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Creative Technology

BACHELOR'S THESIS

Emergence as a Principle of Design Research
Theoretical and Practical Considerations

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Abstract

The concept of emergence - the formation of new, irreducible properties through the interaction of individual elements - has significant implications for industrial design, particularly in fostering user engagement and sustainable innovation. This thesis investigates emergence as a fundamental principle in design, synthesizing perspectives from gestalt psychology, systems theory, and interactive product design. Through a structured literature review, this study establishes a cohesive definition of emergence in design and examines its role in adaptability, user experience, and sustainability. To bridge theory and practice, a modular lighting prototype was developed, designed to exhibit emergent behaviour through reconfigurable magnetic components. A controlled user study using rendered images evaluated participant perceptions, revealing that modularity enhances co-creation and deepens understanding of emergence in design. Findings suggest that embedding emergent principles into products can improve adaptability, foster dynamic user interaction, and promote sustainable material strategies. This research contributes to the ongoing discourse on interactive and sustainable design, proposing emergence as a framework for crafting products that evolve dynamically with user needs over time.

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CHAPTER 1

1. INTRODUCTION

1.1 Background and Context

Emergence plays a role in gestalt theory which has been in discussion since the early twentieth century and similar concepts can be found across many art forms (Smith, 1988). Henri Cartier Bresson's decisive moment (Galassi, 1987), questions raised by Marcel Duchamp's "Readymades" (Rosenthal, 2004) and Walter Gropius' (1965) "total design" philosophy as the founder of the Bauhaus all coincide on the exploration of a similar question: how can individual elements within some composition come together to create a new, unified whole that transcends its parts?

Recent insights from domain experts in design research and behavioural modelling highlight that emergence in design is not merely an abstract construct but a phenomenon that shapes innovation and problem-solving. One expert noted that emergence is often observed in design processes but lacks a standardized methodology for application, emphasizing the need for a structured exploration of its principles.

Aristotle first explored this concept in his book "Metaphysics" where he defined it as "the whole is something beside the parts" (Cohen, 2016). However, the topic's relevance increased exponentially with the industrial revolution and the impact this had on arising disciplines like industrial design (Dormer, 1993; Heskett, 1980). Now, virtually everything **could** be designed - but the question became: **how should** it be designed? This is where emergence may offer a solution.

Despite its deep roots, the term remains largely undiscussed in today's design research space. Based on the discourse in the design sciences as well as references from philosophy, systems theory and art forms like photography and conceptual art, a unified definition of the term can be explored.

The goal of this paper is threefold: To define the concept of emergence within the design space; to explore the term's significance in the field of industrial design; and to create an artifact to communicate the gained knowledge effectively. This could ultimately assist designers in creating more aesthetically pleasing and functional objects for everyone.

1.2 Problem Statement

Emergence is widely acknowledged as a fundamental principle in design, yet its application within industrial design lacks a clear framework. While various disciplines - ranging from philosophy to behavioural modelling - acknowledge emergent phenomena, industrial design often treats emergence implicitly rather than as a structured methodology. The lack of explicit integration of emergence in design theory limits its potential as a tool for innovation, particularly in developing adaptable, sustainable, and user-centred products. This gap necessitates a systematic exploration of emergence within the design space to define its significance and establish a foundation for its practical application.

Given these challenges, it is essential to establish a structured framework that allows designers to effectively engage with emergent principles. By investigating the defining

characteristics of emergence, its impact on design disciplines, and methods for its effective communication, this study aims to provide valuable insights for industrial designers. These efforts are guided by the following research objectives.

1.3 Research Objectives

This research aims to:

1. Identify the key characteristics of emergence in design by analysing how individual elements interact to create a unified whole.
2. Examine the broader impact of emergent principles across different design disciplines, exploring how emergence influences both form and function.
3. Investigate methods for communicating emergence through design artifacts, emphasizing how tangible prototypes can effectively convey emergent properties.

1.4 Research Questions

To address these objectives, the following research questions guide this study:

1. What are the defining characteristics of emergence within design?
2. How can the implication of emergence impact design disciplines?
3. How can the concept of emergence be effectively communicated through a design artifact?

In essence, these questions seek to define emergence in design and explore its theoretical and practical applications.

CHAPTER 2

2. BACKGROUND RESEARCH

2.1 Types of Emergent Behaviours

Although there is some overlap between these domains, three conceptually distinct forms of emergence could be identified.

