1. Research Plan for Ph.D. Qualifying

Research Title

Multi-Device Web Artwork: A Semantic and Modular Framework for Interactive Systems Art
Able

Keywords:

Multi-Device Web Artwork, Systems Art, Interactive, Semantic, Modular, Intearctive Taxonomy, State-based Architecture, Dimensional Transformation, Parametric Interface, Interaction Design, New Media Art, Computational Art, Research-through-Exhibition, Practice-based Research

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Relevance to Design

The often-cited difference between art and design is that art is mainly artist/creator-oriented, while design is heavily user-oriented. Artwork tends to be more subjective as it is created by the artist's own intent, while designed products and artefacts tend to be relatively more objective as they consider users using the product. Interactive art, however, requires audience participation by its definition, and thus occupies an ambiguous space beyond such traditional art-versus-design dichotomy.

Since interactive art cannot fully exist without users, substantial design considerations are essential to enhance their engagement. Although the ultimate goal of interactive art may not be design-oriented—that is, it may not aim to solve tangible problems or match users' needs—once the artist sets an inward, artist-centred vision, the work should still be deliberately designed to deliver that purpose. Thoughtfully crafted interactive art therefore embodies a strong design dimension, serving the artist's intended message. By treating each interactive modality as an experimental 'ingredient', artists can extend their practice beyond conventional forms of interactive art. Thus, while interactive art might be art-oriented in purpose, its invention and proposal of novel structures can be heavily grounded in design.

Especially within computational interactive art, carefully crafting an interactive experience based on Human-Computer Interaction (HCI) considerations and findings is crucial. Despite this, most contemporary interactive art practices focus on a limited range of interactions and interactive design considerations, resulting in a significant gap between academic HCI findings and current artistic practices. Successful computational interactive artworks, such as Rafael Lozano-Hemmer's large-scale relational architecture (1999), Jordà et al.'s Reactable Tabletop DJ interface (2008), or Christopher Bauder's interactive tone-generating ladders (2021), actively invite and motivate user engagement. However, many of these works still rely on bodily interactions and produce primarily audio-visual effects, leaving a more diverse scope of interactive taxonomies, and potentially unexplored semantic interactions.

Focusing on Systems Art and multi-device artworks, both subsets of interactive art, this research integrates interaction design and HCI findings into artistic practice. Specifically, it establishes a design-oriented framework for Multi-Device Web Artwork (MDWA), a key term introduced in this research. Rather than remaining purely theoretical, this research empirically validates the framework through the creation and exhibition of three distinct MDWA series, demonstrating its practical application and effectiveness in practical contexts. Although each artwork may differ in context, a comprehensive design-research framework is necessary to achieve the systematic qualities these forms aspire to.

Methodologically, this research adopts a Research-through-Exhibition strategy, integrating research-through-design with the practice-based methods of fine arts. Rather than ending with a preliminary design prototype, as in many research-through-design processes, the work here extends the artefact into a real exhibition setting, where a broad audience can interact with it. Further details on these frameworks and design considerations will be discussed in Chapter §2.2.3.

Research Aims

Aim 1. To clarify the gap between conceptual ideals and current practices in Systems Art and Multi-Device Artworks. To introduce, define, and propose MDWA as a specific medium within Systems Art, introducing its core interactive, semantic, and modular characteristics.

Aim 2. To develop an interaction design framework for MDWA, by establishing a taxonomy of input-channel modalities. Building on that, to implement a State-based Architecture (SbA) and design a workflow that connects these inputs into outputs via Dimensional Transformation (DT).

Aim 3. To implement the design framework through the creation of three distinct series of MDWAs, which contain distinguishable artistic concepts and narrative, based on the established design framework from Aim 2.

Aim 4. To add to the understanding of how MDWA functions as a distinct medium for Systems Art through Research-through-Exhibition (RtE). To empirically assess, via audience interaction data and qualitative feedback, how the MDWA design framework had actively engaged audience interaction within Systems Art.

Background / Theoretical Underpinning / Research Gap / Rationale

Systems Art, originating from the 1960s, shifted the subject of art from static objects to dynamic processes and relationships, actively referencing cybernetics, information theory, and general systems theory (Burnham, 1968). Focusing on social, ecological, technological, and biological systems, Systems Art often explores complex behaviours and patterns stochastically emerging from the interaction of simpler sub-components.

As contemporary systems become increasingly complex and intertwined, the importance of Systems Art is amplified. Frameworks such as Relational Aesthetics, articulated by Nicolas Bourriaud (2002), highlight art's significance in generating intersubjective relationships and social contexts. This trend is evident in large-scale exhibitions by Philippe Parreno (2024) and Pierre Huyghe (2025), who construct ever-evolving systemic environments within gallery spaces. Actor-Network Theory (ANT) offers another valuable lens, mapping the intricate relationships and translations between human and non-human actors, further situating artistic practice within its broader social-technical and ecological context (Latour, 1996). In a world increasingly defined by complex, invisible, and entangled systems—often referred to as 'hyperobjects' (Morton, 2013)—art retains its unique capability to foster sensory and experiential understanding of these systems. Interactive Systems Art, specifically, holds the potential to move audiences beyond passive spectating, enabling immersion within systemic processes where they can directly observe and potentially change the dynamics of the system itself.

Despite Burnham's vision for Systems Art and its contemporary relevance, a significant gap persists between theoretical ideals and current practices, particularly concerning continuous audience engagement and computationally sophisticated implementations. The ideal, inherited from Burnham (1968) and cybernetic art principles (Ascott, 2003), envisions artworks as ever-evolving systems where audiences actively and dynamically alter the system's behaviour, triggering emergent behaviours within the artwork as a system. However, based on the researcher's current knowledge, there is a notable scarcity of fully realised, algorithmically driven, computationally complex Systems Art that embodies such dynamic interactivity. Many contemporary interactive artworks fail to construct a fully operational system as envisioned by Systems Art pioneers, often due to limitations in interactivity, semantic depth, and modularity. Consequently, this study investigates these existing gaps within interactive art, concentrating on works where audience participation substantively modifies and directly influences the system's behaviour, thereby excluding those where interaction is limited to passive observation.

Gaps in Interactivity, Semantic Depth, and Modularity

Regarding the ***interactive gap***, several Systems Art installations, including those by Philippe Parreno (2024) and Pierre Huyghe (2025), often remain non-interactive or rely solely on passive environmental data integration rather than direct user input. Even with user interaction, activation is often limited to rudimentary functions or linear progression through predetermined scenarios. For instance, Universal Everything's interactive artworks like KinFolk (2024) or Symbiosis (2024) invite audiences to make only minor movements, thereby limiting their ability to change the dynamics of the artworks. Such limited user agency prevents the kind of engagement where participants can alter the core dynamics and emergent behaviours of the system.

A significant ***semantic gap*** also persists. Opportunities for audiences to engage through semantic modalities—interacting with or through information, language, data, or symbolic representation—remain heavily underdeveloped, especially within many visually-driven interactive art contexts. These artworks often prioritise spectacular physical or sensory input derived from the bodily environment over semantic or informational engagement, a trend evident in Teamlab's installations (2025) or Christopher Bauder's Tone Ladder (2021).

Finally, a critical ***modularity gap*** hinders the realisation of Systems Art's potential for ubiquity and environmental integration, a core aspect of Burnham's (1968) vision also echoed in concepts like Weiser's (1991) ubiquitous computing. Current interactive installations often necessitate specialised hardware, external software (frequently using TouchDesigner or Unity), and specific physical setups, typically confined to a white cube. This reliance on non-standardised, context-specific configurations severely limits accessibility and prevents the modular reuse or adaptation of works across different environments (Garcia Cepeda, 2019).

Research Rationale in MDWA

This research directly addresses these identified gaps by proposing, developing, and evaluating Multi-Device Web Artwork (MDWA) as a specific medium and design-led framework within the context of Systems Art. MDWA proposes a robust, technologically contemporary, and theoretically grounded approach. It aims to actively engage audiences with systematic narratives through dynamic interactivity, semantic depth, and modularity.

To enable audiences to fully experience systems, addressing the ***interactive gap*** is crucial. Thus, this research involves developing an Interaction Taxonomy tailored for MDWA, referencing broader cross-device interaction paradigms within HCI (Brudy et al., 2019), and adapting them for an artistic and exhibition setup. This taxonomy will articulate how established web-based interactions can be combined to propose novel systemic interactions within interactive art. Furthermore, this research introduces **State-based Architecture (SbA)**. Influenced by foundational structures like Statecharts (Harel, 1987), this approach explicitly enables non-linear, user-influenced system dynamics. Unlike traditional linear or simple progressive structures, a state-based model allows the system's current state to flexibly integrate user interactions, thus facilitating emergent behaviours.

Furthermore, this research proposes that the multi-device web structure is suitable for addressing the ***semantic gap*** in interactive art. The web provides an inherently flexible creative medium ideally suited for semantic interaction by natively supporting data exchange, information display, hypertextuality, symbolic communication, and diverse software integration. Despite these advantages, web technologies remain underutilised as creative media within interactive art contexts, with practitioners often favouring specialised Visual Programming Language (VPL) tools like TouchDesigner or Unity. However, this reliance on VPLs is likely to diminish due to two key developments: the increasing accessibility of coding through LLM-assisted tools, and the growing support for WebGL and Three.js on contemporary devices. These advances make semantic engagement design within web environments significantly more accessible. Building on this, the proposed MDWA design framework leverages **Dimensional Transformation (DT)** to efficiently manage semantic interactions that traditional tools struggle to facilitate.

Finally, the web-based nature of MDWA is core to addressing the ***modularity gap***. Utilising standard web technologies ensures broad accessibility via common, everyday devices (computers, mobiles, projectors) without requiring specialised external hardware or software installation. Audiences can potentially join the experience from their own mobiles, conceptually emphasising individual agency within the system. This multi-device approach, prioritising modularity is still under rapid development and exploration within contemporary art practice. The multi-device aspect allows artworks to be deployed across various screens and locations, potentially communicating in real-time. This enables distributed, adaptable, and easily installable experiences that move closer to the ubiquitous computing vision (Weiser, 1991). Importantly, this MDWA framework is designed not only for contemporary devices but also with the potential for modification and generalisation for future interaction modalities, such as Head-Mounted Displays or Brain-Computer Interfaces.

In conclusion, this research contributes to filling the current gaps within Systems Art and interactive art by proposing and developing an MDWA-driven interactive, semantic, and modular framework designed to enhance audience engagement within systemic contexts. This work holds the potential to contribute broadly within transdisciplinary academia and practice communities, including interaction design, interactive and new media art practice, systems aesthetics, and human-computer interaction, thus offering insights relevant to contemporary society and ecology entangled with complex systems.

[Key Glossary]

- **Multi-Device Web Artwork (MDWA):** An artistic medium utilising multiple, web-based computational devices to facilitate interactive, semantic, and modular audience engagement, often delivering Systems Art objectives.
- **State-based Architecture (SbA):** An architectural framework for MDWA that aims to comprehend and design the artwork's system behaviour using interconnected states, thus enabling non-linear, audience-influenced interactive dynamics.
- **Dimensional Transformation (DT):** A process within the MDWA framework that meditates between input/system states and system/output states, combining inter-state mapping and contextual change.
- **Research-through-Exhibition (RtE):** A research methodology integrating Practice-based Research and Research-through-Design, where public exhibition of artworks and real-world audience engagement is central for generating generalisable knowledge and frameworks.

Objectives and Methods (Mapped to Aims)

Aim 1. To clarify the gap between conceptual ideals and current practices in Systems Art and Multi-Device Artworks. To introduce, define, and propose MDWA as a specific medium within Systems Art, introducing its core interactive, semantic, and modular characteristics.	
Objective 1. To research the conceptual ideals of Systems Art and clarify the current gap.	Method 1. ***Literature search*** *on conceptual ideals, related aesthetic theories, and their relation to current practices.*
Objective 2. To research the current practices of Multi-Device Artworks and investigate the current gap.	Method 2. ***Literature and Practical search*** *on the current Multi-Device Artworks practices.*
Objective 3. To introduce, define, and propose MDWA as a specific medium within systems art.	Method 3. ***Conceptual Proposition*** *of MDWA, introducing its core interactive, semantic, and modular characteristics.*
Aim 2. To develop an interaction design framework for MDWA, by establishing a taxonomy of input-channel modalities. Building on that, to implement a State-based Architecture and design a workflow that connects these inputs into outputs via Dimensional Transformation.	
Objective 4. To establish a taxonomy of interactive modalities within MDWA.	Method 4. ***Literature search*** *on broader cross-device interactive taxonomy,* ***establishment*** *of MDWA-specific taxonomy, and* ***development*** *of selective interactive modalities.*
Objective 5. To implement a State-based Architecture within MDWA.	Method 5. ***Literature search*** *on system dynamics and state-based architecture,* ***development*** *of various state-based visual outputs,* ***validation*** *within the exhibition environment.*
Objective 6. To implement and propose a Dimensional Transformation within MDWA.	Method 6. ***Proposal*** *of the conceptual significance of Dimensional Transformation within MDWA, and* ***development*** *of experimental Dimensional Transformations.*
Aim 3. To implement the design framework through the creation of three distinct series of MDWAs, which contain distinguishable artistic concepts and narrative, based on the established design framework from Aim 2.	
Objective 7. Development of the first MDWA, which explores the concept of interactive modalities, state-based architecture, and Dimensional Transformation.	Method 7. ***Research-through-Exhibition*** *on the first MDWA project.*
Objective 8. Development of the second MDWA, which advances the concept of interactive modalities, state-based architecture, and	Method 8. ***Research-through-Exhibition*** *on the second MDWA project.*

Dimensional Transformation.	
Objective 9. Development of the third MDWA, which integrates all design framework components.	Method 9. ***Research-through-Exhibition*** *on the third MDWA project.*
Aim 4. To add to the understanding of MDWA functions as a distinct medium for Systems Art through Research-through-Exhibition methodology. To empirically assess, via audience interaction data and qualitative feedback, how the MDWA design framework had actively engaged audience interaction within Systems Art.	

