosting international conferences where small-scale collective decision-making can be efficiently tested.

EC2 seeks to advance the science of cooperation by introducing concepts like *emergent altruism* and *gravitas*. Emergent altruism describes cooperative behaviors arising from optimized voting systems, while gravitas measures the weight of a voter's influence on social outcomes, linking democratic processes to models of stability and persistence. In this regard, the Danish principle of *Samfundssind*, which is the culturally embedded expectation that individuals strive to be useful and contribute positively to society, is particularly relevant for our simulations and piloting.

The project strictly adheres to GDPR and data ethics, and will advance methodologies for synthetic data generation, agent-based experimentation, and FAIR-by-design data flows—aligned with the ambitions of the European Open Science Cloud and Horizon Europe's open research goals.

By combining cutting-edge theory with real-world testing, EC2 introduces a new approach to democracy as an adaptive system. The project aims to influence both academic debates and practical reforms, equipping cities and citizens with tools to strengthen democratic resilience, responsiveness, and public trust in how decisions are made and justified.

1. Introduction: The Challenge to Democracy

In recent years, democratic institutions around the world have come under increasing strain. The European Commission has described this moment as a time when "democracy is under siege", marked by a sustained erosion of trust in governance, declining voter participation, and the rise of autocratic, populist, and majoritarian political movements. Reports from V-Dem, Freedom House, and other monitoring institutions document a global "democratic recession", where established democracies exhibit growing fragility while a significant number of states slide further into authoritarianism.

This decline in democratic quality coincides with deepening societal polarization, disinformation, and institutional gridlock. Traditional models of democratic governance—designed for slower, analog eras—are increasingly challenged by rapid technological change, complex information flows, and the scale of contemporary societies. The digital age has both enabled unprecedented citizen engagement and amplified the risks of division, manipulation, and exclusion.

Against this backdrop, the Horizon Europe programme calls for bold, interdisciplinary approaches to renew and modernize democratic systems. In particular, the call to which the EC2 project responds[1] highlights the urgent need to harness the power of CSS to better understand and design democratic

[1] HORIZON-CL2-2024-DEMOCRACY-01-06

governance. By combining data-rich modeling with agent-based simulations and theoretical integration, CSS offers new tools to analyze complex social systems, test hypotheses, and design participatory mechanisms in controlled yet realistic environments.

EC2 answers this call by proposing a framework for democratic experimentation grounded in CSS and social choice theory. EC2 seeks to explore how alternative voting systems, especially Quadratic Voting (QV) and Quantum Quadratic Voting (QQV), can improve collective decision-making by enabling individuals to express not just preferences but intensities of concern. It draws on advances in quantum modeling, agent-based simulation, and synthetic data generation to develop an integrated environment where democratic institutions can be reimagined, tested, and optimized.

Central to EC2's conceptual foundation is a challenge to the classical limitations established by Arrow's impossibility theorem, which demonstrates that no voting system can simultaneously satisfy a core set of fairness conditions under standard assumptions. Rather than treating these constraints as inviolable, EC2 builds on recent work in quantum social choice theory—particularly the mathematical framework advanced by EC2 consortium partner Ning Bao—to explore how preference aggregation may behave differently in quantum-like environments. In such contexts, decision rules based on superposition, interference, and entanglement suggest novel architectures for expressing and combining preferences, potentially bypassing classical trade-offs through a shift in logic.

By combining theoretical innovation with real-world testing—in collaboration with partners such as the city of Aarhus, Denmark and organizations such as QuantumBasel—EC2 positions democracy not as a fixed institutional form, but as an evolvable system. Through computational experiments and participatory design, it seeks to demonstrate how democratic institutions can adapt to complexity, recover trust, and foster civic cooperation in the 21st century.

2. Intellectual Genealogy of Democratic Governance

Democracy, far from a fixed system, is an evolving experiment in collective self-governance, rooted in Ancient Greek assemblies and refined through centuries into today's complex liberal-democratic institutions. Central to this historical arc are evolving answers to the fundamental question: *how should decisions be made by groups of equals in conditions of disagreement and uncertainty?*

2.1 Deliberation, Voting, and Representation from Antiquity to Modernity

Democracy in its earliest Athenian form emphasized direct participation and deliberation among citizens. With the Roman Republic came innovations in representative governance and institutional checks. As suffrage expanded and modern nation-states emerged, voting became the dominant tool for mass decision-making. However, the tension between deliberation (as dialogical reasoning) and voting (as aggregation of preferences) has persisted across centuries. In the modern period, this tension manifests in the design trade-offs among electoral systems, public consultation mechanisms, and deliberative bodies.

2.2 Political Theory Foundations: Aristotle, Rousseau, Condorcet

The classical canon offers enduring insights into the promises and pathologies of democracy. Aristotle identified democracy as rule by the many and was among the first to explore the idea of *mixed regimes* as a solution to factionalism. Rousseau, in contrast, advanced a radical notion of *popular sovereignty*, insisting that the legitimacy of political authority derives from the general will, expressed directly by citizens.

The Enlightenment mathematician and philosopher Marquis de Condorcet introduced a probabilistic model of collective decision-making. His famous *Condorcet Jury Theorem* showed how majoritarian voting, under certain conditions, can outperform individual judgment. Yet, paradoxically, his work also revealed fundamental inconsistencies in majority rule, anticipating later impossibility theorems in social choice.