2.1.1 Ontological emergence

What is ontological emergence? Ontological emergence is primarily defined based on Aristotle's conceptual framework, but it is further expanded upon and parameterized. Barnes (2012) characterizes emergence using notions of fundamentality and dependence, stipulating that emergence is fundamental in system analysis to explain how individual parts collectively create distinct entities. Furthermore, he states that the distinct and potentially novel properties that the whole system exhibits would not be foreseeable by solely considering the separate elements.

Pepper's (1926) view on emergence aligns with this emphasis on fundamentality and dependence. He describes emergence as a kind of cumulative change that can be explained as

a function of variables at different levels of integration, arguing that emergent properties cannot be deduced from lower-level conditions. However, Pepper (1926) introduces the concept of epiphenomenalism to highlight a dilemma. He challenges the distinctiveness of emergence as a separate phenomenon by arguing that the emergent properties are either epiphenomenal (only occurring once and without causal influence) or must integrate with existing lower-level functions, making the properties neither distinct nor novel. Bar-Yam (2004) affirms this definition of emergence, while interposing the dilemma which Pepper (1926) pointed out by distinguishing between “strong” and “weak” emergence. According to Bar-Yam (2004), strong emergence denotes that the predictability of the properties of the whole is not solely dependent on its parts, implying a non-reducible complexity. Conversely, weak emergence can be understood as a form of emergence more closely related to the natural sciences, in that the properties of the whole can be predicted by its parts.

Lichtenstein (2014) further emphasizes that generative emergence captures the dynamic interactions within complex systems, where continuous adaptation and learning lead to new orders and properties. Together, these perspectives underscore the importance of a robust theoretical framework for understanding emergence in the design space.

2.1.2 Cognitive Emergence in Design

Cognitive emergence in design focuses on how user interaction with products generates new meanings and values. One example of this are Gestalt principles, which provide a foundational framework for understanding how users perceive and interact with emergent design elements. These principles explain how individual components are visually grouped to form coherent structures, impacting how emergence is recognized in design. Wagemans et al. (2012) highlights that designers rely on intuitive visual structuring, aligning with Gestalt principles such as proximity, similarity, and continuity to make sense of complex visual arrangements.

Buchanan (1999) further argues that interaction design relies on emergent properties formed through user engagement with artifacts, where meaning is co-created in real-time. This emergent process makes each interaction unique and responsive, as products adapt based on users’ actions and interpretations. The concept of cognitive emergence is further highlighted in Madsen & Vistisen’s (2019) work, which suggests that designs fostering user interaction can reveal emergent behaviours, enabling the product to develop new qualities or functionalities as users adapt them to personal needs.

Perspectives from practitioners in behavioural modelling further reinforce this, highlighting that user engagement is not only a byproduct of design but a catalyst for emergent behaviour. One expert emphasized that emergent functionality is often shaped through unforeseen user interactions, where adaptation extends beyond intended use cases.

Jain et al. (2011) extends this idea by introducing abduction as a reasoning approach within design, allowing designers to explore potential emergent properties by envisioning multiple possibilities. Abductive reasoning supports cognitive emergence by encouraging flexibility in product functionality and adaptability to user expectations. This aligns with Gregor’s (2013) assertion that design processes are generative, with potential for innovation stemming from how users interact with design elements. Thus, cognitive emergence becomes

central in creating user-centred designs that adapt and evolve through user input, offering dynamic interactions that foster personal connections and engagement.

2.1.3 Systemic Emergence in Design

Systemic emergence in design considers how interdependent components interact within a larger system, yielding complex behaviours and functionality. Lichtenstein (2014) refers to this as “generative emergence,” a framework where ongoing adaptation and feedback within a system enable complex interactions and new properties.

Johnson IV et al. (2013) argue that emergence in complex systems is closely tied to entropy and information flow, where increasing disorder allows new system configurations to arise. This perspective aligns with the role of modularity in design, where components dynamically interact to produce unforeseen yet cohesive results.

In the context of sustainable design, systemic emergence is crucial for creating products that adapt to environmental shifts, contributing to resource conservation and reducing ecological impact. Ågerfalk & Karlsson (2020) also discuss how emergence supports sustainable practices by optimizing system interactions to minimize waste and promote efficiency.

A systemic perspective on emergence considers how interdependent components within a design ecosystem interact to create complex behaviours. Practitioners in design optimization and computational modelling affirm that modular adaptability is a key strategy for fostering systemic emergence, citing examples such as transformable furniture and interactive systems that respond to environmental conditions.