Stages in Argument

A: Significance of Systems Art and Its Current Research Gap
A1. Systems Art is increasingly significant in contemporary society, which is entangled with complex systems.
A2. However, current Systems Art practices do not sufficiently allow audiences to thoroughly influence the artwork, contrary to Systems Art's ideal vision.
A3. Notably, current Systems Art practices lack in-depth design considerations and research regarding 1) Interactivity, 2) Semantics, and 3) Modularity.
A4. Implementing Multi-Device Web Artwork can introduce a robust design-based framework to address those interactive, semantic, and modular gaps.

B: Significance of Multi-Device Artwork and Its Current Research Gap
B1. Multi-device interactive artworks are becoming more common in both contemporary art and the media/entertainment industries.
B2. Many of these artworks focus on surface-level interaction without deeper attention to 1) Interaction, 2) Semantic context, and 3) Modular design.
B3. This shortfall stems from a lack of in-depth design considerations and research in this emerging medium.
B4. With the integration of Systems Art principles, the presentation of Multi-Device Web Artwork offers a strong design-based framework that can broaden the scope of multi-device interactive art beyond current practices.

C: Introducing Multi-Device Web Artwork
C1. Multi-Device Web Artwork incorporates multiple computational devices within a web environment, enabling diverse, systematic, and semantic audience interaction within a modular setup.
C2. MDWA can address the interactive gap by establishing a taxonomy of interactive modalities and using a state-based architecture to simulate system dynamics.
C3. MDWA can address the semantic gap by introducing a solid workflow that connects interactive modalities with a state-based architecture supported by Dimensional Transformation and a parametric interface.
C4. MDWA can address the modularity gap as its web-based foundation leverages standard web technologies, facilitating distributed, adaptive, and ubiquitous Systems Art.
C5. Through Research-through-Exhibition, this research can show MDWA's effectiveness in bridging the identified research gaps, not just as a theoretical proposition but as substantiated evidence.

Expected Research Outcome

As practice-based research, the primary outcomes will be the creation and public exhibition of three distinct series of Multi-Device Web Artworks (MDWA), supplemented by related experimental pieces. These artworks will serve as tangible, empirically grounded demonstrations of the research concepts, moving beyond purely theoretical propositions. The research methodology fosters a reciprocal development process where the proposed frameworks (Interaction Taxonomy, State-based Architecture, Dimensional Transformation) inform the artworks, and the practical implementation and audience interaction with these artworks iteratively refine and validate the frameworks. This ensures the frameworks evolve as robust, practical tools integrated with real-world applications. The exhibitions themselves are integral to this process, functioning as a core empirical research method (Research-through-Exhibition), extending research-through-design principles into exhibitions beyond the lab setting, inviting hundreds of audiences. In summary, this research anticipates delivering three significant MDWA exhibitions alongside a comprehensive and validated Interactive, Modular, and Semantic framework designed for Systems Art.

Research Schedule

	2024		2025		2026		2027	
	1	2	3	4	5	6	7	8
Aim 1								
Objective 1								
Objective 2								
Objective 3								
Aim 2								
Objective 4								
Objective 5								
Objective 6								
Aim 3								
Objective 7								
Objective 8								
Objective 9								

Bibliography (annotated)

A. Key Philosophical and Conceptual References

Baudrillard, J. (1981). *Simulacres et simulation*. Galilée.

- Baudrillard's postmodern analysis of *Simulacres et simulation* posits a contemporary condition where the distinction between the real and its representation collapses. This concept is pertinent to Systems Art in several ways: firstly, in the artwork's potential to simulate system dynamics. Secondly, and more critically, Systems Art, and by extension MDWA, can engage with the notion that contemporary systems themselves are simulacra. Such artworks might invite audiences to critically examine or even resist these systemic illusions, offering an artistic platform for what might be termed Baudrillardian provocations against pervading simulated realities, thereby exploring the critical messages Systems Art can convey.

Bourriaud, N. (2002). *Relational aesthetics* (S. Pleasance & F. Woods, Trans.). Les Presses du Réel. (Original work published 1998)

- Bourriaud's theory of relational aesthetics prioritises human relationships and intersubjective encounters, a perspective that resonates with Systems Art's emphasis on dynamic processes over static objects. Notably, Bourriaud incorporates terminology from the internet era, such as "user-friendliness" and "interactivity." This creates a strong conceptual linkage to the MDWA research, as 1) MDWA is inherently web-based, 2) MDWA proposes a design-oriented and user-friendly approach to artistic creation, and 3) MDWA centralises interactivity as a core component.

Dostoevsky, F. (1993). *Notes from underground* (R. Pevear & L. Volokhonsky, Trans.). Vintage Books. (Original work published 1864)

- Written amidst post-industrial faith in scientific progress, Dostoevsky's work challenges the supremacy of pure reason. The protagonist's assertion that "2x2=5" can be as appealing as "2x2=4," and his symbolic defiance ("sticking his tongue out") against a "crystal palace" of perfect rational order, underscores the enduring value of non-rational aspects of human existence. This critique aligns with a crucial message for Systems Art: that it should not aim to create perfectly predictable or deterministic systems that reduce human audiences to mere components. Instead, Systems Art, particularly through MDWA, can provide opportunities for audiences to re-evaluate existing systems from alternative perspectives, fostering critical thought about the relationship between the individual and the system, and potentially enabling forms of agency or even rebellion against established systemic norms.

Latour, B. (1996). On actor-network theory: A few clarifications. *Soziale Welt*, *47*(4), 369–381.

- Actor-Network Theory (ANT) conceptualises the world as a series of constantly shifting networks comprising heterogeneous actors, that is, humans, non-humans, and objects. This perspective aligns with the holistic vision of Systems Art. For example, understanding an ecological system through an ANT lens necessitates incorporating not only human-centric views but also non-human and system-centric perspectives. Such an approach resonates with the proposed ubiquitous vision of MDWA, where artworks are not isolated interactive installations but are conceived as potentially embedded within broader socio-technical and ecological domain.

Morton, T. (2013). *Hyperobjects: Philosophy and ecology after the end of the world*. University of Minnesota Press.

- "Hyperobjects" are phenomena that are of human origin yet so massively distributed in time and space (e.g., climate change, global capitalism, nuclear radiation), transcending direct human comprehension and control. This term is highly relevant for articulating the kinds of complex, often invisible, "hyper-systems"—financial, ecological, social, algorithmic—that Systems Art and MDWA aim to engage with.

Nietzsche, F. (1995). *Thus spoke Zarathustra: A book for all and none* (W. Kaufmann, Trans.). Modern Library. (Original work published 1883)

- Nietzsche's allegory of the three metamorphoses of the spirit—the camel, the lion, and the child—offers a pertinent framework for understanding the potential evolution of both interactivity and the narrative aims of MDWA.

  The camel, burdened by established values and slave morality, can represent passive engagement with current interactive art, where audiences conform to pre-determined interactions. The lion, which rebels against these values, signifies a move towards interactive experiences that allow for questioning and resistance against existing systemic structures. The child, embodying innocent creation and affirmation of uncertainty, represents the ultimate goal: an interactive paradigm where audiences can co-create the system itself, leading to emergent dynamics.

  Narratively, Systems Art and MDWA aspire to guide audiences beyond being mere "camels" within dominant systems. They aim to foster the "lion's" critical stance towards flawed established systems and hyperobjects (e.g., financial, economic, ecological). Ultimately, the goal is to inspire the "child's" affirmative power to envision and participate in the creation of new, alternative systemic possibilities, thereby moving from critique to transformative engagement.

Nietzsche, F. (2000). *The birth of tragedy out of the spirit of music* (S. Whiteside, Trans.; M. Tanner, Ed.). Penguin Books. (Original work published 1872)

- Nietzsche's distinction between the Apollonian (associated with form, order, individuation, and visual beauty) and the Dionysian (associated with impulse, chaos, collective ecstasy, and the primal unity of being) provides an essential aesthetic dialectic. While the Apollonian has historically been aligned with the plastic and visual arts, interactive art, though often visual, can profoundly engage Dionysian principles through the act of interaction, embodied experience, and multi-user participation. Crucially, within Systems Art and MDWA, Dionysian experiences can emerge from the sudden, unexpected behaviours of the system—its emergence, collapse, or unforeseen harmonies. The immersive environment created by multiple, interconnected devices can itself evoke a Dionysian sensibility, akin to a harmony. The pursuit of such Dionysian aesthetic achievements, emerging from complex systemic interactions, is a significant aspiration for Systems Art and MDWA.

Taleb, N. N. (2012). *Antifragile: Things that gain from disorder*. Random House.

- Antifragility describes systems that benefit from shocks, volatility, and disorder, as opposed to merely resisting them (robustness) or breaking under them (fragility). Understanding a system's fragility or antifragility by examining its underlying dynamics, rather than relying solely on explicit empirical evidence, is central to systems thinking and gains critical importance when confronting modern complexities. This perspective has significantly influenced the researcher's interdisciplinary approach to communicating complexity and system dynamics through artistic practice.

Taleb, N. N. (2005). *Blackswan: The Impact of the Highly Improbable*. Random House.

- Taleb's "Black Swan" theory highlights the profound impact of highly improbable, unpredictable events that lie outside the scope of normal expectations and predictive models. This notion resonates with Dostoevsky's critique of the "Crystal Palace" and Burnham's foundational ideas for Systems Art, particularly the concept of "emergence." Systems Art, especially when realised through the multi-device configurations of MDWA, can be conceptualised as an ever-evolving, interactive ecological landscape where such "Black Swan" events might stochastically emerge. This can prompt audiences to confront uncertainty as an inherent aspect of complex systems, shifting perspectives from avoidance to engagement, thereby fostering an understanding related to antifragility.

B. Artwork References

Bauder, C. (2021). *Tone Ladder* [Interactive light and sound installation]. Part of Dark Matter: KOLLEKTION, Dark Matter, Berlin, Germany. Retrieved May 17, 2025, from https://en.darkmatter.berlin/tonleiter

- Interactive exhibition where stepping over each ladder creates a dynamic tone. Good example of showing how Instrumental Interaction can form intuitive interaction for audiences. Limited in a sense that it only creates non-semantic, fully phenomenological interaction.

Huyghe, P. (2025). *Liminal* [Exhibition]. Leeum Museum of Art, Seoul, South Korea. Retrieved May 17, 2025, from https://www.leeumhoam.org/leeum/exhibition/85

- Large-scale exhibition depicting an evolving, systemic ecological environment where human and non-human elements hybridise. Explores emergent behaviours and complex systems, audience agency and interaction is highly limited.

Lozano-Hemmer, R. (1999). Utterance 4 relational architecture. *Performance Research*, *4*(2), 52–56.

- An early example of networked participatory art, where user-interacted commands induce the generation of different light patterns. Illustrates "Relational Architecture" by connecting participant action to large-scale urban display, amplifying the user interaction. Yet the interaction is somehow simple and employed technology is outdated.

Parreno, P. (2024). *VOICES* [Exhibition]. Leeum Museum of Art, Seoul, South Korea. Retrieved May

17, 2025, from https://www.leeumhoam.org/leeum/exhibition/76

- Large-scale exhibition depicting computational, algorithmic system where audiovisual elements respond to environmental data and internal logic in real-time. Emphasises emergent aesthetics and the artwork as evolving entity, yet no direct audience influence/interaction is present.

teamLab. (2018–present). *teamLab Planets TOKYO DMM* [Digital art museum]. teamLab Planets TOKYO, Tokyo, Japan. Retrieved May 17, 2025, from https://planets.teamlab.art/tokyo/

- Immersive digital art museum featuring multiple large-scale, body-centric interactive environments, some powered by multi-device web interaction. Prioritises spectacular and intuitive audio-visual feedback triggered by visitor movement, limited user agency and semantics within interaction, user cannot ultimately alter the systematic logic.