2.3 Ramon Llull and Josep Colomer

In the 13th century, Catalan philosopher Ramon Llull pioneered algorithmic approaches to collective decision-making, predating Enlightenment thinkers. His *Ars Magna* and *Ars electionis* introduced exhaustive pairwise comparisons among candidates, a computationally intensive method that anticipated modern social choice theory's structured preference aggregation. By prioritizing rational deduction over divine or coercive authority, Llull foreshadowed, as a distant predecessor, deliberative institutional design and modern voting innovations like quadratic voting, which optimizes preference expression through mathematical cost functions. His work on open versus secret ballots also prefigured debates on electoral transparency and coercion.

Contemporary scholar and EC2 consortium partner Josep Colomer reinterprets Llull's contributions, positioning him as a pioneer of rational voting systems within his broader thesis that voting mechanisms are endogenous institutions shaped by political strategy and historical context. In his 2013 *Social Choice and Welfare* article, Colomer highlights Llull's pairwise comparisons as responses to the medieval Church's need for enforceable majority-based decisions, moving beyond unanimous consent. This perspective underscores Llull's relevance to social choice theory, particularly in designing adaptable voting systems that inform modern methods like quadratic voting.

Colomer's view of voting as a redesignable technology aligns with EC2's mission to enhance democratic mechanisms through computational tools. By drawing on Llull's algorithmic insights and extending them to innovations like quadratic voting, EC2 integrates historical precedents into contemporary electoral design. This convergence reflects the document's narrative of democracy as an evolving system, where rational design and computational approaches address challenges in governance and preference aggregation.

2.4 Democratic Theory in the Age of Data and Computation

In the 21st century, digital technologies and data-driven analytics have transformed both the scale and speed of political communication and mobilization. At the same time, they have exposed the limits of traditional institutions to deal with complexity, polarization, and strategic manipulation. These developments demand a rethinking of democratic theory not merely in historical or philosophical terms, but in terms of computation, inference, and system design.

This is where EC2 situates its normative and scientific agenda. By treating democracy as an adaptive system, EC2 seeks to fuse classical insights into legitimacy, deliberation, and representation with the algorithmic tools of computational social science. The result is a new approach to democratic governance—one that honors its intellectual roots while equipping it for the epistemic, technological, and institutional challenges of our time.

3. Theoretical and Scientific Foundations

3.1 Social Choice, Cooperation, and Decision Theory

Democracy is ultimately a mechanism for aggregating individual preferences into collective decisions. Yet as Arrow's Impossibility Theorem mathematically demonstrated, no voting system can convert individual preferences into a collective decision without violating at least one fair condition, given certain assumptions. The EC2 project approaches this classical paradox not by accepting it as a limit, but by seeking new formulations through both computational and conceptual innovations.

3.2 From Qualitative to Quadratic Voting: Institutional Innovations

EC2 Consortium partner Rafael Hortala-Vallve's concept of Qualitative Voting, introduced in a 2007 working paper and published in 2012 in the *Journal of Theoretical Politics*, marked a significant advance in expressive voting systems.[2] In Qualitative Voting, voters receive a fixed budget of votes (e.g., 10 votes) to distribute across multiple candidates or issues, allowing them to express both the direction and intensity of their preferences. Emerging from political economy and social choice theory, this system empowers voters to prioritize issues of strong concern, offering a simpler alternative to traditional binary voting and enabling minority representation. While less mathematically complex than Quadratic Voting, Qualitative Voting's intuitive design makes it effective in multi-issue contexts. Within EC2, variations of Qualitative Voting will be implemented in preference aggregation modules alongside Quadratic Voting and majoritarian systems, enabling comparative evaluations of their impact on fairness, cooperation, and civic trust, as tested in EC2's simulations. Hortala-Vallve's work lays the conceptual groundwork for EC2's exploration of expressive voting mechanisms.

EC2 Consortium partner E. Glen Weyl's proposal for Quadratic Voting, developed independently and first circulated in 2012, built on this conceptual shift but introduced a transformative mathematical logic. In Quadratic Voting, each additional vote on a given issue costs the square of the number of votes cast, making the marginal cost of influence increase with intensity. This elegantly aligns voting behavior with economic principles of marginal utility and discourages vote hoarding. Quadratic Voting offers a scalable and theoretically rigorous mechanism for resolving collective decisions in both small and large groups—whether in civic, economic, or digital contexts.

Building on the exploration of expressive voting systems, EC2 will also experiment with voting models inspired by the Danish principle of *Samfundssind*, such as consortium partner Luis Razo's proposal for *Competitive Cooperation*. In competitive cooperation, voters start on an equal footing but are given additional voting influence in proportion to their measurable, objective commitment to the common good. A person's commitment to the common good can be measured in any number of ways, such as through voluntary work, voluntary taxes, etc. Preliminary quantum analyses (section 3.7) suggest that a quadratic version of this principle might serve as an effective mechanism for enhancing fairness and emergent altruism. To test this model alongside Qualitative Voting, Quadratic Voting, and majoritarian systems within EC2's preference aggregation modules, the framework will: (1) incorporate taxation/contribution modules into agent-based modeling to simulate commitment to the common good; (2) support longitudinal simulations to capture lifetime contribution effects; and (3) enhance ethical evaluation criteria to assess the implications of allowing an initial voter equality to evolve unequally over time, giving more votes in proportion to a voter's commitment to the common good. These enhancements, integrated into EC2's simulation architecture, ensure rigorous comparative analysis of quantum-supported democratic innovation.