Koch (2022) emphasizes that industrial design within systemic emergence allows for adaptability to technological advances, which is critical for creating products that can evolve with changing user demands. This adaptability is foundational in smart devices and IoT systems, where components (e.g., sensors, software, connectivity modules) are interconnected and responsive, adjusting their behaviour based on user input or environmental conditions. Systemic emergence thus encourages a holistic approach in design, where the product functions within a networked system that enhances its adaptability and relevance over time.

2.2 Synthesis and Definition

Synthesizing these perspectives, I propose that emergence in the design space be defined as: *“a process where individual design elements - whether material, functional, or aesthetic - interact with each other or the user to form a unified, innovative, and irreducible whole that differs from the properties of the individual parts.”*

The understanding of emergence is particularly relevant for industrial designers as it underscores the necessity of recognizing user interactions and environmental factors as integral components of the design process. By leveraging the concept of emergence, designers can develop innovative solutions that are not only aesthetically pleasing but also responsive to the complex demands of modern users and sustainable practices. This holistic approach also encourages a deeper engagement with the multidimensional nature of design, allowing for the creation of products that are not merely functional but might also resonate better with the users on a contextual and emotional level.

As seen in Koch's (2022) and Gregor's (2013) work, the capacity for products to exhibit emergent properties, such as adaptability, functionality, and aesthetic appeal, is key to the future of design innovation. Next to this, Barnes (2012) and Bar-Yam (2004) provide a robust framework for thinking about emergence through a philosophical and theoretical lens. Their perspectives encourage designers to think of products as complex systems, where emergent properties arise from the interplay of components and contexts, enabling the occurrence of more innovative and effective designs.

Ultimately, acknowledging emergence in industrial design goes hand in hand with a mindset that values adaptability and responsiveness. Designers who integrate emergent properties into their processes can better hedge against evolving user needs and environmental challenges, enabling and leading to more effective and sustainable design practices. As the field continues to evolve, integrating the principles of emergence will be essential for designers to create meaningful and impactful designs that thrive in an increasingly complex world.

2.3 Potential benefits of Applied Emergence

2.3.1 User Experience

Building on the discussion of the creative process, user interaction serves as a critical catalyst in shaping the emergence of design properties, fundamentally influencing how products evolve and perform in real-world contexts. This leads to the question: "What role does user interaction play in the emergence of design properties?" Gregor (2013) contends that design must be viewed as a generative process, wherein the interplay between user engagement and designed elements culminates in innovative outcomes. Buchanan (1999) supports this idea by stressing the dynamism of artifacts. He suggests that the design of artifacts is about the interrelation of users and products, which leads to the emergence of new meanings and values.

By recognizing the dynamic interplay between individual design elements, designers can create innovative products that transcend traditional limitations. Likewise, Koch (2022) suggests that the ability to harness emergent properties facilitates the development of responsive solutions that better address user needs and environmental considerations. The practical implications of embracing emergence are profound. Gregor (2013) emphasizes that leveraging emergent properties enables designers to create products that fulfil functional requirements while enhancing user experiences and addressing pressing environmental challenges.

Co-creation further amplifies these benefits by transforming users from passive participants into active contributors to the design process. Through co-creation, users collaborate with designers to shape the emergent properties of a product, ensuring that these properties align more closely with user expectations, needs, and contextual realities. This collaborative approach allows the design process to adapt dynamically to user feedback, fostering a sense of shared ownership while enhancing the relevance and functionality of the final product. By embedding co-creation into the design of emergent systems, designers can cultivate deeper engagement and create solutions that are not only innovative but also personally meaningful to the users involved. Research on co-design and participatory

methodologies highlights how user participation through structured interactions, such as workshops and iterative feedback loops, enhance user involvement and contribute to the development of emergent design properties (Wang et al., 2023).

2.3.2 Adaptability

The understanding of emergence is particularly relevant for industrial designers as it underscores the necessity of recognizing user interactions and environmental factors as integral components of the design process as underscored by Chiapponi (1998). By leveraging the concept of emergence, designers can develop innovative solutions that are not only aesthetically pleasing but also responsive to the complex demands of modern users and sustainable practices. This holistic approach also encourages a deeper engagement with the multidimensional nature of design, allowing for the creation of products that are not merely functional but might also resonate better with the users on a contextual and emotional level.