C. Academical References

Ascott, R. (2003). *Telematic embrace: Visionary theories of art, technology, and consciousness*. University of California Press.

- Explores foundational concepts of telematic art and connective art, offering insights to networked consciousness and cybernetic principles, related to systemic nature of MDWA.

Brudy, F., Holz, C., Rädle, R., Wu, C. J., Houben, S., Klokmose, C. N., & Marquardt, N. (2019). Cross-device taxonomy: Survey, opportunities and challenges of interactions spanning across multiple devices. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (pp. 1–28). Association for Computing Machinery.

- Provides a comprehensive HCI taxonomy for cross-device interactions. Good starting point for looking for taxonomies proposed within MDWA framework, yet cannot be directly applied for MDWA/artistic context as its basis presents wider/practical scope.

Burnham, J. (1968). *Beyond modern sculpture: The effects of science and technology on the sculpture of this century*. George Braziller.

- A foundational text establishing Systems Art, analysing the shift from object-based art to process-oriented systems. Fundamental for contextualising MDWA within the historical and theoretical lineage of Systems Arts and its ideals.

Cepeda, R. G. (2019). Rescuing new media art from technological obsolescence. *DAT Journal*, *4*(3), 37–46.

- Addresses critical issue of technological obsolescence in new media art, relevant to MDWA's web-based approach and its consideration for modularity.

Harel, D. (1987). Statecharts: A visual formalism for complex systems. *Science of Computer Programming*, *8*(3), 231–274.

- Foundational research on visual formalism for modeling complex reactive systems, offering theoretical underpinning for the State-based Architecture in the MDWA framework, which helps better modeling of Systems Art within MDWA.

Hunt, A., Wanderley, M. M., & Paradis, M. (2003). The importance of parameter mapping in electronic instrument design. *Journal of New Music Research*, *32*(4), 429–440.

- Investigate parameter mapping strategies in electronic musical instrument design, emphasising their role in non-trivial engaging interactions. Informs the concept of Dimensional Transformation within MDWA, particularly regarding how transformation can induce playful interaction within multi-device context.

Jordà, S. (2008). On stage: the reactable and other musical tangibles go real. *International Journal of Arts and Technology*, *1*(3-4), 268–287.

- Discusses the design and performance aspects of tangible music interfaces like the Reactable, highlighting principles of instrumental and collaborative interaction. Provides valuable precedents for MDWA in terms of designing instrumental, engaging, real-time interactive experiences.

Paul, C. (2015). *Digital art* (3rd ed.). Thames & Hudson.

- Broad overview on the history, practices, and theoretical foundations of digital art. General contextual reference for situating MDWA within the wider field of new media and computational art practices.

Weiser, M. (1991). The computer for the 21st century. *Scientific American*, *265*(3), 94–104.

- Articulates the visionary concept of ubiquitous computing, resonating with the MDWA's modular, web-based nature of potentially contributing adaptable, distributed, public art experiences.

2. Critical Study of Literature

This research proposes Multi-Device Web Artwork (MDWA) as a novel approach to designing semantic and modular interactive art, thereby bridging current research gaps within contemporary Systems Art and Multi-Device Art practices. To this end, the present chapter first contextualises MDWA by examining existing System Art, Interactive Art, and Multi-Device Artworks, focusing primarily on the artistic domain (§2.1). Subsequently, the second subsection explores various interdisciplinary theories to clarify the design approach for MDWA, incorporating concepts such as interactive taxonomy, state-based architecture, and Dimensional Transformation, drawing from fields like Interaction Design, HCI, Musical Research, and Systems Dynamics (§2.2). Finally, the third subsection emphasises the Research-through-Exhibition methodology, positioning it at the intersection of Practice-based Research in art and Research-through-Design (§2.3).

Table of Contents: Chapter 2

2.1. Contextualising MDWA: Relevant Art Practices and Theories

This chapter investigates the theoretical roots, historical references, and contemporary examples of Systems Art (§2.1.1), Interactive Art (§2.1.2), and Multi-Device Artworks (§2.1.3).

2.1.1. Systems Art

Building on its 1960s origins rooted in cybernetics, information theory, and general systems theory (Burnham, 1968), Systems Art marked a critical departure from static, object-based art towards dynamic, process-oriented works. This approach inherently engages with the complexities of social, ecological, technological, and biological systems. Pioneering figures like Hans Haacke exemplified this through works such as *Ice Stick* (1966), which engaged with ecological processes, *News* (1969) with social systems, and *MoMA Poll* (1970) with political dynamics. These early examples underscored a focus on complex, emergent behaviours, positioning the artwork not as a finished object but as an evolving entity in dialogue with its context and, often, its audience.

The contemporary relevance of Systems Art is amplified by the escalating complexity and interconnectedness of modern global systems. Recent Large-scale exhibitions in Leeum, such as Philippe Parreno's *VOICES* (2024) and Pierre Huyghe's *Liminal* (2025), demonstrate this by constructing evolving, environment-responsive systemic architectures within gallery spaces. These works attempt to make palpable the intricate, often invisible, and deeply entangled nature of the systems we inhabit, echoing concepts like Morton's "hyperobjects" (2013) – entities so vast and complex they challenge direct comprehension. A core tenet of Systems Art, therefore, is its assertion that the whole system generates effects and meanings that transcend the mere aggregation of its nindividual parts; that the perceived "objects" are manifestations of larger, ceaselessly evolving dynamics.

Despite such compelling explorations of systemic representation, a persistent gap exists between the conceptual ambitions of Systems Art and the interactive depth realised in many contemporary practices. The vision, influenced by cybernetic art principles (Ascott, 2003), is one of artworks as fully operational, automated systems that actively respond to audience interaction, thereby fostering emergent behaviours and allowing participants to palpably influence the system's trajectory. However, many current examples often fall short of enabling this level of profound, audience-driven systemic alteration. This highlights a crucial opportunity for computational interactive art to serve as a medium to more fully realise the foundational ideals of Systems Art, particularly in fostering meaningful and transformative audience engagement.

2.1.2. Computational Interactive Art

2.1.2.1. Literature on Computational Interactive Art

Although all art arguably involves spectator engagement, this research specifically addresses computational interactive art, where audience participation directly alters the artwork itself through computational methodology. A foundational concept here is a creative process wherein audience interaction is “amplified or superseded by the computer” (Cornock & Edmonds, 1973). Cornock and Edmonds further proposed a taxonomy of such artworks based on the audience’s role within the interactive situation, ranging from 'Static System' and 'Dynamic-passive System' to more complex 'Dynamic-Interactive System' configurations and 'the Matrix'.

Building upon such early frameworks, subsequent literature has explored various facets of computational interactive art. Different approaches to designing interactive art systems and the evolving role of interaction have been discussed (Edmonds et al., 2004). Additionally, the dynamics of digital interactive art installations have been investigated, considering the interplay between artwork, audience, environment, and artist (Ahmed, 2018). From a technical perspective, software engineering issues specific to developing interactive art installations have been highlighted (Trifonova et al., 2008), alongside the emergence of practice-oriented guides for artists looking to integrate software into their interactive systems (Baalman, 2022).

Despite these contributions and their frequent invocation of ‘systems,’ the primary focus often remained on computational or algorithmic aspects, rather than broader, complex social or contextual systems. Consequently, early literature on Computational Interactive Art frequently underexplored the semantic potential inherent in Systems Art. This has led to a lack of research into semantic interactions, which involve the meaningful exchange or manipulation of information, data, or symbolic representations beyond immediate physical or sensory responses.

Furthermore, while early literature often adopted a broad contextual lens to analyse general principles of interaction, it frequently did not deeply examine the specific interactive characteristics of particular media, contexts, or device combinations. For instance, while Cornock & Edmonds' taxonomy (1973) effectively categorises four different types of systems, it operates at a general level of interactivity rather than addressing the specific affordances of different media or technologies. Such abstract approaches typically did not yield the robust, solid, and actionable insights required to genuinely advance the creation and comprehension of novel interactive art experiences within particular technological or conceptual settings. These limitations in the theoretical disclosure are reflected in current Computational Interactive Art practice, which often lacks the use of diverse, semantic interactive modalities.

2.1.2.2. Practice on Computational Interactive Art

Numerous practitioners have benefited from computational technologies to explore interactive audience engagement. For instance, Teamlab often employs body tracking to create immersive, responsive visual environments, fostering a “digital ecosystem” (Lawhead, 2023). Similarly, Universal Everything’s *KinFolk* (2019) and *Symbiosis* (2019) utilise camera-based motion tracking, using audience movements as a source to process dynamic visual displays. Christopher Bauder’s *Tone Ladder* (2021) translates audiences' tangible interaction, such as stepping on or touching ladder segments, into real-time auditory responses. *YOU:R:CODE* (2017) by Bernd Lintermann and Peter Weibel used camera input to convert the audience’s image into evolving abstract visual figures, akin to a unique code.

While compelling and engaging, these artworks often rely on a narrow range of interactive modalities, primarily centred on body tracking, motion detection, or direct tactile input. This predominant focus on bodily movement often overlooks deeper semantic engagement. Consequently, audiences in these experiences tend to trigger pre-defined audio-visual outputs rather than co-creating the system's informational or symbolic core. This approach diverges from the more ambitious cybernetic visions of Systems Art (Burnham, 1968; Ascott, 2003), which imagined audiences profoundly influencing and co-evolving with the artwork as a system.

In essence, a significant limitation persists in both research and practice regarding the diversity and semantic depth of interactive modalities. This study, therefore, adopts a focused approach on a specific medium—multi-device artworks. It investigates their potential for richer semantic interaction within information-driven systems, aiming to facilitate interactions where audiences can alter the system's core, rather than solely triggering superficial effects.

2.1.3. Multi-Device Artworks

The use of multiple devices in media art has a notable history, traceable to early video art such as Nam June Paik's *TV Garden* (1974-1977), which utilised numerous television sets to create an immersive, garden-like landscape. While Paik's work pre-dates modern computational interactivity, it established a precedent for multi-screen environments. This research, however, will focus on interactive multi-device artworks, which 1) explicitly involves computational interaction, and 2) where interactive input channel and output channel are located within different computational devices.

Early explorations in computationally interactive multi-device art include Jeffrey Shaw's *Legible City* (1989), where a participant's pedalling and steering of a stationary bicycle (input device) controlled their navigation through a projected digital cityscape (output device). Rafael Lozano-Hemmer has also extensively employed multi-device configurations; *Vectorial Elevation* (first realised in 1999) allowed internet users to design light formations with large-scale robotic searchlights via a web interface, while *Pulse Room* (2006) translated participants' heart rates, captured by a sensor, into the pulsing of an array of incandescent light bulbs. These works often exemplify an 'amplified interaction', where simple inputs produce multiplied or large-scale outputs. Golan Levin's *Dialtone (A Telesymphony)* (2001) further illustrates this by coordinating hundreds of audience members' mobile phones to create a distributed sound performance.

The proliferation of smartphones from the mid-2010s spurred new forms of multi-device interaction, frequently incorporating personal mobile devices as primary input channels. *Unnumbered Sparks* (2014) by Janet Echelman and Aaron Koblin, for example, enabled participants to use their smartphones to collaboratively paint light patterns onto a monumental public sculpture. James She et al.'s *Drag a Star 3.0* (2017) reportedly integrated smartphone and mobile messaging inputs to generate shared visualisations. More recently, Ian Cheng's AI-driven artwork *BOB (Bag of Beliefs)* (2018) allows audience members to influence the AI character's behaviour via a smartphone application, offering a degree of GUI-based semantic input. Teamlab's installations, such as the *Catching and Collecting Forest* (2020), also leverage smartphones, enabling visitors to 'catch' projected creatures with their device camera, 'collect' them, and 'release' them back into the digital ecosystem. Conversely, some multi-device works like Max Magaldi's *Vain Glory* (2021) utilise arrays of smartphones for display purposes, such as showcasing social media feeds, although it hasn't incorporated direct audience interaction.

The use of multiple devices in interactive art offers distinct advantages. It can inherently broaden the available interactive taxonomy beyond sole reliance on camera-based bodily tracking. Furthermore, multi-device configurations naturally facilitate a decoupling of input and output channels; these channels need not share the same interface and can differ significantly in modality and scale, as seen in Lozano-Hemmer's work. The integration of familiar web-based or smartphone app interfaces can also enhance accessibility and engagement for contemporary audiences. Thus, multi-device artworks have inherent potential as a distinguishable medium for interactive art.