Within the EC2 project, all voting mechanisms, including Qualitative Voting, Quadratic Voting, voting based on *Samfundssind*, and majoritarian systems, are evaluated through simulation environments and real-world experiments to test the hypothesis that democratic systems can be adaptive, evolvable, and

[2] The term "expressive voting systems" refers to mechanisms like Qualitative Voting and Quadratic Voting, which allow voters to convey preference intensity, as defined in the Glossary.

computationally tractable. These experiments, conducted within EC2's preference aggregation modules (section 3.4) and empirical pilots (section 5.2), aim to assess their impact on civic cohesion, strategic distortion, and emergent altruism based on empirical results. Hortala-Vallve's Qualitative Voting introduced flexible vote allocation, Weyl's Quadratic Voting provided a rigorous mathematical framework, and the *Samfundssind* model links voting power to an individual's commitment to the common good, collectively informing EC2's results-driven exploration of democratic innovations.

Together, these models exemplify EC2's core insight: that voting is not a fixed ritual, but a programmable interface—a social technology whose performance can be analyzed, improved, and adapted to the complexity of modern democratic life.

3.3 Gravitas, Altruism, and the Physics of Cooperation

The EC2 project introduces a novel theoretical framework to understand democratic influence and cooperation by borrowing concepts from physics and information theory. At the center is the notion of Gravitas—a mathematically grounded measure of the causal weight of individual contributions to collective outcomes.

The name of this concept is inspired by analogies to mass in general relativity: just as mass distorts spacetime, informational relevance distorts the decision landscape. Gravitas is operationalized using Fisher Information and weak values from quantum measurement theory. These tools quantify the degree to which an agent's signal—such as a vote or expressed preference—alters the probability distribution of collective outcomes.

This formalization serves two key purposes:

1. It enables a computational definition of civic influence based on measurable impact within a decision system.
2. It provides, hypothetically, a natural pathway for the emergence of cooperation or "mutualism." Under certain structural conditions—such as quadratic cost mechanisms or information-sensitive payoff functions—we theorize that agents who act with higher Gravitas tend to converge toward more socially optimal or cooperative behavior.

The above process gives rise to what the EC2 team calls emergent altruism: the natural result of systems optimized for influence-efficiency rather than dominance.

EC2 thus reinterprets foundational political concepts—voice, influence, altruism—not as normative ideals but as emergent features of appropriately tuned institutional architectures. These dynamics are not assumed; they are tested and simulated in computational environments built to reflect real-world constraints, cognitive biases, and data structures.

3.4 Simulation Architecture and Gravitas Integration

While theoretical innovation is critical, EC2's distinctive contribution lies in its ability to operationalize democratic models as dynamic, testable systems. The simulation framework is designed to integrate theoretical insights—ranging from social choice theory to quantum-preprocessed influence weights—within modular agent-based environments. This enables comparative evaluations of institutional designs with a level of detail and realism beyond traditional political theory. Although quantum formalisms inform the derivation of initial influence weights, the simulation itself runs entirely classically. This modular architecture allows EC2 to test quantum-inspired fairness effects without requiring entangled-state dynamics during runtime.

Modular Simulation Design: The EC2 simulation platform is composed of discrete modules, each corresponding to a core function of democratic systems:

- *Preference Aggregation Modules:* Implement a variety of voting rules—First-Past-the-Post, Condorcet, Qualitative Voting, and Quadratic Voting—allowing direct comparisons under controlled conditions.
- *Agent Cognition Modules:* Model rationality, bounded reasoning, and learning based on behavioral economics, Bayesian inference, and neuroscience.
- *Gravitas Computation Layers:* Incorporate fairness-optimized voting weights calculated via quantum preprocessing techniques—specifically, Two-State Vector Formalism (TSVF) and ABL-inspired logic. These weights are assigned during simulation initialization, eliminating the need for a runtime quantum-classical interface while enabling influence-sensitive feedback dynamics.