The influence of emergence on the creative process in industrial design is substantial, affecting how designers approach the integration of components and the interplay between form and function. This leads to the central question: "How does emergence impact the creative process in industrial design?" Gregor (2013) posits that design should be perceived as a generative process, where the collaboration of individual components can yield innovative outputs that exceed the capabilities of each part. In contrast, Koch (2022) underscores the need for industrial design to adapt to rapidly changing technological landscapes, highlighting that understanding emergent behaviours resulting from user interactions is crucial for creating products that effectively respond to evolving needs.

2.3.3 Sustainability

Understanding emergence is crucial for advancing sustainable design practices, as it provides insights that lead to innovative and environmentally adaptive solutions. This prompts the inquiry: "How can understanding emergence contribute to sustainable design practices?" Senge (2006) argues that emergent processes within sustainable design yield not only innovative solutions but also long-term value creation. Koch (2022) reinforce this connection by asserting that the innovative processes associated with emergence allow industrial designers to adapt to technological advancements while upholding ecological responsibility.

By recognizing the dynamic interplay between individual design elements, designers can create innovative products that transcend traditional limitations. Likewise, Koch (2022) suggests that the ability to harness emergent properties facilitates the development of responsive solutions that better address user needs and environmental considerations.

CHAPTER 3

3. METHODS AND TECHNIQUES

This study employs a mixed-method approach, combining a literature-based framework with artifact development and user testing, to validate the artifact's effectiveness in conveying the concept of emergence to users. The methodology encompasses three main phases: establishing an analytical framework through literature review, developing an interactive artifact, and conducting a controlled user test to assess the artifact's communicative effectiveness.

3.1 Expert Interviews

To complement the literature-based framework, this study integrates insights from structured discussions with design researchers and experts in behavioural modelling as a qualitative research method. The approach was guided by Robert Kaiser's *Qualitative Experteninterviews*, which provided a systematic framework for conducting interviews with domain experts to elicit in-depth, field-specific knowledge. Expert interviews were selected for their ability to bridge theoretical discourse with practical insights, allowing for a nuanced understanding of emergence in industrial design. These discussions focused on the unpredictability of emergent properties, user-driven interaction, and the role of modularity in fostering adaptable designs. The responses were thematically analysed to extract recurring patterns, such as "interaction-driven emergence," "configurational unpredictability," and "adaptive modularity." These findings informed both the theoretical exploration and the artifact development phase, ensuring that emergent principles were considered in a practical design context.

3.1.1 Rationale for Expert Interviews

Kaiser (2014) outlines expert interviews as a method particularly suited for topics that require specialized knowledge beyond what is available in existing literature. Emergence, as explored in this thesis, spans multiple disciplines, including philosophy, systems theory, and industrial design. While theoretical perspectives on emergence exist, their application within the design space remains underexplored. By engaging with experts in design research, behavioural modelling, and material innovation, this study seeks to refine the conceptual framework of emergence and identify its practical implications in design practice.

The inclusion of expert interviews serves three key objectives:

1. **Validation of Theoretical Constructs** – Experts provide insights into whether the ontological, cognitive, and systemic categories of emergence accurately represent the phenomenon in design contexts.
2. **Application-Oriented Perspectives** – Practitioners offer reflections on how emergence manifests in real-world design processes and how it can be harnessed intentionally.
3. **Identifying Gaps and Future Directions** – Interviews highlight limitations in the current understanding of emergence and suggest avenues for further research or design experimentation.

3.1.2 Structure and Question Development

Kaiser emphasizes that expert interviews should strike a balance between structure and flexibility. While a predefined set of questions ensures consistency across interviews, open-ended questions allow experts to introduce novel insights. Accordingly, this study employs a **semi-structured interview format**, ensuring that key themes—emergence types, user interaction, sustainability, and design challenges—are systematically addressed while allowing for expert-driven elaboration.

The interview questions were formulated in alignment with Kaiser’s approach, which differentiates between **exploratory, clarifying, and evaluative** questions.

This structured progression from broad conceptual discussions to practical evaluation follows Kaiser’s recommendation for **gradual knowledge elicitation**, ensuring that expert responses contribute meaningfully to the research objectives.