Artwork	*Artist(s)*	*Year*	*Input Device/Modality*	*Output Device/Modality*
Legible City	Jeffrey Shaw	1989	Stationary bicycle (physical navigation)	Projected screen (digital cityscape)
Vectorial Elevation	Rafael Lozano-Hemmer	1999	Web interface (designing light patterns)	Large-scale robotic searchlights (public light display)
Pulse Room	Rafael Lozano-Hemmer	2006	Heart rate sensor (biometric data)	Array of incandescent light bulbs (pulsing light)
Telesymphony	Golan Levin	2001	Audience mobile phones (registration, receiving calls)	Co-ordinated ringing of audience mobile phones (sound performance)
Unnumbered Sparks	Janet Echelman & Aaron Koblin	2014	Smartphones (touch/draw on web app)	Monumental public light sculpture
Drag a Star 3.0	James She et al.	2015	Smartphone, mobile messaging (text/app commands)	Shared screen/projection (visualisation)
BOB (Bag of Beliefs)	Ian Cheng	2018	Smartphone application (GUI-based semantic adjustments)	AI character behaviour (real-time on screen/projection)
Catching and Collecting Forest	Teamlab	2020	Smartphone (camera interaction, app gestures like swipe)	Projected screen (digital ecosystem), smartphone (collection)
Vain Glory	Max Magaldi	2016	N/A (non-interactive by audience)	Arrays of smartphones (displaying social media feeds)

Table 1. Analysis of nine different Multi-Device Artworks, focusing on their Input/Output Devices/Modalities.

Despite these benefits and notable examples, current multi-device interactive art practices often exhibit several limitations:

1. **Constrained Interactive Modalities:** Many works, despite using multiple devices, still rely on a single primary input modality for interaction within a given piece.
2. **Predominance of Audio-Visual Outputs:** Outputs are frequently spectacular and audio-visual, with less emphasis on conveying or enabling the manipulation of complex semantic information.
3. **Limited Real-Time Systemic Dialogue:** While effects may be real-time, the interaction may

not always support a continuous, granular dialogue that reflects immediate, deep changes within the artwork's underlying system based on ongoing user input.

4. **Prevalence of Single-Stage Interactions:** Many interactions follow a direct input-output logic, rather than enabling audiences to engage in complex, iterative processes that fundamentally alter the artwork's systemic rules or emergent behaviours.
5. **Limited User Agency**: User often simply navigates or decorates within pre-defined scenario, leaving limited impact to the algorithmic dynamic of the artwork itself, a common criticism raised within interactive art.
6. **Challenges in Modularity:** Bespoke hardware and large-scale installations can present significant challenges for technical and deployment modularity. Contrastingly, several web-based approaches inherently offer greater flexibility.

Artwork	*L1: Constrained Modality*	*L2: A/V Output (Low Semantic)*	*L3: Limited Real-Time Dialogue*	*L4: Single-Stage Interaction*	*L5: Limited User Agency*	*L6: Modularity Challenges*
Legible City	O	X	X	O	O	O
Vectorial Elevation	O	O	O	O	O	O
Pulse Room	O	O	X	O	O	O
Telesymphony	O	O	O	O	O	X
Unnumbered Sparks	O	O	O	O	O	O (sculpture)/ X (app)
Drag a Star 3.0	X	O	X	O	X	X
BOB (Bag of Beliefs)	X	X	O	X	X	X
Catching and Collecting Forest	X	X	O	X	O	O (projection)/ X (app)
Vain Glory	O (N/A)	O (N/A)	O (N/A)	O (N/A)	O	X
Links to Identified Gaps	*Interactive Gap*	*Semantic Gap*	*Interactive Gap*	*Interactive, Modular Gap*	*Semantic Gap*	*Modular Gap*

Table 2. Analysed limitations of nine different Multi-Device Artworks.

These limitations suggest a need for more dedicated research into this specific artistic medium. As of current knowledge, there has been no in-depth research on multi-device systems in interactive art. The relative scarcity of frameworks addressing how to design for rich interactivity, semantic depth, and true modularity in multi-device contexts may contribute to the persistence of these issues.

This research directly addresses this gap. The proposed focus on the interactive, semantic, and modular characteristics of MDWA aims to overcome the identified limitations. By investigating the potential for diverse input modalities, meaningful semantic exchange, complex systemic interactions, and adaptable web-based architectures, this study seeks to provide the first in-depth research framework for this distinguishable medium, which it terms MDWA. This approach is intended to facilitate artworks where audiences can more profoundly engage with and alter the core dynamics of the system, moving beyond triggering primarily audio-visual effects.

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2.2. Designing MDWA: Three fundamental approaches constructing the MDWA framework

To establish a framework for designing interactive, semantic, and modular MDWA, this section first addresses input modalities by investigating cross-device interaction options suitable for contemporary multi-device exhibition settings (§2.2.1). It then highlights the need to move beyond traditional linear narratives by implementing State-based Architecture for MDWA (§2.2.2). Finally, it examines Dimensional Transformation, a concept influenced by parametric mapping from musical instrument literature, as a means of bridging input with output (§2.2.3).

2.2.1. Taxonomy for Interactive Input Modalities

HCI has extensively explored cross-device interaction, with comprehensive surveys detailing taxonomies based on ontology, spatial dimensions, application domains, interaction techniques, and evaluation methods (Brudy et al., 2019). For instance, early research demonstrated direct manipulation techniques for transferring data across devices, such as 'Pick-and-Drop' (Rekimoto, 1997). Others have explored collaborative 'roomware' systems within personal devices and shared surfaces (Streitz et al., 1999), alongside concepts for interaction between displays and mobile devices within public transportation context (Kühn et al., 2013).

While this body of research provides a broad overview, its focus on utilitarian and practical solutions may not fully align with the specific experiential and artistic aims of MDWA within an experimental exhibition setting. This research, therefore, narrows its focus to synchronous distributed spatial user interfaces within a multi-user, multi-device context (Brudy et al., 2019). Such a context frequently necessitates mobile devices as flexible, accessible input channels for multiple users, complementing fixed installation outputs (e.g., projectors, screens, audio systems). However, the principles developed for MDWA interaction are envisioned to be extensible to future web-integrable devices, including augmented reality environments (Hertel et al., 2021).

To move beyond purely practical concerns of efficiency and usability often addressed in mobile HCI literature—such as surveys of mobile phone sensing (Lane et al., 2010), studies on multimodal mobile interactions (Elouali, 2019), and general multimodal interfaces (Oviatt, 2003)—this research seeks to cultivate richer artistic possibilities. This requires incorporating perspectives that prioritise the quality and nature of the artistic and experimental experience. The philosophy on phenomenology, particularly Merleau-Ponty's (1945) work on perception and lived experience, might provide an important theoretical perspective. Phenomenological ideas have significantly influenced HCI, leading to concepts such as embodied interaction, which emphasises the physical, experiential aspects of engaging with computational systems (Dourish, 2001), and tangible interaction, which aims to seamlessly integrate physical objects with digital information (Ishii & Ullmer, 1997). These perspectives offer vital dimensions for designing MDWA, focusing on the embodied nature of the artistic experience.

Specifically, the Reactable, a tangible electronic musical instrument, exemplifies these principles in an artistic context (Jordà, 2008). It serves not only as a novel conceptual and practical implementation but also as a test-bed for tangible interaction, highlighting music performance as a domain fostering collaborative, real-time, complex, and explorative engagement. This approach moves beyond mere data transmission. It successfully introduces a motion-centric, continuous mode of interaction. Jordà (2008) particularly emphasises 'continuums' in real-time interaction, which contrasts sharply with the discrete, event-based inputs typical of traditional WIMP (Windows, Icons, Menus, Pointer) interfaces (Kimball and Harslem, 1982). This suggests that metaphors from digital music and instrumental performance are valuable for designing phenomenological and playful interactions in multi-device artistic setups. Indeed, successful interactive artworks like Bauder's *Tone Ladder* (2021) or Levin's *Dialtone (A Telesymphony)* (2001) possess a strong instrumental quality, although not primarily focused on deep semantic exchange. This reveals the possibility for considering MDWA interfaces and interactions partly as instruments, thereby aiming to balance the semantic intent of Systems Art with engaging, phenomenological experiences.

Bridging semantic interaction with such instrumental qualities is crucial. Beaudouin-Lafon's (2000) model of "Instrumental Interaction" offers a pertinent HCI framework, proposing a post-WIMP paradigm that considers interaction through computer-based tools or 'instruments'. While principles of instrumental interaction are partially implemented in modern interfaces (e.g., drag-and-drop, scrollbars), their full potential, particularly the nuanced design of 'degrees of indirection' (the configurable spatial and temporal relationships between user actions and their effects), remains underexplored in many artistic contexts. Thoughtfully designed indirection can facilitate interactions that are neither purely semantic nor purely phenomenological, but rather embody both: enabling information transmission while retaining bodily and instrumental engagement.

This conceptual blending allows for a spectrum of interaction modalities for MDWA, from semantic (information-focused) to phenomenological (body-centric, instrumental, sensory). Contemporary interactive art often tends towards one extreme. This research posits that MDWA can achieve a more compelling synthesis by strategically combining techniques from across this spectrum. The aim is to leverage the unique affordances of multi-device setups to embed rich semantic and systemic narratives within engaging, phenomenologically satisfying interactive frameworks. The ubiquity and personal nature of mobile phones make them primary candidates for exploring this synthesis, offering diverse input methods mappable to both semantic and phenomenological actions.

2.2.2. State-based Architecture for MDWA

To effectively manage and construct the complex, dynamic, and interactive systems envisioned for MDWA, departing from the structural limitations often seen in computational interactive art is crucial. This section proposes and defines a State-based Architecture (SbA) tailored for MDWA, designed to model system dynamics and structure the artwork's behaviour.

2.2.2.1. Limitations in Interactive Art and Precedents in State-based Modelling

Current computational interactive art practices, as discussed in §2.1.2 and §2.1.3, frequently exhibit limitations such as linear storytelling or single-stage interactions, constraining user agency to predetermined paths or superficial systemic impact (Ahmed, 2018). Such approaches often treat audience interaction as a mere trigger for progression rather than a force for systemic re-evolution, a legacy perhaps of linear narrative forms employed in traditional moving images artforms. The limited user agency, where participants often decorate or navigate within fixed algorithmic boundaries rather than influencing the system's core dynamics, necessitates a more robust architectural approach. Especially within the multi-device complexity inherent to MDWA, a structural framework is crucial. Given this research's focus on Systems Art, examining system-relevant literature, particularly from system dynamics and computational state modelling, offers valuable foundational principles.

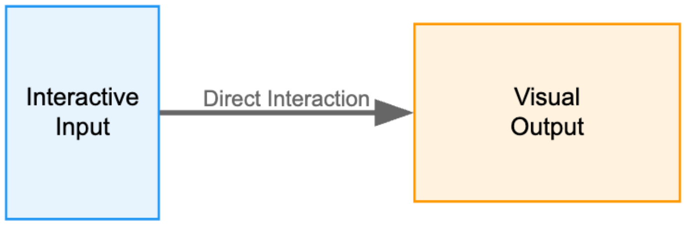

Figure 1. In traditional computational interactive art, interactive input results in visual output through direct interaction, as illustrated in this simple state diagram. This process typically occurs without systematic depth.

Multidisciplinary approaches have long sought to comprehend and model the behaviour of complex systems. System dynamics, for instance, utilises concepts like feedback loops, stocks (state variables), and flows (inter-state transition mechanisms) to illustrate how system states evolve. In computer science, Finite State Machines (FSMs) and their extension, Statecharts (Harel, 1987), provide visual formalisms for complex reactive systems by incorporating hierarchy, concurrency, and history. Petri nets offer graphical descriptions of distributed systems (Peterson, 1977), while Discrete Event System Specification (DEVS) provides modular formalism for general systems analysis (Zeigler et al., 2000). Hybrid models combining discrete states with continuous processes, such as Hybrid Petri Nets (David & Alla, 2001), further extend these capabilities. Operations research utilises state-based models like Markov Decision Processes for sequential decision-making under uncertainty (Puterman, 1990). In mathematics, state-space representations model systems as vectors of state variables, formulating behaviour via difference or differential equations.

These state-based models have also informed Interaction Design extensively. Harel's (1987) Statecharts, for example, implicitly depict how a digital interface's state changes through user interaction. Buxton's (1990) three-state model explicitly uses a state-based architecture to delineate system responses to graphical input, building on earlier explorations of touch-sensitive tablet input states (Buxton, Hill, & Rowley, 1985). Such literature implies that interactive systems can be effectively modelled using state-based architectures, where 'state' denotes the system's current configuration or characteristics, and user interactions or internal dynamics induce inter-state transitions.