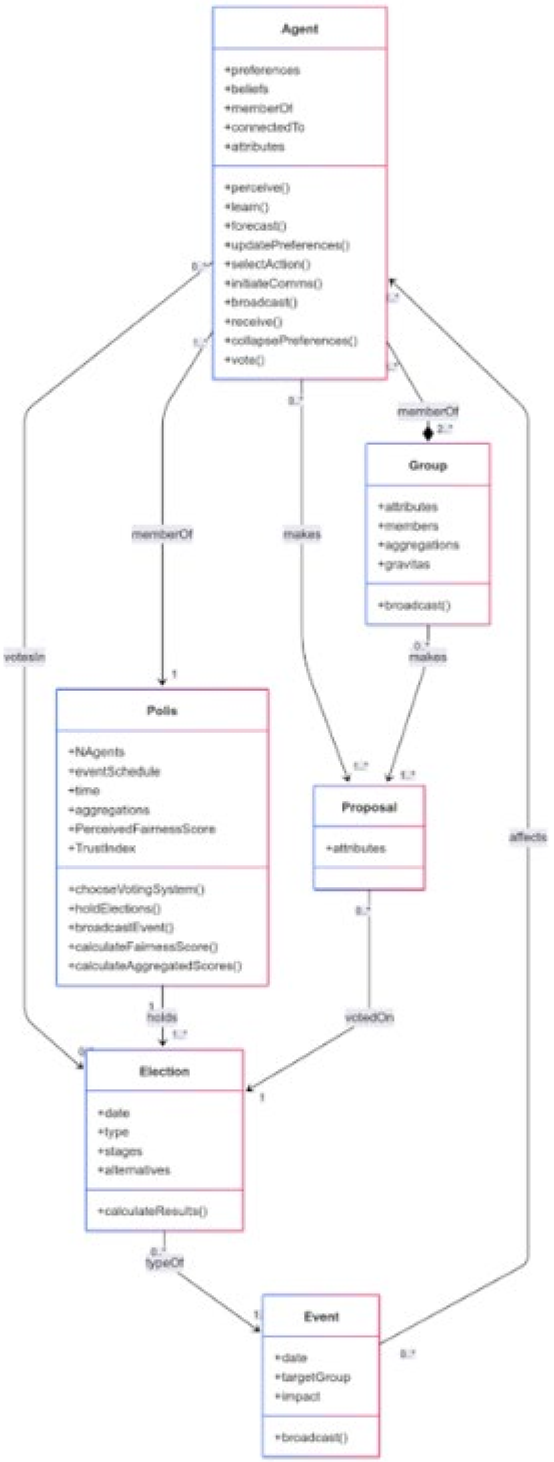

Figure 1: EC2 Domain Model

Synthetic Populations and Empirical Grounding: To ensure empirical plausibility, EC2 uses real-world data and synthetic population models tuned to demographic, economic, and political variables. The platform adheres to FAIR principles for data stewardship and is designed to integrate with the European Open Science Cloud (EOSC).

3.5 Active Inference and Cognitive Modeling

To realistically simulate democratic behavior, EC2 incorporates recent advances in cognitive modeling, especially those grounded in neuroscience and machine learning. At the core of this effort is Karl Friston's **Free Energy Principle**, which posits that cognitive systems operate by minimizing surprise (or "free energy") through a continuous process of prediction, inference, and adaptive behavior.

Agents as Inference Engines: In the EC2 simulation environment, each agent is not a static preference-holder but a dynamically updating inference system. Agents anticipate the likely consequences of actions, assess discrepancies between expected and observed outcomes, and revise their beliefs accordingly.

This process—called **active inference**—enables the modeling of real-world political behaviors such as:

- Learning from civic feedback
- Shifting preferences after debate or deliberation
- Imitating peers under uncertainty
- Withdrawing or re-engaging based on perceived efficacy

This approach allows EC2 to encode:

- Epistemic uncertainty: How sure an agent is about its environment or beliefs
- Policy selection: Which actions are expected to reduce future uncertainty or cost
- Social simulation of deliberation: Where agents recursively model others' beliefs and simulate group-level dynamics

Why This Matters: Standard agent-based models often treat preference change as exogenous or random. By contrast, active inference allows EC2 to simulate belief formation and revision as a rational, adaptive process. This shift is essential to studying:

- How political polarization emerges and recedes
- How consensus may self-organize under information constraints
- How institutional feedback loops amplify or dampen civic participation

This cognitive realism is foundational to EC2's larger hypothesis: that voting systems must be designed not only for fairness or efficiency, but for how actual minds behave in collective settings.

The domain model defines the core entities and relationships of the EC2 simulation architecture. Individual *Agents* form preferences, update beliefs, interact through communication, and cast votes. Agents belong to *Groups*, which serve as aggregation nodes for collective attributes and influence (*gravitas*). *Proposals* are generated by agents or groups and voted on during *Elections*, which are orchestrated within the broader *Polis* environment that manages events, scheduling, and system-level metrics such as fairness and trust. *Events* introduce exogenous shocks affecting agent states and system dynamics. This modular structure supports flexible experimentation across classical, quantum, and active inference models.

3.6 Synthetic Populations and Empirical Testbeds

While EC2 is grounded in formal theory and simulation, its commitment to empirical realism is equally foundational. To bridge the gap between conceptual models and actionable insights, the project builds synthetic populations and collaborates with a local government (Aarhus, Denmark) and a private organisation (QuantumBasel) for real-world validation.

Synthetic Populations: EC2 creates high-resolution artificial societies calibrated to actual demographic, economic, and political distributions. These synthetic populations:

- Reflect real-world variation in age, income, education, ideology, and civic behavior
- Enable controlled testing of voting rules across population segments
- Support counterfactual analysis (e.g., "What if city X had used Quadratic Voting?")

This strategy addresses the challenge raised in the Horizon call: how to do rigorous social science when data access is constrained by privacy law, noise, or availability. Synthetic populations solve this by preserving statistical fidelity while avoiding personally identifiable data.

Data Governance and FAIR Principles: EC2 commits to GDPR-compliant data stewardship by adhering to FAIR principles (Findable, Accessible, Interoperable, Reusable). All synthetic datasets are generated and stored in formats that support:

- Open reproducibility
- Integration with the European Open Science Cloud (EOSC)
- Modularity and customization for future policy scenarios

Empirical Testbeds: Aarhus and Basel: To ensure the models are more than academic abstractions, EC2 partners with two innovation-minded organisations (Aarhus city and QuantumBasel) willing to experiment with collective decision process design. These sites potentially provide:

- Participatory budgeting forums
- Citizen assemblies and deliberative panels
- Digital and in-person voting contexts

Within these testbeds, EC2 pilots key features such as:

- Quadratic Voting allocations
- Altruism-based influence metrics
- Cognitive models of voter attention and dropout

These experiments provide a crucial feedback loop: insights from testbeds are re-integrated into simulation design, allowing iterative refinement and external validity.

From Models to Impact: This combination—synthetic internal testing and live civic deployment—positions EC2 to move beyond speculative theory. It is a methodological architecture designed not only to **describe** democratic systems, but to intervene in them, ethically and experimentally.