3.1.4 Ethical Considerations and Data Handling

All participants were informed about the study’s objectives and provided consent for their interviews to be recorded and transcribed. Kaiser (2014) stresses the importance of **transparency and data protection**, which was ensured by anonymizing responses where necessary and storing data securely. The transcripts were thematically coded using an **iterative analysis process**, wherein emerging patterns were categorized in relation to the theoretical framework of the study

3.2 Literature Review and Analytical Framework

The initial phase involved a comprehensive literature review to identify key concepts of emergence - ontological, cognitive, and systemic - and to define their implications for design. Drawing from foundational theories (such as Aristotle’s concept of the whole being more than the sum of its parts) and contemporary research on emergence in design (Barnes, 2012; Buchanan, 1999; Lichtenstein, 2014), a structured analytical framework was established. This framework categorizes the types of emergences relevant to design and outlines anticipated implications for user experience, adaptability, and sustainability. The review also provided the theoretical grounding to inform the artifact’s design, aligning the artifact’s features with key emergence concepts to ensure it would serve as an effective educational tool.

3.3 Artifact Design and Development

Building on insights from Mader & Eggink (2014), the design process followed an iterative and structured approach that aligns with established Creative Technology methodologies. Rather than centring solely on the final prototype, this research emphasizes the design process as a framework for exploring emergent properties within industrial design.

3.3.1 The Creative Technology Design Process

The design process used in this study follows a **four-phase model** comprising **Ideation, Specification, Realization, and Evaluation**. Each phase was structured to ensure a balanced integration of user-centred and technology-driven design methods. The iterative refinement

process allowed for an exploration of configurational unpredictability and emergent behaviours in a way that aligns with the conceptual objectives of the research.

- **Ideation:** The design exploration began with a broad conceptualization of emergence in industrial design. Various possibilities for form, materiality, and interaction mechanisms were explored to assess their potential to stimulate emergent behaviour.
- **Specification:** After refining the core ideas, a structured framework of functional and non-functional requirements was established. This phase ensured that the balance between modularity and system integration was maintained while keeping the design practical for real-world application.
- **Realization:** Given the constraints of this study, the prototype was developed as a high-fidelity digital model rather than a physical artifact. This approach was chosen to facilitate a controlled evaluation process, where participants could assess emergence-related properties without being influenced by material inconsistencies or manufacturing limitations.
- **Evaluation:** The final phase assessed the prototype in its different configurations through structured testing, allowing insights into how users perceive and interpret emergent behaviours in design.

3.3.2 Balancing Modularity and Integration

One of the primary design challenges was maintaining an equilibrium between modular adaptability and systemic cohesion. Emergence in design is often characterized by elements that contribute to an evolving whole in ways that are unpredictable yet coherent. To address this, the design process incorporated prototyping iterations with varying levels of modularity, ensuring that changes in connectivity, form, and function influenced emergent behaviours as intended.

3.3.3 Rationale for an Iterative Approach

Rather than adopting a linear engineering methodology, the study employed an iterative and feedback-driven approach. This ensured:

- **Progressive refinement of emergent properties**, with configurations tested before committing to a final design.
- **User-informed evolution of the design**, allowing participant insights to shape the adaptability and coherence of modular arrangements.
- **Flexible material and interaction integration**, ensuring that emergent properties were not constrained by rigid design parameters but allowed to develop organically.

3.3.4 Alignment with Research Scope

This approach ensures that emergence was not only a conceptual principle but also an actively explored phenomenon throughout the development process. The structured, iterative refinement aligns with the study's objectives, emphasizing design as a process-driven exploration rather than merely a final product evaluation.

3.4 User Testing

To assess whether the modular lighting prototype successfully conveyed emergent properties, a structured user study was conducted. The evaluation aimed to measure participants' perception of emergence, the impact of modularity on their understanding, and their ability to imagine various configurations and applications of the design.

3.4.1 Study Design

Participants were presented with a set of rendered images of the prototype in multiple states and configurations. They were then guided through a structured questionnaire designed to capture both quantitative and qualitative insights. The study was divided into three key components:

1. **Pre-Exposure Assessment:** Participants answered baseline questions to gauge their prior understanding of emergence in design.
2. **Stimulus Presentation:** Participants were shown a series of rendered images depicting different configurations and lighting scenarios of the modular lamp. These images were carefully curated to highlight systemic emergence, configurational unpredictability, and user-driven interaction.
3. **Post-Exposure Questionnaire:** After viewing the images, participants responded to a combination of Likert-scale items and open-ended questions assessing their perception of the prototype's emergent qualities, functional adaptability, and aesthetic coherence.