Furthermore, state-based paradigms resonate strongly with modern web technologies. Object-oriented programming languages, foundational to web development, naturally accommodate stateful design. Empirically, contemporary web frameworks within the React ecosystem (e.g., React itself with useState and global state management libraries like Redux or Zustand) explicitly encourage or enforce a state-based mental model for web-based development. This technological alignment makes an SbA a natural fit for designing and implementing web-based MDWA.

2.2.2.2. Proposing State-based Architecture (SbA) for MDWA

Building upon these foundations, this research proposes State-based Architecture (SbA) for MDWA as a specialised architectural framework and design lens for conceptualising, structuring, and implementing Multi-Device Web Artworks. SbA for MDWA focuses on modelling the artwork's core systemic behaviour, the inter-device relationships, and the status of components within each device through a defined set of interconnected states. It is not intended as an entirely new universal theory of state machines, but rather a tailored application and configuration of state-based principles to specifically address the interactive, semantic, modular, systematic, and multi-device characteristics of MDWA.

MDWA, at its core, comprises a system, interactive inputs, and multi-device outputs. An effective SbA for MDWA must capture all these characteristics, providing a comprehensive architectural framework that mediates and orchestrates the informational flow between devices and the central system. Thus, SbA in MDWA is characterised by four primary categories of states, crucial for delineating this flow:

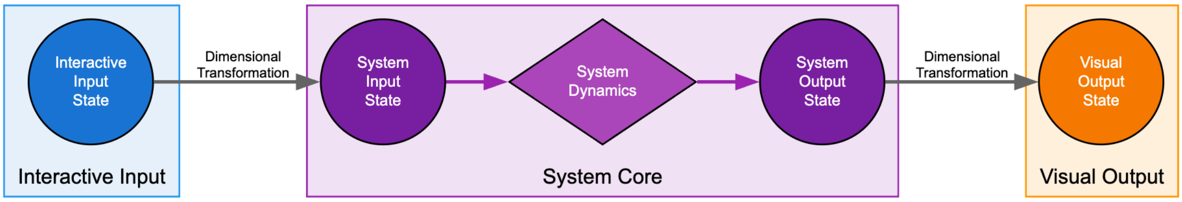

Figure 2. A simple statechart showing the skeleton structure of SbA, with four primary categories of states: Interactive Input States, System Input States, System Output States, and Visual Output States.

1. Interactive Input States: Represent the status of input channels and user interaction modalities on the various input devices. Each input device can possess its own independent state space and current state, reflecting raw user actions and sensor readings.
2. System Input States: Define the processed and interpreted inputs that feed into the artwork's core underlying system logic. These states represent the data after initial transformation from raw Interactive Input States, ready to influence the central system.
3. System Output States: Describe the outputs generated by the artwork's core system dynamics. These states reflect the outcomes of the system's internal logic, based on System Input States and the modelled systemic rules (e.g., ecological, social, technological processes).
4. Visual Output States: Detail the behaviour and configuration of output channels across various devices (e.g., projectors, screens, audio systems). These states represent how the System Output States are translated into perceivable forms for the audience. Each output device can have its own independent state space and current state.

Each state within these categories can be described by:

A. Discrete States (Qualitative): Conceptual phases or operational conditions of the artwork or its components (e.g., 'Idle', 'Frontend', 'Backend' for algorithmic system or 'Expansion', 'Peak', 'Recession', 'Contraction', 'Trough' for economic system). Transitions between these qualitative states represent significant shifts in the artwork's behaviour or meaning. The set of all possible discrete states forms the state space.
B. **Continuous Parameters (Quantitative State Variables):** Numerical values, vectors, or other data types that characterise the nuances, intensity, or dynamic evolution within a given discrete state (e.g., currently focused components/models, economic growth rate/interest rate, spatial-temporal coordinates).

Changes in continuous parameters can, over time or by crossing thresholds, trigger transitions between discrete states, and a transition to a new discrete state may reconfigure the set of active continuous parameters.

The inter-state relationships, particularly transitions between discrete states, can be mapped akin to FSMs or Statecharts. However, unlike exhaustive low-level state diagrams which can lead to a "state-explosion problem" (Harel, 1987), SbA for MDWA typically functions as a higher-level abstraction. It focuses on the dominant states and transitions that define the artwork's primary experiential and systemic arcs. This high-level approach makes the system's overall structure comprehensible while allowing for complex dynamics within or between individual components, which can be hierarchically modelled if necessary.

Inter-state transitions function distinctly across the four categories:

1. Interactive Input State transitions are primarily triggered by direct user interaction or sensor input.
2. **System Input State** transitions are influenced by Interactive Input States, often mediated by a transformation process (to be detailed in §2.2.3 on Dimensional Transformation). This separation is key for managing multi-device inputs.
3. System Output State transitions are determined by the combination of System Input States and the artwork's internal system dynamics (which vary per artwork).
4. Visual Output State transitions are influenced by System Output States, again often via a transformation process (as per §2.2.3), to translate abstract system outputs into perceivable experiences across multiple devices.

It is important to note that this framework does not rigidly predefine the specifics of interactive inputs or system inputs/outputs, as doing so might unduly narrow the scope of MDWA. SbA is intended as a universal framework applicable across diverse MDWA contexts, each differing according to the artist's intent. For instance, the 'system' itself might model social, ecological, technological, or biological processes—reflecting Systems Art's broad definition—and the specific combination of system input/output states will vary accordingly. Rather, SbA proposes a structural approach to provide order and a baseline architecture that can be referenced when designing MDWA.

2.2.2.3. Novelty and Contribution of SbA within MDWA

The novelty of SbA for MDWA lies not in the invention of state-based modelling itself, but in its specific adaptation and application as a conceptual and structural toolkit for designing and analysing interactive, semantic, and modular Systems Art realised across multiple web-connected devices. It offers several advantages over common practices.

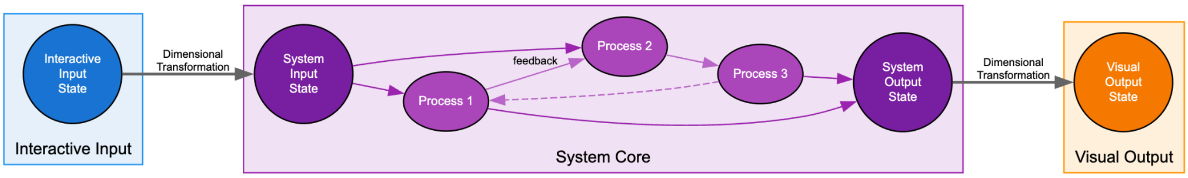

Figure 3. A simple statechart showing how the 'System Dynamics' or systematic feature of MDWA can be integrated with SbA. SbA enables easy integration of state-based System Dynamics at the core of the MDWA architecture.

Primarily, SbA facilitates non-linearity and emergence. It explicitly supports non-linear, user-influenced system dynamics, allowing audience interaction to not just influence parameters within a state but to fundamentally alter the system's state trajectory, fostering more emergent and co-creative experiences. This contrasts with linear or single-stage interactive artworks.

The framework is also instrumental in supporting semantic depth. By defining distinct system states and the logic for transitioning between them, SbA allows for the modelling of complex rule-sets and the representation of varied semantic contexts within the artwork. Programmatic implementation of SbA, often favoured for web-based MDWA, offers greater flexibility for intricate state transition logic and robust integration of diverse data sources compared to some VPLs like TouchDesigner or Unity, which, while powerful for audio-visual processing, may present challenges in managing deeply nested semantic logic or distributed state across web-native devices without extensive customisation (Trifonova et al., 2008). The increasing accessibility of coding, partly due to LLM-assisted tools, further supports this programmatic approach.

Furthermore, SbA aids in enhancing modularity in multi-device contexts. The clear delineation of Interactive Input, System Input, System Output, and Visual Output states promotes a modular design where components responsible for handling inputs on specific devices, processing system logic, and rendering outputs on other devices can be developed and maintained more independently. Such modular consideration also allows for greater flexibility in changing device configurations, combinations, and alternations, which is crucial for the adaptable and distributed nature of MDWA.

Finally, SbA provides clarity for complex interactions by offering a coherent framework for understanding and orchestrating how interactions on multiple input devices collectively influence a central system, and how that system's responses are then distributed and manifested across multiple output devices.

While SbA provides a robust structure for defining system states and their transitions, it does not fully address how the raw inputs from users are meaningfully translated into systemic changes, or how abstract system outputs are transformed into compelling perceptual experiences. This crucial translation layer is the domain of Dimensional Transformation, discussed next.

2.2.3. Dimensional Transformation and Parametric Mapping for MDWA

While SbA, as discussed in §2.2.2, provides a necessary structural foundation for MDWA, it does not fully specify the translation mechanisms between user inputs, core systemic logic, and perceptual outputs. A direct connection of system states to device inputs or outputs, such as plotting raw economic data graphically, presents several critical limitations. Firstly, such an approach risks the work becoming merely a system simulation, potentially indistinguishable from a technical demonstration if it only maps user parametric interactions to systematic outputs. Secondly, this directness can diminish artistic value; the artwork might be perceived as a decorative or didactic representation rather than a piece embodying specific artistic intention or narrative, thereby aligning more with a designed experience rather than an artistic output. Thirdly, such configurations are often not playful; audiences may lose interest in what appears as a straightforward simulation without unexpected effects, thereby offering limited interactive value beyond the observation of systemic processes.

The concept of "parametric mapping," as explored by Hunt et al. (2003) in the context of electronic musical instrument design, offers initial insights for addressing the previously identified limitations. Hunt et al. (2003) argue that direct, one-to-one mappings between user input and system parameters often result in predictable experiences, thereby diminishing user engagement. In contrast, they propose that more complex mapping strategies can foster more rewarding and "instrument-like" interactions. To manage this complexity, Hunt et al. (2003) advocate for the use of intermediate or "abstract" parameter layers, exemplified in their two-layer and three-layer models.

Applying this idea to Systems Art suggests the utility of a 'transformative' layer between the interactive input and the system input, as well as between the system output and the visual output, moving beyond direct system simulation. However, the direct application of parametric mapping might encounter limitations in the context of Systems Art. Parametric mapping's inherent focus is primarily synthetical and instrumental, often lacking the capacity to incorporate the layers of narrative or semantic intent that are central to Systems Art. While the principle of mapping between interactive input, system processes, and perceptual output is valuable, MDWA requires a concept that extends beyond such purely algorithmic or instrumental mapping. This necessitates the introduction of Dimensional Transformation (DT).

2.2.3.1. Dimensional Transformation (DT)

This research introduces Dimensional Transformation (DT) as a complementary strategy to SbA within the MDWA framework. DT is defined as the process of mediating the connection between Interactive Input States and System Input States, and subsequently between System Output States and Visual (or Perceptual) Output States. This mediation occurs through a combination of (algorithmic) parametric mapping and (semantic) contextual change. DT parametrically maps data between different states or state-spaces; however, its primary function is to enable a transformation from one contextual dimension to another, guided by artistic intent and serving as a metaphorical and conceptual shift that also involves numerical and structural transformation.

The term ‘Dimensional’ in DT has a dual connotation. It first connotates algorithmic transformation, by referring to the technical transition between different states and parameters, analogous to transformations between vectors or matrices in linear algebra. Simultaneously, it also connotates semantic and contextual transformation. It signifies an inter-domain or inter-contextual shift, such as transforming numeric states from abstract economic models into visual states within a simulated commercial environment, or translating specific user inputs into control parameters in a different domain.

DT addresses the limitations of direct state connections as it moves beyond mere simulation, facilitates artistic narrative and semantic depth, and enhances playfulness and engagement.

Traditional input-output models often yield artworks that function as mere imitations of a situation or process. Dimensional Transformation (DT) departs from this by introducing intermediate transformative layers. These layers ensure the artwork is no longer a direct imitation of a real-world situation or a simple plotting of parametric interactions against systematic outputs; instead, DT adds speculative, imaginative, or non-realistic dimensions, characteristically moving beyond mere simulation. This approach allows for more complex and potentially unprecedented systemic behaviour to emerge. DT specifically proposes the following workflow in five stages:

1. Interactive Input Modalities: User interaction generates initial states and associated state variables (parameters).
2. Input Dimensional Transformation: These raw input states are transformed into System Input states.
3. System Dynamics: The core system processes System Input states into System Output states.
4. Output Dimensional Transformation: Abstract System Output states are transformed into User-Facing Perceptual Output states, creating a parametric interface.
5. Perceptual Output: The transformed perceptual output states rendered across multiple output devices.