3.7 Quantum Foundations and the Symmetry of Plurality

The EC2 project draws on interdisciplinary insights, including a recent convergence between quantum mechanics and social choice theory proposed by Michal Fabinger, Michael Freedman, and Glen Weyl. In their 2022 paper *Prospecting a Possible Quadratic Wormhole Between Quantum Mechanics and Plurality*, the authors show that, in the context of optimal funding, certain quantum game-theoretic problems are mathematically equivalent to classical game-theoretic problems with stochasticity, and that there exists a limit in which this setting approaches the original Quadratic Funding (QF) mechanism.

For EC2, this insight supports a foundational hypothesis: that voting systems can be engineered to reflect deep physical principles of coherence, symmetry, and optimization. Rather than treating democratic processes as socially arbitrary, EC2 sees them as structures that—like physical systems—can be tuned for efficiency, stability, and emergent cooperation.

This perspective strengthens EC2's ambition to circumvent limitations such as Arrow's Impossibility Theorem, not by breaking its logic, but by changing its assumptions—especially around how preference is represented, encoded, and aggregated. In this view, quantum-inspired frameworks become tools for designing new civic mechanisms, where democracy is not a fragile compromise, but a dynamic equilibrium rooted in both logic and physics.

4. Methodological Architecture

The EC2 project is built on a robust and interdisciplinary methodological framework that draws together tools from CSS, ABM, and small-scale empirical research. Our approach aligns with the Horizon Europe call's emphasis on methodological innovation, interdisciplinarity, and data ethics—especially the need to bridge CSS with broader traditions in the social sciences and humanities.

4.1 Computational Social Science as Integrator

Computational Social Science serves as the foundational integrator for EC2's theoretical and empirical ambitions. It enables the rigorous modeling of complex social processes using tools that were traditionally reserved for the natural sciences.

- Statistical physics, network theory, and machine learning provide tools for detecting patterns, modeling diffusion processes, and exploring the conditions under which coordination, cooperation, and polarization emerge.
- Agent-based modeling (ABM) offers a flexible framework for simulating interactions among heterogeneous agents—each equipped with cognitive, social, and strategic dimensions.
- We bridge these quantitative approaches with interpretive methodologies from the social sciences and humanities, allowing for theoretical nuance, historical sensitivity, and normative depth. This interface ensures that formal models are not detached from real-world complexity or ethical reflection.

EC2 also emphasizes synthetic data generation as a critical strategy for circumventing the limitations of sensitive or inaccessible datasets. These datasets are developed under the FAIR data principles (Findable, Accessible, Interoperable, and Reusable) and are fully GDPR-compliant, ensuring ethical rigor in all data handling. In this way, EC2 addresses both the analytical promise and regulatory challenges of data-driven social science.

4.2 Agent-Based Modelling and Participatory Simulation

ABM is the core tool for simulating institutional alternatives under EC2. Unlike top-down models, ABM allows for bottom-up emergence of macro-level patterns from individual behavior. This is essential for analyzing democratic processes, where micro-level actions (votes, discussions, preferences) collectively shape large-scale outcomes (policy, governance, stability).

- Real-world deployment sites serve as empirical laboratories for small-scale democratic experimentation. Citizen assemblies, participatory budgeting, and local referenda provide environments to test the outcome of the most interesting and effective EC2 simulation results.
- These environments allow us to simulate and evaluate counterfactual institutional scenarios—What if Aarhus used Quadratic Voting? What happens to polarization under an adaptive voting system?—under both micro (individual preference shifts) and macro (collective cohesion, efficiency) lenses.
- Our modeling is informed by the empirical and conceptual frameworks developed by consortium partners Iza Romanowska (agent-based modeling in archaeology and complex systems) and Jan Lorenz (opinion dynamics, social cohesion, and bounded confidence models). Their approaches ensure that ABMs remain empirically grounded, computationally rigorous, and socially meaningful.

4.3 Empirical Anchoring and Data Governance

EC2's simulation and modeling efforts are anchored in real-world demographic, economic, and attitudinal data—either directly accessed through partner collaborations or generated as synthetic populations. These populations are calibrated to reflect key social variables (e.g., age, income, tax bracket, ideology, digital behavior) and used in iterative simulation loops.

To further address challenges in data accessibility and privacy in simulated environments:

- We engage with EOSC (European Open Science Cloud) infrastructures and other European Research Infrastructures to ensure that data is interoperable, accessible, and reusable beyond the EC2 consortium.
- Our data management strategy is designed with a long-term perspective, contributing to the development of ethical data use standards in experimental democratic research, particularly through the integration of synthetic data, privacy-preserving simulations, and transparent AI governance.
- Synthetic populations are generated using LLM-driven methods, with human-in-the-loop oversight and bias detection protocols applied to ensure that synthetic data reflects realistic diversity while safeguarding against distortion or misuse.
- Data processing activities, including synthetic data use and real-world pilot data handling, are governed by the EC2 Data Management Plan (D1.2), with compliance monitored by the Data Protection Officer (AU) and the Ethics Lead (EISM), in alignment with GDPR and research ethics requirements.

4.4 Language Model Integration Strategy

Large Language Models (LLMs) play a supporting role in the EC2 simulation architecture. Their primary function is to enrich the contextual grounding of agent-based models by generating structured synthetic data, simulating naturalistic communication, and enabling cognitive diversity. Unlike the quantum and active inference modules, LLMs do not introduce new voting logics or decision frameworks, but instead enhance the plausibility and diversity of agent inputs, discourse patterns, and environmental stimuli.