3.4.1a Additional Consideration:

While prior research emphasizes the value of physical prototype manipulation in evaluating emergence, the image-based approach used in this study was carefully structured to retain validity. By presenting participants with highly detailed renders of various configurations, the study ensured that perceptual emergence remained the focal point of evaluation, compensating for the lack of direct physical interaction.

3.4.2 Data Collection and Analysis

Data was collected through both quantitative measures (Likert-scale ratings) and qualitative feedback (open-ended responses).

- **Statistical analysis** was conducted on Likert-scale responses to measure trends in perception.
- **Thematic analysis** was applied to qualitative responses to identify recurring patterns in how participants described emergent properties.

3.4.3 Expected Outcomes and Iteration

The outcomes from the user testing phase will inform the artifact's success in enhancing user understanding of emergence. If the experimental group demonstrates a statistically significant increase in comprehension compared to the control group, it will validate the artifact's capacity to communicate emergent principles. Qualitative feedback will guide future refinements to the artifact, further enhancing its educational impact and providing insights into effective approaches for embedding emergence into design practices.

By combining theoretical grounding with interactive learning and controlled testing, this methodology aims to validate both the artifact's design efficacy and its role in enhancing users' understanding of emergence in design contexts.

3.4.4 Ethical Considerations

Ethical approval for the user study was obtained from the Ethics Committee Information & Computer Science (CIS) at the University of Twente before involving participants. A detailed information brochure and consent form were provided, ensuring participants were fully informed about the study's objectives and data collection methods.

CHAPTER 4

4. IDEATION

4.1 Constraints

In the ideation phase, key constraints are essential for narrowing down the artifact's potential design and ensuring that it effectively conveys the concept of emergence to users. These constraints address both practical and conceptual challenges, guiding the design process toward an artifact that balances complexity with clarity in illustrating emergent properties.

4.1.1 Identifiability of the Emergent Process

One primary constraint is ensuring that users can easily perceive the relationship between individual components and the emergent whole. As noted, if an artifact is divided into too many parts, the emergent process may become obscured, as users might struggle to mentally integrate these parts into a cohesive whole. This effect is seen in systems with highly granular structures, like pixels on a screen, where individual units are nearly indistinguishable, making it difficult for users to conceptualize the emergent property they form together.

To address this, the design should limit the number of discrete parts to a manageable level, allowing users to identify how each component contributes to the overall emergent quality. This constraint aligns with ontological emergence by helping users intuitively grasp how separate elements interact to create a unified property. Structuring the artifact in a way that maintains the identifiability of the emergent process would enhance users' ability to understand emergence visually and conceptually.

4.1.2 Simplicity of Interaction

Another constraint is ensuring that user interactions with the artifact remain simple and intuitive, a key factor according to Chang et al. (2007). Cognitive emergence relies on the user's ability to engage with the artifact meaningfully, so overly complex interactions may hinder comprehension of the emergent properties. By designing an artifact that requires only a few,

clear actions to reveal emergent effects, users are more likely to connect their inputs with the resulting emergent qualities.

To support this, the artifact might include straightforward controls or modular adjustments, minimizing the risk of cognitive overload. Simplified interaction pathways would also allow users to focus on observing how their interactions contribute to the artifact's emergent properties rather than navigating overly intricate processes.

4.1.3 Dynamic, Observable Change

A third constraint involves ensuring that emergent properties are observable as users interact with the artifact. Emergent properties must be dynamically expressed in a way that allows users to witness the shift from individual parts to a holistic outcome. This is particularly relevant for systemic emergence, where the artifact should visibly adapt or respond as users engage with it, illustrating how interdependent components give rise to complex behaviours.

Achieving this might involve including elements that visibly change based on user input or environmental factors, allowing users to recognize the adaptive qualities of the artifact. Ensuring that these changes are noticeable without being too gradual or too rapid would help users appreciate the emergent behaviours without becoming confused or disengaged.

4.1.4 Balance Between Modularity and Integration

Another important constraint is maintaining a balance between modularity and integration. For emergence to be identifiable, the artifact should avoid extreme modularity where components appear too isolated, as this could prevent users from perceiving the whole. Conversely, components must remain distinct enough to highlight their roles within the emergent process, enabling users to see how individual parts contribute to the overall system.

In practical terms, this balance might involve designing components that fit together in a way that is visually and functionally coherent, allowing users to see how each module contributes to the emergent outcome without overshadowing the whole. This balance would reinforce users' understanding of both cognitive and systemic emergence.