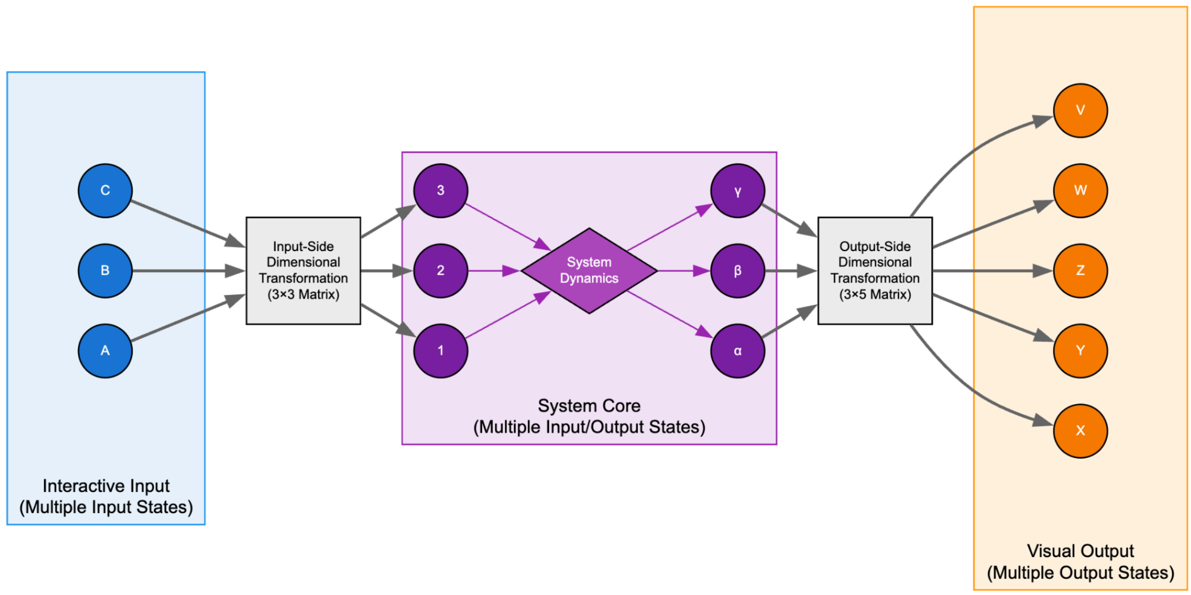

Figure 4. A statechart depicting how DT can be integrated with SbA: Input-Side DT transforms the interactive input states into system input states, whilst output-side DT transforms the system output states into visual output states.

Furthermore, DT facilitates artistic narrative and semantic depth. The artist crafts the transformations between dimensions with their artistic imagination guiding these inter-domain and inter-symbol transitions. This methodology shares common ground with artistic strategies such as collage, bricolage, or Dadaist juxtaposition, where meaning emerges from unconventional associations. For example, a Dimensional Transformation that converts inputs representing abstract economic growth theories (e.g., numerical data) into the observable behaviour of an exaggerative simulated commercial shopping interface can serve as an artistic critique of the separation between academic theory and lived practice, or explore paradoxes of consumerism. The selection of a specific interactive modality and its target transformed dimension, thus contributes a significant layer to the artwork's meaning and the artist's intended message.

Simultaneously, by avoiding direct manipulation and predictable cause-and-effect relationships, DT can foster more engaging and playful interactions. The non-obvious nature of these mappings, a direct result of moving beyond simple one-to-one correspondences (a common criticism of early interactive art's single-stage interactions - see §2.1.1.), prompts users to establish new mental models. The use of intermediate or "abstract" layers and the complexity induced by them, as highlighted in discussions of parametric mapping (Hunt et al., 2003), facilitates a stronger, more instrumental, and playful experience. The interaction is no longer based on obvious mappings but can incorporate artist-framed arbitrary or unexpected connections, thus making the experience less predictable and more "instrument-like."

DT, like SbA, is proposed as a guiding conceptual method rather than a rigid set of prescriptive rules. The use of transformative strategies to create novel relationships between user input and artwork output has precedents in computational interactive art. Rafael Lozano-Hemmer have often connected one modality to another (e.g., physiological data to light manifestations, *Pulse Room*, 2006), and Jeffrey Shaw's *Legible City* (1989) translated the physical act of cycling into navigation through a virtual, textual environment. These examples demonstrate how Dimensional Transformation has been employed to establish arbitrary and conceptually driven relationships between audience interaction and artistic output.

However, a key distinction pertinent to this research is that while such prior artworks effectively utilised transformative mappings, they often exemplified mere Dimensional Transformation without integration into an explicit, complex underlying system, resulting in a single-stage interaction. In contrast, the MDWA framework formalises DT not as a standalone interaction technique, but as a core architectural component specifically combined with SbA to structure, manage, and articulate the dynamics of complex systemic interactions, thereby advancing beyond simple transformative effects.

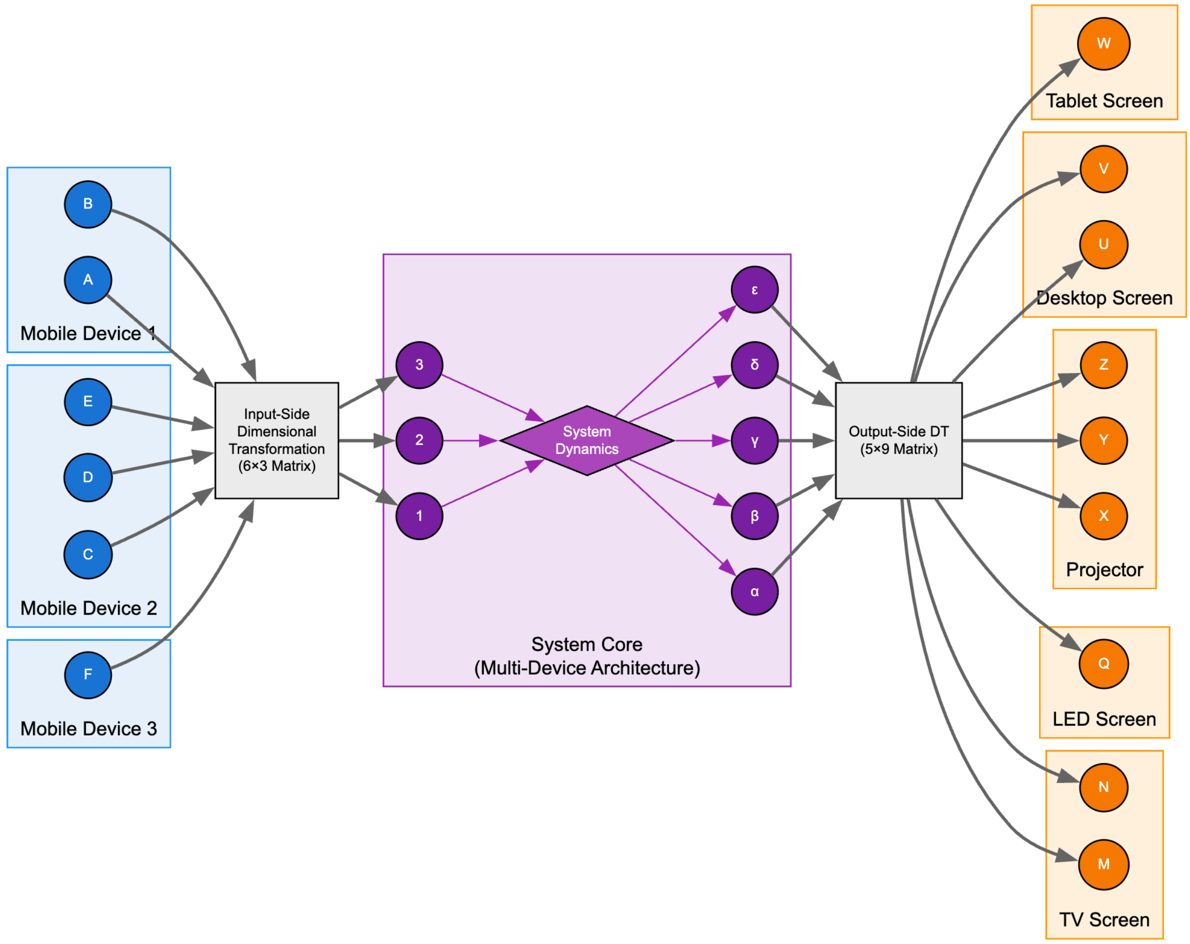

Figure 5. A sample statechart depicting how DT can integrate multiple input/output devices, potentially enabling many-to-many interactions within MDWA. Through a rigid SbA and DT structure, artists are able to control and design more complicated many-to-many device configurations.

Furthermore, DT empowers the modular nature of MDWA by supporting many-to-many (M:N) relationships. Inputs from M devices can be transformed to influence α system input dimensions; similarly, β system output dimensions can be transformed to manifest across N output devices or perceptual elements. This is relevant for representing complex, intertwined systems or "hyperobjects" (Morton, 2013), where phenomena have multiple, distributed causes and effects. The transformative nature of DT, which can be conceptualized through matrix operations (e.g., mapping an M-dimensional input vector to an α-dimensional system input vector, and a β-dimensional system output vector to an N-dimensional perceptual output vector), offers a structure for managing this complexity.

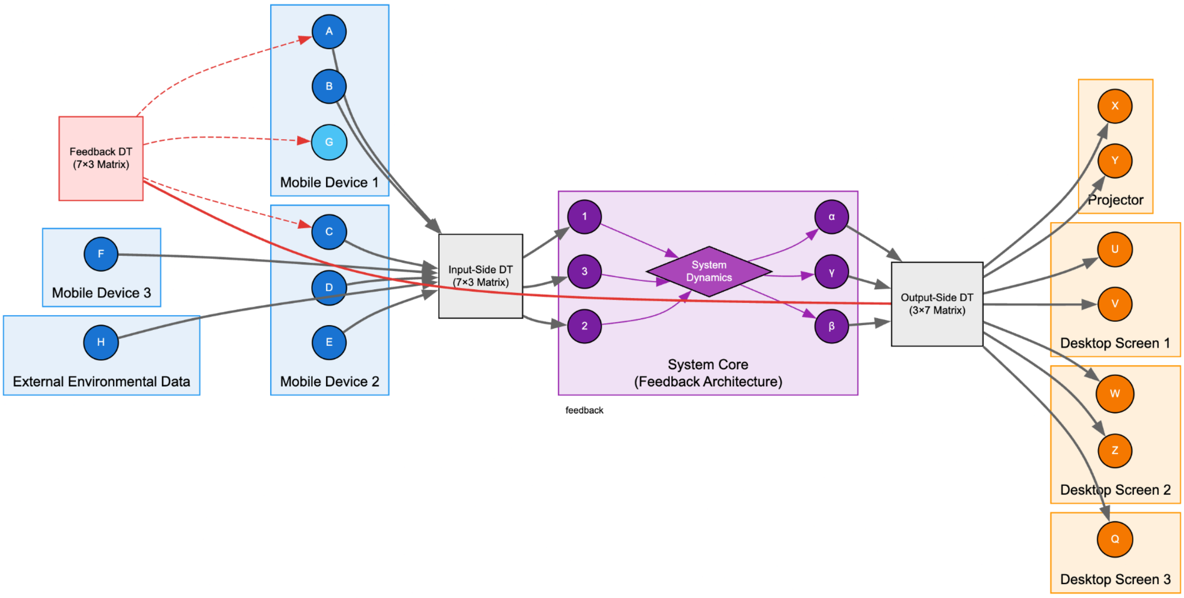

Figure 6. A sample statechart depicting how SbA and DT can accommodate more complex feedback loop structures, moving beyond straightforward interactions to a more systematic circular loop, where input devices are influenced by their own inputs.

The overall workflow facilitated by Dimensional Transformation connects audiences' input modalities to multi-device outputs: Interactive Input → Input Device State → (Input DT) → System Input State → (System Dynamics) → System Output State → (Output DT) → Output Device State. While the connection from interactive input to system input states is further detailed within the discussion of interaction taxonomy (§2.2.1), the translation from System Output States to perceivable Output Device States and visuals warrants specific attention. To address how system states affect the interface via Dimensional Transformation, the concept of the Parametric Interface is introduced.

2.2.3.2. Parametric Interface

To translate System Output States (specifically, their continuous quantitative state variables) into perceivable and artistic forms via Output Dimensional Transformation, this research utilises the concept of the Parametric Interface. While DT is the broader artistic and conceptual strategy for linking states across contextual divides, the Parametric Interface offers a practical approach for realising the output side of this transformation. It focuses on translating system parameters into dynamic visual, auditory, or other sensory features within the multi-device web environment. This approach also aims to explore the aesthetic potential of web technologies, addressing potential limitations in comparison to works created with specialised VPLs.

Traditional methods for depicting parametric values in art or information display generally fall into two categories, each with limitations for the artistic aims of MDWA.