Core Integration Functions

LLMs will be integrated into the simulation in the following key capacities:

1. *Proposal and Scenario Generation:* Policy proposals, ballot options, and deliberative prompts will be seeded using LLM outputs to ensure linguistic plausibility and contextual nuance. This allows the simulation to test framing effects and narrative variation.
2. *Communication Simulation*: LLMs will model agent-to-agent and group communications, capturing rhetoric, influence, misinformation, and discursive alignment. This supports the simulation of opinion dynamics, polarization, and trust formation.
3. *Framing and Belief Perturbation:* By presenting semantically distinct framings of identical proposals, LLMs allow the system to model how surface language affects preference evolution, strategic voting, and group dynamics.

Design Considerations

- *Offline vs. Runtime Use:* Most LLM tasks will be handled during pre-simulation setup or between episodes, to ensure deterministic and reproducible outputs. Runtime use may be explored in constrained scenarios for communication modeling.

- *Prompt Templates and Constraints*: Prompt engineering will be standardized and documented, with constraints to ensure consistency, avoid bias, and maintain interpretability.
- *Validation and Grounding*: Outputs will be benchmarked against known survey data, polling results, and media corpora to ensure alignment with empirical plausibility.
- *Modular Implementation*: LLM components will interface with the simulation engine through structured I/O wrappers and JSON-based payloads, enabling modular replacement and scenario-specific customization.

Link to WP6 and Deliverable D6.1

The initial demonstration of LLM integration will be delivered as part of D6.1: LLM Proof of Concept, due Month 8. This will include:

- A small-scale agent population generated via LLMs,
- Sample proposals and framings,
- Observed variation in voting behavior or belief update patterns.

This deliverable will guide future iterations of LLM use and serve as a design template for integrating generative models into agent-based political simulations.

4.5 Normative Objectives for Electoral Systems

To guide the design, interpretation, and evaluation of simulations and experiments conducted in EC2, we identify a set of normative objectives that electoral systems should satisfy. These criteria reflect theoretical insights from social choice theory, cognitive science, political philosophy, and quantum-informed fairness logic. They serve as evaluation benchmarks for comparing voting mechanisms, institutional configurations, and agent behavior within the EC2 simulation environment.

Desirable Normative Objectives

1. *Representation Fidelity:* Electoral outcomes should accurately reflect the underlying distribution of individual and group preferences within the electorate, including the perspectives of minority populations and non-majoritarian clusters.

2. *Fairness and Equity:* Voting systems should minimize structural biases and promote equitable influence, ensuring that decision-making power is not disproportionately allocated based on arbitrary or unearned attributes such as socioeconomic status, geography, or group identity.

3. *Resistance to Strategic Distortion*: Electoral mechanisms should be designed to limit the effectiveness of insincere voting, manipulation, or preference misrepresentation aimed at distorting collective outcomes for individual advantage.

4. *Cognitive Accessibility and Expressivity:* Electoral processes must accommodate cognitive diversity and enable agents to meaningfully express preferences, including uncertainty or intensity, without excessive technical or conceptual barriers to participation.

5. *Robustness to Polarization and Fragmentation*: Voting systems should demonstrate resilience against societal polarization, supporting mechanisms that reduce the likelihood of systemic division and facilitate convergence in beliefs, preferences, or outcomes under conditions of disagreement.

6. *Trust and Perceived Legitimacy:* The electoral process and its results should be experienced by participants as fair, transparent, and procedurally sound, fostering compliance and acceptance even among those whose preferred outcomes do not prevail.

7. *Dynamic Responsiveness:* Electoral systems should possess the capacity to adapt to evolving social preferences, emerging political issues, and exogenous shocks, enabling democratic governance to remain responsive and contextually relevant over time.

8. *Context-Dependent Application of Arrow's Fairness Criteria*: Foundational fairness principles articulated by Kenneth Arrow—including universality, non-dictatorship, and Pareto efficiency—will be applied as appropriate to specific simulation scenarios and institutional configurations, recognizing that no single voting system can satisfy all fairness conditions simultaneously under all circumstances.

Operationalization in Simulation

Each of these criteria will be translated into measurable simulation metrics, including but not limited to: preference-outcome alignment, trust scores, polarization indices, agent dropout rates, fairness indicators (e.g., influence vs. contribution ratios), and decision efficiency. These normative goals form the evaluation framework that links simulation design (Section 4.1–4.3), agent behavior (Section 5), and policy implications (Section 7).

5. Use Cases and Prototypes

The EC2 project is committed to practical validation through real-world experimentation. Beyond theoretical refinement and computational modeling, our goal is to produce actionable insights and scalable democratic innovations. This section outlines the concrete environments in which our prototypes will be deployed, the types of institutional changes we will explore, and the conditions for scaling these innovations across diverse European contexts.

5.1 Initial Pilots in Small-Scale Civic and Industrial Forums

Our first set of real-world interventions will be piloted in small-scale civic and private sector forums, using the natural contexts in which they make collective decisions.

These pilots are designed to:

- Provide empirical validation of our agent-based models and institutional simulations.
- Enable citizen co-creation of new decision-making protocols, such as modified voting rules or deliberative structures.
- Generate ethically collected, GDPR-compliant data for ongoing refinement of our synthetic models.

By working closely with our piloting partners, these early use cases provide both the testing ground and feedback mechanism for institutional innovation.

5.1.1 Leveraging Aarhus's November 2025 Election for Pilot Preparation

The city of Aarhus, EC2's central governmental partner, will hold municipal elections in November 2025, presenting a timely opportunity to advance the project's empirical and cultural groundwork. While the EC2 Operational Board has unanimously agreed that a full-scale pilot during this election would be premature—given the need for further refinement of Quadratic Voting (QV) protocols, voter education, and technical infrastructure—the consortium is committed to leveraging this election cycle to prepare both technically and socially for future pilots.