4.2 Accessibility and Ease of Use

Finally, accessibility is a constraint that will influence the artifact's physical and conceptual design. The artifact should be approachable for a general audience, with minimal prerequisites for understanding or engaging with it. Avoiding specialized knowledge requirements ensures that users from various backgrounds can engage with and appreciate emergent principles, making the artifact a more effective educational tool.

4.3 Iterative Validation and Refinement of Concepts

To ensure the constraints identified for the artifact align with user needs and theoretical underpinnings, the ideation phase involved iterative development informed by stakeholder validation and background research. This process balanced conceptual exploration with practical considerations, leading to a preferred concept for development in the Specification

phase.

4.4 Stakeholder Validation and Concept Refinement

An iterative approach was adopted to validate the emergent design principles with stakeholders, including design researchers and industry professionals. Initial concepts were presented in the form of sketches and descriptions, emphasizing core constraints such as simplicity of interaction and dynamic, observable change. Feedback from stakeholders indicated the importance of maintaining a clear relationship between modular components and emergent properties, highlighting that overly complex designs could obscure the artifact's educational purpose. Based on this input, concepts were refined to ensure greater clarity in how user interactions would result in observable emergent effects.

Additionally, these discussions revealed a strong preference for intuitive design features, which informed the prioritization of accessibility and ease of use in subsequent iterations. Stakeholder feedback was particularly influential in refining the balance between modularity and integration, ensuring that the artifact could convey emergent behaviours without overwhelming users. This aligns with Buchanan's (2001) insights into cognitive emergence, which emphasize that user engagement and co-creation play a pivotal role in shaping emergent design outcomes.

4.5 Iterative Concept Development

The ideation phase followed a structured process of divergence and convergence, as outlined by Mader & Eggink (2014). During the divergence stage, multiple design concepts were generated to explore the range of possibilities within the identified constraints. These included variations in modularity, interaction simplicity, and the scale of observable change. For instance, one concept focused on extreme modularity with interchangeable parts, while another prioritized integration and seamless transitions between states.

In the convergence stage, these concepts were evaluated against stakeholder feedback and the identified constraints. Iterative prototyping allowed for the testing of key features, such as the perceptibility of emergent properties and the intuitiveness of interaction pathways. Concepts that failed to meet the criteria or elicited confusion from stakeholders were discarded, while promising designs were further refined. This iterative refinement process reflects the principles of systemic emergence (Lichtenstein, 2014), where complex behaviours arise through structured adaptation and user interaction.

4.6 Preferred Concept Selection

The iterative process culminated in the selection of a preferred concept that best fulfilled the identified constraints and stakeholder expectations. The chosen design balances modularity and integration by using components that visually and functionally connect to illustrate the emergent process. Interaction simplicity is achieved through intuitive user controls, enabling users to observe dynamic changes without requiring extensive instructions. Stakeholders particularly appreciated the artifact's ability to visually adapt based on user input, reinforcing the concept's systemic and cognitive emergence qualities.

CHAPTER 5

5. SPECIFICATION

5.1 Introduction

The specification phase translates the preferred concept of the modular lamp into a detailed and structured design framework. This phase refines preliminary requirements into well-defined functional and non-functional requirements while validating the technical feasibility and user expectations. Given the emergent nature of the lamp, the specification must address modularity, interaction dynamics, and sustainability aspects to ensure coherence between conceptual intent and practical execution. Additionally, stakeholders emphasized the **didactic potential** of the prototype, ensuring that it serves as a tool to explain emergence effectively. The final interaction must also integrate **co-creation** elements, allowing users to collaboratively explore emergent properties.

5.2 Functional and Non-Functional Requirements

The functional requirements (FRs) describe what the modular lamp does, whereas the non-functional requirements (NFRs) define the qualitative characteristics that influence usability and sustainability. These requirements were directly derived from the constraints established in the ideation chapter and further refined based on iterative stakeholder feedback and feasibility constraints.

Functional Requirements:

1. **Modularity:** The lamp must allow users to assemble different configurations using magnetic attachment points.
2. **Independent Light Control:** Each module must contain an independent battery-powered light source.
3. **Interactivity:** Users should be able to rearrange the modules freely, experiencing emergent lighting patterns.
4. **Configurability:** The system should support at least **2** distinct configurations.
5. **Magnetic Connectivity:** Modules must attach and detach effortlessly through magnetic connectors.
6. **Base Stability:** The base should provide adequate stability for various configurations.
7. **Didactic Design:** The prototype should effectively demonstrate the concept of emergence in a visually and functionally comprehensible manner.
8. **Co-Creation Support:** The final interaction should include mechanisms for collaborative assembly and design exploration.