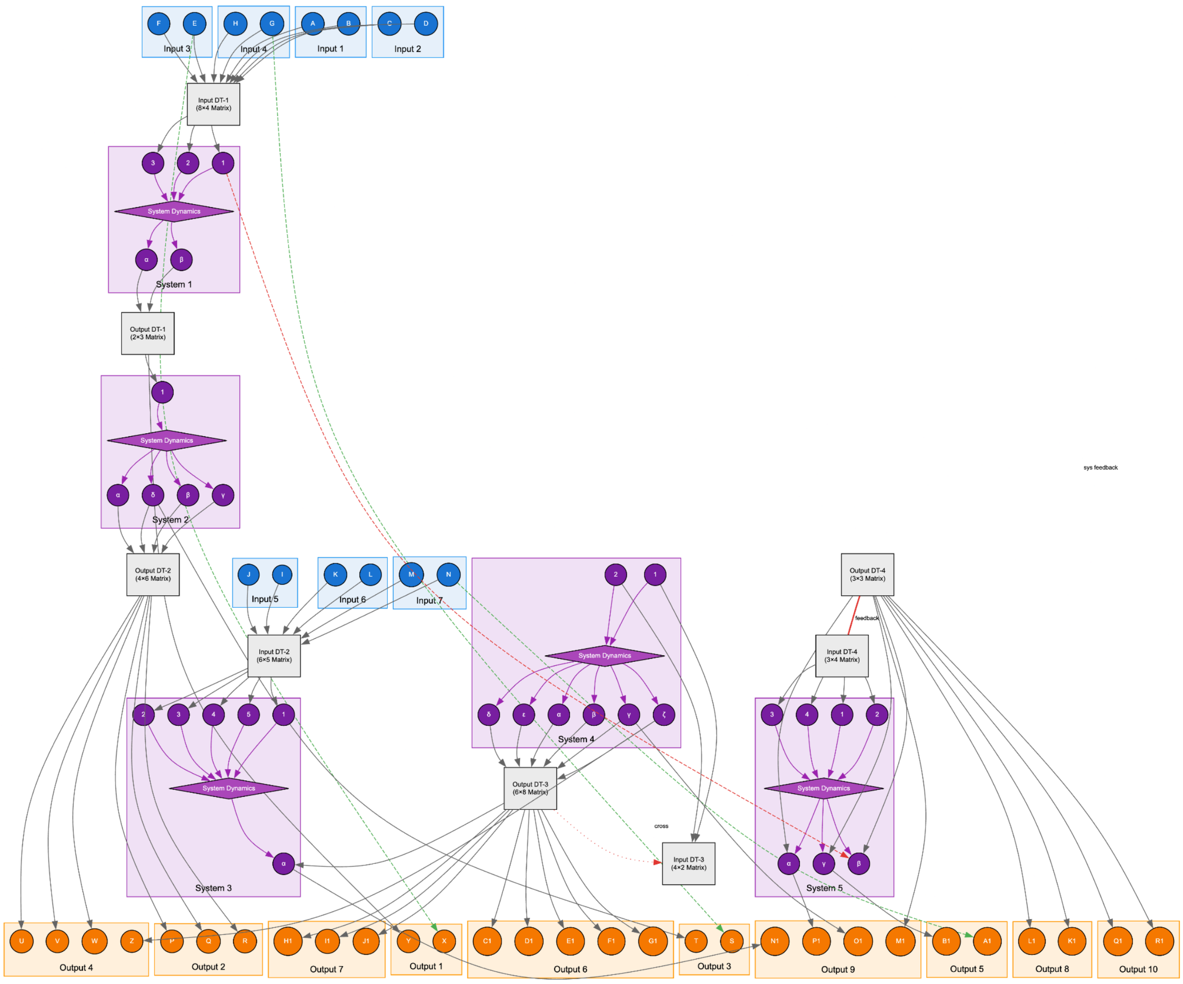

Figure 7. A sample statechart depicting complicated SbA, where multiple systems, DTs, feedback loops are enabled for depicting more complex many-to-many device system. This sample suggests that a rigid SbA and DT enables more extensive experiments on MDWA, successfully leveraging its interactive, semantic, and modular characteristics.

1. Traditional Data Visualisation: This encompasses established methodologies for presenting parameters through charts, graphs, or direct numerical displays (Card et al., 1999; Ware, 2019). While effective for conveying information clearly, this approach can be overly literal or didactic within an artistic context, often lacking nuanced interpretative layers.

2. Abstract Audio-Visuals: This involves translating fluctuating or altering parameters into immediate, often abstract, sound or visual patterns, a common practice in creative coding or VLPs like TouchDesigner. While capable of producing dynamic outputs, such visualisations may sometimes lack a discernible semantic connection to the underlying system being modelled. This can lead to a perception of the output as primarily decorative, a critique often directed at some forms of media art. For instance, Refik Anadol's data sculptures are often critiqued that varied data sources yield outputs of a similar aesthetic character, potentially obscuring deeper engagement with the underlying algorithmic system's meaning in favour of visual spectacle (Davis, 2023).

MDWA, through Parametric Interfaces, pursues dynamic and semantic outputs where the behaviours of interface elements are directly and legibly altered by the system's current state and history. A Parametric Interface employs elements—ranging from conventional Graphical User Interface (GUI) components to abstract visual forms or descriptive 3D environments (e.g., using Three.js)—that change their attributes (e.g., spatial-temporal coordinates, animations, emergent behaviour) parametrically based on the evolving quantitative state variables of the system output. Visual elements, textual content, and layout configurations dynamically shift to reflect system states or parameter intensities.

Instead of explicit data visualisation or abstract audio-visuals, Parametric Interfaces embed data to directly drive interface configurations. For instance, economic change could be depicted through Dimensional Transformation where a shopping interface's dynamics (e.g., product cycling, item prominence) reflect an economic model's output, thereby conveying artistic meaning about consumerism. This method of presenting a consistent structural interface with parametrically varied content is analogous to Andy Warhol's *Campbell's Soup Cans* (1962), where the uniform label design frames varied soup flavours, illustrating a "least marginal difference." The capacity of Parametric Interfaces to articulate such minimal significant differences makes them a pertinent tool for exploring themes characteristic of contemporary socio-economic systems and simulacra, as discussed by Baudrillard (1981).

Increasingly accessible web development tools, including LLM-assisted coding, lower the barrier for artists to rapidly create complex, dynamic Parametric Interfaces. These interfaces, whose elements change in real-time based on systemic shifts, align with Manovich's (2001) conception of new media wherein the interface itself becomes an active, generative medium, systematically producing variations and serving as a primary site for dynamic content and aesthetic experience. This systematic, computational production of varied interfaces offers a contemporary parallel to Walter Benjamin's discussions on mechanical reproduction (1935), re-contextualised for the parametric capabilities of the digital age and offering a means to depict a system's evolving nature.

In summary, the combination of State-Based Approach (SbA), Dimensional Transformation (DT), and Parametric Interfaces provides a comprehensive workflow for MDWA: from user interaction captured as Interactive Input States, through Input DT to System Input States, processed by System Dynamics into System Output States, and finally manifested through Output DT (often via Parametric Interfaces) as perceivable Visual/Perceptual Output States across multiple devices. This framework is intended to enable the creation of MDWA that are interactively engaging, semantically rich, and systematically coherent.

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2.3. Researching MDWA: Methodologies for Practice-based Inquiry

As an empirical methodology to validate the design frameworks and assumptions made for MDWA, focusing whether it can deliver the interactive, semantic, and modular gap - this research propose a methodology denoted as Research-through-Exhibition (RtE, §2.3.3). This approach combines the Practice-based Research (PbR, §2.3.1) and Research-through-Design (RtD, §2.3.2), situating the research at the intersection of art and design's practice-based methodologies.

2.3.1. Practice-based Research

Practice-based Research (PbR) is adopted in this study as a research paradigm where new knowledge and understanding are acquired principally through the act of practice and reflection upon it (Candy, 2006). This research selects PbR as it aligns with the aim of discovering knowledge through the creation and iterative development of MDWA. Research on MDWA could not be fully realised without direct engagement with, and reference to, the outcomes of the practice itself: the developed artworks.

It is crucial to distinguish PbR from Practice-led Research. While practice-led research may utilise practice as an inspiration for conventional scholarly outputs, PbR positions the creative process as central to the research inquiry. The practice is not merely illustrative but is a primary mode of investigation and a source of original findings (Haseman, 2006). The artworks generated within this research are therefore not simply examples, but serve as integral sites for knowledge production.

The "originality, mastery, and contribution to the field," as articulated by Frayling (1993), are critical considerations within PbR. Hence, originality in this research is pursued through the novel configurations and experiential qualities of MDWAs—both artworks and framework. Mastery is achieved through proficient execution of the artistic and technical aspects of the practice, carefully bridging practice to the framework. The contribution lies in the new knowledge generated regarding MDWA as a medium and specific approach for Systems Art, Computational Interactive Art, and Web Art, articulated through both the artworks and the dissertation.

Furthermore, PbR inherently resonates with phenomenological perspectives, where the lived experience of creating and interacting with the artworks provides a crucial lens for understanding. The subjective experiences encountered during the creative process, and by audiences during exhibitions, inform the research and contribute to insights that might not be derivable from purely theoretical methods.

Thus, this research is primarily grounded in PbR, as the development, exhibition, and analysis of the three MDWA series form the primary mechanism for investigating and validating MDWA as a new medium. Knowledge iteratively emerges from the interplay of artistic practice and the designed framework, accumulatively addressing the proposed gaps in Systems Art and Multi-Device Artworks.

2.3.2. Research-through-Design

Research-through-Design (RtD) offers another methodological lens for this research. Frayling (1993) notably introduced the term "research through art and design," describing it as a process where research questions are explored and insights are generated via the act of making. In this approach, the knowledge produced is often embodied in the artefact or the design process itself.

Zimmerman et al. (2007) further contributed to formalising RtD as a legitimate research method within Interaction Design and HCI. Building upon Frayling's conception, they adapted RtD by distinguishing between a standard design artefact and a research artefact, positioning the latter as a valid research outcome. A research artefact in RtD is expected to produce transferable knowledge that contributes to research and practice communities, as well as demonstrate significant invention or innovation (Zimmerman et al., 2007). The contribution of RtD can be evaluated based on criteria of Process, Invention, Relevance, and Extensibility.

While this structured approach enabled design practice to be recognised as a valid form of research, applying RtD to the development and validation of interactive public artworks like MDWA reveals certain limitations. RtD processes often culminate in prototypes or proof-of-concept demonstrators, primarily intended for controlled experiments and user testing (Koskinen et al., 2011). However, to properly validate an artwork's design, experimenting with a small, selected group of participants in a laboratory setting may be insufficient for capturing the complexities of real-world public engagement.

Several factors contribute to this insufficiency. Firstly, human perception and behaviour can be significantly influenced by the experimental context, a phenomenon often referred to as the Hawthorne effect, where participants may alter their behaviour due to awareness of being observed. In a controlled lab setting, audiences might exhibit more focused or engaged behaviour than they would in a typical exhibition setup. An MDWA framework aiming to actively engage users must demonstrate its capacity to foster such interaction within an actual in-situ exhibition, not solely under controlled settings.

Secondly, exhibition settings present unique challenges regarding audience demographics and engagement styles. Artworks in galleries often encounter casual or indifferent passersby, who may not have the pre-set intentionality of a 'user' in a typical HCI study. Designing interactions that can capture attention and meaningfully engage such audiences is crucial for an artwork's success in a public environment.

Lastly, creating an exhibition-ready interactive experience involves substantial design and engineering considerations distinct from those for a lab prototype. These include ensuring robustness in unpredictable environments, addressing unstable internet connections (particularly relevant for MDWA), managing unexpected audience interactions (such as leaving mid-interaction), implementing reliable session resets, guaranteeing an undisturbed interactive experience, maintaining interaction accessibility for diverse audience groups, and addressing numerous unexpected edge cases. This rigorous fine-tuning and debugging, especially for complex multi-device systems, can be as resource-intensive as developing the core system logic. These practical considerations can also critically shape or constrain MDWA design decisions.

Overlooking these practical and experiential realities of public exhibition can lead to the development of an MDWA framework that, while theoretically sound or functional in a lab, proves impractical in real-world artistic deployment. Therefore, to properly validate the proposed MDWA framework and its ability to create successful interactive artworks, an RtD approach that concludes with a prototype is limited. This research must extend its inquiry into the authentic context of the public exhibition itself.

2.3.3. Research-through-Exhibition

Building upon the foundations of PbR and RtD, this research proposes Research-through-Exhibition (RtE) as its primary methodological framework. RtE naturally involves the public exhibition of artworks as a core component and further incorporates an explicit research dimension. Through exhibitions, RtE aims to produce generalisable knowledge relevant to MDWA, interactive art, and design, as well as to propose a novel framework that extends beyond existing approaches.