In particular, the consortium recognizes the relevance of the Danish cultural principle of *Samfundssind*, which embodies the expectation that individuals strive to be useful and contribute positively to society. This principle provides fertile ground for democratic innovations like QV, which depend not only on technical validity but also on social norms that emphasize responsibility, cooperation, and meaningful participation.

Building on *Samfundssind*, EC2 will design pre-pilot activities that go beyond technical preparation to align with local values. Planned activities include:

- Collecting anonymized voter behavior data to inform the construction of realistic synthetic population models.
- Conducting citizen and stakeholder workshops that frame QV and emergent altruism within the Danish tradition of contributing to the common good.
- Testing communication strategies that resonate with citizens' sense of usefulness and social responsibility, enhancing both understanding and acceptance of new democratic mechanisms.

These efforts, currently under development, align with EC2's iterative approach to democratic experimentation and ensure that future pilots are not only technically robust but also culturally legitimate and socially embedded. Specific plans will be detailed in upcoming deliverables, reflecting the consortium's commitment to both empirical rigor and community alignment.

The Added Value of Samfundssind for EC2 Simulations, Algorithms, and Democratic Scalability

Samfundssind offers more than a cultural backdrop—it provides a measurable behavioral principle that EC2 can rigorously formalize, simulate, and test within computational models of democracy. Denmark's consistent ranking among the world's happiest, most cohesive, and most resilient societies is not treated here as a vague sociological observation, but as an empirical phenomenon open to algorithmic investigation. EC2 will apply mathematical tools—including agent-based modeling, gravitas weighting, and preference aggregation algorithms—to explicitly test how civic norms like *Samfundssind* influence cooperation, trust formation, and democratic stability.

By translating this principle into quantifiable behavioral parameters—such as an agent's propensity for useful action, preference for public goods, or sensitivity to emergent altruism—EC2 can isolate the causal pathways through which cultural factors shape democratic outcomes. This allows us not only to replicate the Danish experience in silico but to interrogate its mechanisms with scientific precision.

Moreover, the project does not treat *Samfundssind* as unique to Denmark or culturally static. Rather, EC2 uses computational experimentation to explore the *scalability* of this principle to other democracies. Through synthetic population models, preference aggregation simulations, and adaptive algorithm design, the project assesses how variants of civic usefulness and cooperative norms might emerge or be incentivized across different cultural, institutional, and historical contexts.

In this way, EC2 offers a scientifically grounded pathway to generalizing lessons from Denmark's democratic success. By embedding culturally aware but computationally universal models into its simulations, EC2 demonstrates that democratic innovations—such as Quadratic Voting and gravitas-sensitive governance—can be both locally legitimate and globally scalable. This fusion of algorithmic rigor with cultural sensitivity is essential for designing adaptive democracies capable of addressing complexity, fostering cooperation, and enhancing collective well-being worldwide.

By harnessing *Samfundssind* as a cultural and behavioral anchor, EC2 aims to test whether Razo's competitive cooperation model (section 3.2), which rewards contributions to the common good with proportional voting influence, can replicate Denmark's social success in fostering trust, cohesion, and happiness. If validated through simulations and pilots in Aarhus and QuantumBasel (section 5.1), this model could serve as a transformative blueprint for global democratic innovation, scalable to less homogeneous societies. Such an outcome would position EC2 as a milestone in human governance, redefining democracy as a dynamic system that aligns individual incentives with collective well-being, leveraging quantum-inspired analyses (section 3.7) to optimize fairness and sustainability across diverse cultural contexts.

5.2 Electoral Rule Experimentation and Deliberative Model Testing

A central focus of EC2's empirical agenda is testing novel voting and deliberation mechanisms in controlled but real-world settings.

Specifically, we will:

- Prototype and test Quadratic Voting mechanisms—initially in advisory decision contexts—to assess impacts on preference aggregation, minority representation, and satisfaction.
- Compare these outcomes with those from Qualitative Voting schemes and majoritarian baselines.
- Evaluate deliberative enhancements, such as structured feedback loops, preference clarification interfaces, and rotating moderation systems, to study the dynamics of information updating and belief convergence.

These tests will draw on established methods from deliberative democracy, experimental political science, and computational sociology, ensuring both methodological rigor and relevance to current democratic challenges.

5.3 Pathways to Scaling and Replicability in Other European Contexts

Scalability is not merely a technical problem—it is a social, institutional, and epistemic challenge. EC2 is designed from the outset to ensure its models and methods are adaptable across geographies, demographics, and governance regimes.

To this end, we will:

- Produce modular toolkits (e.g., open-source voting platforms, ABM frameworks, policy design templates) for deployment in other cities and civic environments.
- Develop scaling protocols based on simulation testing: before any large-scale intervention, proposed changes will be evaluated in simulations using context-specific synthetic populations.
- Collaborate with other European municipalities and democratic innovation hubs to build a transnational testing network for experimental governance.

Through these strategies, EC2 positions itself not only as a project of discovery, but also as a platform for democratic replication, adaptation, and transformation.

6. Democracy as Evolvable Design

6.1 From static institutions to adaptive, testable systems

Traditional models of democracy assume fixed constitutional structures and procedural norms. However, the EC2 project reconceptualizes democratic institutions as adaptive systems—ones that can evolve in response to social complexity, technological shifts, and empirical feedback. By treating democratic mechanisms as hypotheses rather than dogmas, EC2 promotes institutional experimentation grounded in real-world data, computational simulation, and iterative public engagement.

6.2 The role of design, diversity, and redundancy in political systems

In systems engineering and biological evolution, robustness often arises from design principles such as modularity, functional redundancy, and distributed adaptation. EC2 applies these insights to democratic governance. Rather than relying solely on one-size-fits-all procedures (e.g. majority rule), the project explores mechanisms—like Qualitative and Quadratic Voting—that allow for diverse input channels and layered modes of aggregation. This fosters institutional resilience and responsiveness across different social and cultural contexts.

6.3 Democracy as a form of distributed intelligence

Democracy is not merely a normative aspiration but an epistemic process: a way for societies to process information, weigh competing values, and generate adaptive responses. Drawing from fields such as statistical physics, information theory, and cognitive science, EC2 frames democracy as a form of distributed intelligence. This reframing allows us to see voting not as the final step in decision-making, but as one cognitive layer within a broader architecture of deliberation, simulation, and feedback. In this view, democracy becomes a testable, improvable process—one that can evolve in tandem with human needs and scientific understanding.

7. Policy Recommendations and Next Steps

7.1 Synthetic and critical policy pathways for democratic renewal

While the EC2 project is at an early stage, its interdisciplinary foundation offers a platform for identifying key leverage points in democratic governance. Our initial hypotheses suggest that institutional design exploration, particularly in electoral mechanisms, can play a role in reducing polarization and increasing trust in democratic processes. Mechanisms such as Quadratic Voting, Qualitative Voting, and others merit structured policy exploration as part of a broader toolkit of adaptive democratic instruments. These should be introduced not as silver bullets, but as experimentally testable alternatives within controlled and participatory environments.

Moreover, EC2 proposes that the notion of voting as infrastructure be rethought: democratic mechanisms must evolve as societies do and should be treated as designable systems subject to iterative refinement, rather than static constitutional artifacts.

7.2 Guidance for future research and governance integration

To ensure rigorous impact, the project will produce transferable simulation templates and empirical methodologies for cities and institutions interested in experimenting with democratic innovation. Aarhus and Basel, as early testbeds, will inform frameworks for public sector and industry engagement, ethical safeguards, and citizen-centered co-design.

Future research should:

- Prioritize synthetic data methodologies that respect GDPR constraints while enabling high-resolution political modelling.
- Integrate CSS with critical interpretive approaches to ensure both technical robustness and democratic legitimacy.
- Create multilingual, modular simulation environments deployable across the EU.

EC2 also advocates for an emergent research-policy interface—an iterative dialogue where empirical findings feed into policy adaptation and vice versa.

7.3 Contribution to EU strategic autonomy in democratic innovation

A key ambition of EC2 is to support European leadership in democratic systems innovation. In a geopolitical context of rising autocracy and digital manipulation, democratic governance must become more robust, more transparent, and more intelligent. The project's agent-based simulation tools, data governance models, and institutional design insights can contribute to Europe's strategic autonomy—not only in technology, but in democracy itself.

By offering scalable, open-source, and ethically grounded tools, EC2 helps position the EU as a normative innovator in the future of participatory governance.

Glossary of Key Terms

1. **Quadratic Voting** - A voting system where voters allocate votes to show preference strength, with each additional vote costing more, encouraging thoughtful choices. EC2 tests it for fairer decisions.
2. **Qualitative Voting** - A method where voters distribute points across options to express preference intensity, used in EC2 to compare with Quadratic Voting.
3. **Computational Social Science -** A field using data and computer models to study human behavior, guiding EC2's democratic system designs.
4. **Agent-Based Modeling** - Computer simulations of individual actions to predict group outcomes, used in EC2 to test voting systems.
5. **Synthetic Populations** - Artificial datasets mimicking real demographics, used in EC2 to test voting while protecting privacy.
6. **Gravitas** - A measure of a voter's influence on group decisions, based on their vote's impact, inspired by physics.
7. **Emergent Altruism** - Cooperative behavior arising naturally from optimized voting systems like Quadratic Voting in EC2.
8. **Active Inference** - A model of how people update beliefs based on new information, used in EC2 to simulate voter behavior.
9. **Free Energy Principle** - A theory that brains minimize surprise, guiding EC2's voter behavior simulations.
10. **Quantum Social Choice** - Applying quantum mechanics ideas to voting, explored in EC2 to improve decision-making.
11. **Quantum Quadratic Voting** - An advanced Quadratic Voting model using quantum concepts, studied in EC2.
12. **FAIR Principles** - Rules (Findable, Accessible, Interoperable, Reusable) for ethical data use, followed in EC2's data management.
13. **European Open Science Cloud** - An EU platform for sharing research data, used by EC2 for open data access.
14. **Arrow's Impossibility Theorem** - A theory showing no voting system meets all fairness criteria, challenged by EC2's innovations.
15. **Two-State Vector Formalism -** A quantum technique for calculating voter influence weights, used in EC2 simulations.
16. **Fisher Information -** A statistical tool measuring a vote's impact, used in EC2 to define gravitas.
17. **Co-Design Workshops** - Collaborative sessions with citizens and officials to design voting systems, planned in EC2's Aarhus pilots.
18. **Participatory Budgeting** - A process where citizens decide budget allocations, a context for EC2's voting pilots.
19. **Computer Simulations** - Virtual tests of voting scenarios, used in EC2 to compare Quadratic Voting with traditional methods.