RtE integrates the artistic and design-centric approaches of both PbR and RtD. Thus, the core findings of this RtE involve a distinct series of MDWAs, alongside a design framework for creating systematic MDWAs. Each artwork, while possessing significant artistic context and functioning as a standalone professional interactive art piece, also serves as an instantiation and test-bed for the evolving MDWA framework.

Feature	*Practice-based Research (PbR)*	*Research-through-Design (RtD)*	*Research-through-Exhibition (RtE)*
Primary Driver	Practice & reflection	Design & making process	Public exhibition of practice
Role of Artefact	Primary site of knowledge production	Embodies research & innovation (prototype)	Tests framework & engages public in-situ
Key Outputs	Original creative works; insights from practice	Design artefacts/prototypes; transferable knowledge	Exhibited original artworks; validated design framework
Validation Method	Reflection on practice; iterative creation	Controlled experiments; user testing (often lab-based)	Real-world public engagement during in-situ exhibition
Focus for MDWA	Grounds research in MDWA creation & experience	Offers methods for framework development	Primary method for MDWA framework validation & iterative artwork development

Table 3. Comparison of PbR, RtD, and RtE as different research methodologies.

RtE draws from PbR by generating knowledge from the processes of production, creation, and audience interaction during the creation of exhibitions. Simultaneously, RtE aligns with RtD as its outputs function not only as design artefacts but as research artefacts—specifically, the Interactive Taxonomy, SbA, and DT developed for MDWA. Thus, this research is not solely PbR or RtD in isolation, but rather a combination that fosters a dynamic interplay between the creation of works and the construction of knowledge, aligning with the notions of Charles L. Owen (1998).

In doing so, RtE transcends the individual characteristics of both PbR and RtD. It goes beyond PbR by being explicitly situated within design research, aiming to contribute a structured MDWA framework to both design research and artistic communities. Concurrently, RtE extends beyond RtD by not limiting its outputs to design prototypes or laboratory experiments. Instead, it validates findings within public exhibitions, which may span several months and involve thousands of audience members. This emphasis on in-situ, long-term public engagement provides a richer and more ecologically valid basis for assessing the artwork's efficacy and the framework's utility (Koskinen et al., 2011).

These unique characteristics position RtE as a particularly well-suited approach for MDWA research. RtE methodologically supports the iterative development of three distinct MDWA series while iteratively strengthening the design framework for MDWA, thereby addressing the research aims in a holistic and empirically grounded manner.

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3. Plans for Empirical Research

As noted in §2.3.3, this research employs Research-through-Exhibition (RtE) to empirically validate the findings on the MDWA framework and to cyclically add knowledge to this generalisable framework through the exhibition process. Hence, the act of exhibition and the act of research coexist, forming a well-informed feedback loop that reinforces each, preventing the research from being purely theoretical (i.e., resulting in an impractical MDWA framework) or entirely project-specific (i.e., yielding ungeneralisable knowledge lacking tangible research contribution).

Specifically, this PhD research aims to focus on three distinct MDWA exhibitions. These exhibitions will 1) naturally be web artworks configured in an interactive multi-device format, 2) be positioned within the domain of Systems Art, 3) successfully bridge the identified research gaps (Interactive, Semantic, and Modular), and 4) contribute to and strengthen the three design approaches for MDWA: Interactive Taxonomy for MDWA, State-based Architecture (SbA), and Dimensional Transformation (DT), respectively. Thus, within the PhD research process, these three fundamental design approaches will be procedurally derived and iteratively refined; the relationship is not such that one artwork maps 1:1 with one design approach, but rather they are intertwined, as detailed in Table 4.

As of the time of writing this document, the first case study is confirmed. The subsequent two case studies are to be determined (TBD) but are expected to follow.

Feature	Case Study 1. SoTA: Algorithmic System	*Case Study 2. Ecological System (TBD)*	*Case Study 3. Economical System (TBD)*
Bridging the Identified Research Gap			
1. Bridging the ***Interactive Gap***	Mobile GUI and Device Motion-based interactions, Disengagement-triggered Narrative Shift	*Multi-user interactions through iPads which facilitate co-interaction.*	*Multi-user interactions where audiences interact from commercial GUIs with a wide range of interactions.*
2. Bridging the ***Semantic Gap***	Detailed Visualisation of 118 Neural Network Models, with in-depth explanation for each model	*Ecologically ever-evolving system where interaction actively influences its dynamics, transcending purely bodily interaction.*	*Explicit Economic System Interfaces revealed, alongside Implicit Interfaces depicting various Economic Outcomes.*
3. Bridging the ***Modular Gap***	Two projectors, four PCs, single mobile setup, all modular/primarily existing as a website.	*Multiple iPads, Multiple screens, and projector setup, primarily existing as a website.*	*Multiple mobiles, Multiple screens, and projector setup, primarily existing as a website.*
Contributions to the MDWA Design Framework			

*1. Contributions on **Interactive Modalities** for MDWA*	Successfully implemented phenomenological interaction with semantic context, including unprecedented narrative shift triggered by user disengagement.	*Actively engages different interactive modalities: From touching, finger-morphing, to voice interaction, which is connected with the whole storyline.*	*Successfully utilises traditional GUI-based interactions to create a phenomenological/playful experience.*
*2. Contributions on **State-based Architecture (SbA)** for MDWA*	Experimental implementation of Frontend, Backend, Idle SbA based on user activeness.	*Rigid SbA implemented through all iPads and Projector channels, for handling complex inter-device state management.*	*Rigid SbA is implemented through all channels, with each mobile/screen/projector channel depicting discrete economic states/trends.*
*3. Contributions on **Dimensional Transformation (DT)** for MDWA*	Speculative visualisation of 118 Neural Networks Architectures and LLM Embedding Vector's Cross-Similarity.	*Active DT between channels; e.g., iPad interaction might positively influence an adjacent screen but negatively influence a projector.*	*Active DT implemented to 1) Transform Mobile GUI interactions into Economic System Input, and 2) Depict various Economic Outputs visually.*

Table 4. Summary of Key Contributions of Each Case Study to Bridging Research Gaps and Advancing the MDWA Design Framework.

Empirical Study 1: SoTA (State-of-the-Art)

Medium: 2 Projectors (Synced), 4 PCs, 1 Audience Mobile
MDWA Type: Single Input Device, 6 Output Devices
Premiere Installation: KAIST Art Museum, 2024.12 - 2025.06
Artwork Completed: 2024.12

Artwork Description

State-of-the-Art (SoTA) refers to cutting-edge AI models, analogous to achieving an artistic pinnacle. Early SoTA architectures (CNN/RNN) were designed to mimic human cognition, echoing the representational approach. Yet, as Rich Sutton's "Bitter Lesson" argues, ever-growing GPU power now eclipses human-designed intricacies, nudging SoTA from carefully crafted forms toward vast, computation-driven abstractions.

This shift parallels how art moved from representation into Modernism's more abstract modes, especially after photography's rise. A century ago, Benjamin spotted the profound influence of mechanical reproduction on aesthetics. Decades later, abstract expressionism emerged at the extreme of modernism, epitomised by Pollock's action paintings and Greenberg's emphasis on flatness. Likewise, today's AI reproduction propels neural networks beyond human comprehension—a realm of "AI for AI's sake"—hintable from Eric Schmidt's warning.

SoTA is an XAI(Explainable AI)-driven interactive multi-device web artwork that makes our evolving metaphor tangible. Two projectors, four PCs, and audiences' mobiles present 118 neural architectures in a 3D, interactive, and representational form—initially mirroring SoTA's earlier pre-modernist era (the Frontend). But once audiences stop interacting and leave the site, unprecedentedly, the screens flip to chaotic monochrome visuals that abstractly depict LLM token cross-similarities (the Backend). Like Pollock's expressive drips, the swirling lines of connectionism immerse audiences in a vortex of high-dimensional complexity no longer intelligible to us.

Mirroring Modernism's shift, SoTA reveals how AI can reshape society, identity, and creativity. It questions whether massive models will foster inclusive, human-centred progress or slip into self-referential abstraction—a Black Box. By uncovering AI's hidden layers, SoTA urges us to reflect on the implications of State-of-the-Artificial Intelligence and responsibly guide these systems.

Figure 8. The installation view of *SoTA*, an interactive Multi-Device Web Artwork on AI's trajectory towards abstractness, at KAIST Art Museum.

Validation Process: Research-through-Exhibition:

The validation process involves a large-scale exhibition of *SoTA* and an empirical user study (N=30) including interviews and observations. The interviews will observe if the artwork's State-based Architecture (Frontend-Backend), triggered by specific multi-device user interaction (i.e., user disengagement), and its Dimensional Transformation have affected the audience's experience, specifically in changing their understandings and opinions about AI (understanding the trajectory of AI models, Human-AI relationships, and AI's societal impact). This validation verifies if the implemented MDWA key design approaches are valid.

Implementation of MDWA Design:

- **Interactive Taxonomy:** A mix of phenomenological and semantic interaction is implemented. This includes semantic interaction (user name input for better avatar docent context, where both Frontend and Backend explicitly mention the audience's name within their LLM text generation), mobile device motion (which rotates the Three.js Neural Network visualisation scene accordingly), and user disengagement (i.e., when the user exits the mobile website, unprecedentedly transforming the artwork into the Backend state).

- **State-based Architecture (SbA):** A Frontend-Backend structure forms the main output state, adjusted by the user engagement status of the input (on vs. off). The intermediary system, while not controlling this main state directly, manages state variables (parameters). It converts a user's mobile selection from one of the 118 Neural Networks into the visualisation and screen output across four screens. An additional parameter adjusts the mobile device motion to the projector/output's screen orientation without passing through the explicit semantic system.

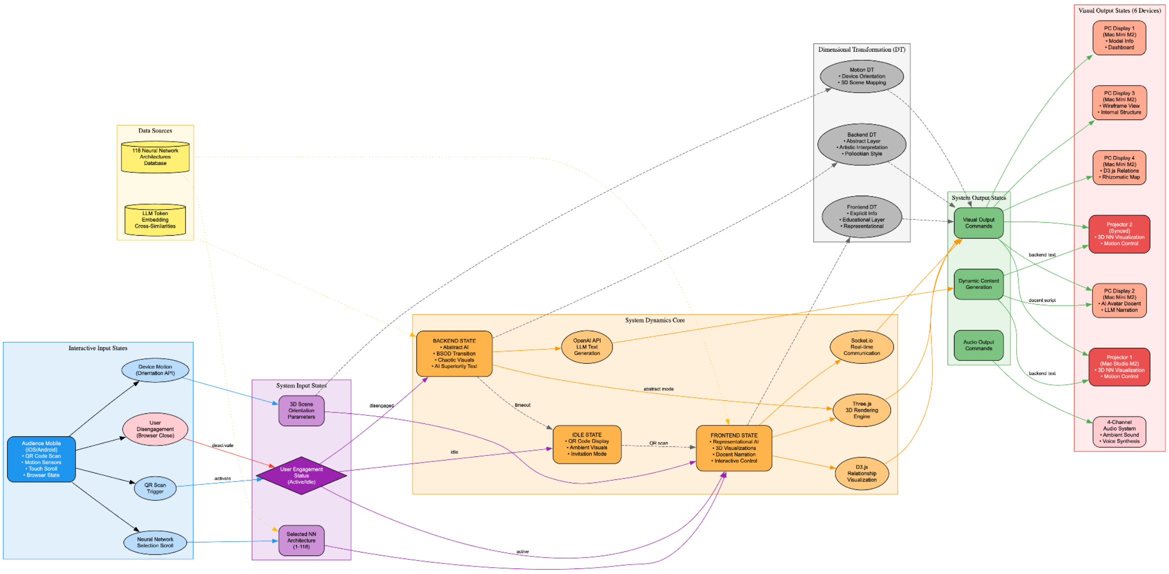

Figure 9. Sketch of SbA and DT for *SoTA*.

- **Dimensional Transformation (DT):** The Frontend is somewhat more explicit in plotting and providing information about each AI model. In contrast, the Backend employs a strong layer of Dimensional Transformation, not only in its visualisation (which depicts the cross-similarity of LLM's token embeddings) but also in conjunction with 1) more abstract text (representing "AI for AI's sake"), and 2) more chaotic visuals (representing an abstract expressionist, Pollock-like visual style). These decisions do not simply visualise the system output but add artistic interpretation (Dimensional Transformation) in presenting the output.

Bridged Research Gaps:

- **Interactive Gap:** Clear and active user interaction is facilitated, where the user has agency over the system, including the novel interaction of disengagement triggering a significant state change.
- **Semantic Gap:** Users can scroll through 118 Neural Network architectures and learn semantic information via four distinct screen outputs, which present rhizomatic relationships, academic information, and avatar docent narration.
- **Modular Gap:** The artwork exists primarily in the form of web links, allowing it to be easily installed and deinstalled using universal digital equipment (PCs, screens, projectors).

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