Non-Functional Requirements:

1. **Aesthetic Longevity:** The lamp should develop a visually appealing wear pattern over time.
2. **Sustainability:** The materials should be biodegradable or recyclable, reducing environmental impact.

3. **Light Diffusion Quality:** The chosen materials must provide soft, ambient lighting without glare.
4. **Structural Integrity:** The modules must be lightweight yet durable to withstand repeated reconfigurations.
5. **User-Friendly Assembly:** No special tools should be required for assembly or disassembly.

5.3 Stakeholder Validation

Stakeholder feedback was integral to refining the lamp's requirements. The primary considerations included:

- **Intuitiveness of Interaction:** Stakeholders emphasized the need for a seamless, intuitive user experience.
- **Material Concerns:** There was a preference for bio-based alternatives to traditional resin.
- **Wear and Aging:** The concept of aesthetic wear-in was well received, reinforcing the decision to use a coated metal base.
- **Didactic Utility:** Stakeholders stressed that the lamp should be able to explain emergence as a core concept.
- **Co-Creation Potential:** Emphasized the importance of allowing multiple users to interact with and modify the lamp collaboratively.

5.4 Product Specification

The final specification details the core components, their interactions, and design constraints.

5.4.1 Modular Components

The modular lamp consists of eight primary components:

- **Base:** A pressed-down half-spherical structure, made of coated aluminium.
- **Two Plate-Like Modules:** Flat elliptical forms contributing to surface diffusion.
- **Two Vase-Shaped Modules:** Organic forms introducing sculptural variation.
- **One Elongated Rod:** Enhances vertical stacking possibilities.
- **Two Connector Pieces:** Enable alternative assembly formations.

5.4.2 Interaction Mechanics

The lamp's magnetic attachment system allows:

- **Rotational Adjustments:** Modules can pivot without losing the electrical connection.
- **Incremental Expansion:** Users can gradually increase the lamp's height or lateral spread.
- **Modular Independence:** Light modules function both when attached to the base and when separated.
- **Collaborative Assembly:** Users can experiment together in arranging modules, fostering co-creation.
- **Emergent Demonstration:** The interaction process should illustrate the fundamental principles of emergence.

5.5 Material Selection

The specification process refined material choices to balance sustainability and functionality:

- **Light Modules:** Bio-based polycarbonate or reinforced bioplastics for translucency and durability.
- **Magnetic Connectors:** Small metallic points embedded within each module for seamless connectivity.
- **Base Coating:** A deep blue paint designed to chip over time, revealing the aluminium base.

5.6 Summary

This specification phase establishes the detailed framework for the modular lamp, ensuring coherence between conceptual vision, emergent design principles, and functional realization. The lamp must also serve a **didactic** function, visually demonstrating emergence through interaction. Additionally, the final prototype will incorporate **co-creation** features, encouraging multiple users to collaboratively engage with its reconfiguration. The next phase involves the **realization** of this specification through iterative prototyping and evaluation.

CHAPTER 6

6. REALISATION

6.1 Introduction

The realisation phase of this project focused on translating the conceptual design of the modular lamp into a functional prototype that embodies emergent properties. The iterative development process ensured alignment with the theoretical foundation of emergence, with particular attention to modularity, user interaction, and sustainability. The prototype was evaluated through rendered images rather than physical testing, necessitating precise digital representation to communicate its design principles effectively.

6.2 Development Approach

The design and development of the modular lamp prototype followed an iterative and combinatorial approach. Various modular elements were analysed based on their emergent potential, categorized into form, function, and materiality, and then cross-matched to create meaningful combinations. This process was informed by references such as modular furniture designs and industrial design artifacts that prioritize adaptability and interaction. Among the various design references, Pfersdorf (2022), and Bradbury (2014) offered invaluable insights into different established artifacts. These included references to works like Zettel'z by Maurer, I. and Shuffle MH1 Hamborg, M. which matched the aforementioned criteria of adaptability and interaction.

6.2.1 Prototyping Strategy

Given the constraints of this study, the prototype was developed as a high-fidelity digital model rather than a physical artifact. This approach was chosen to facilitate a controlled evaluation process, where participants could assess emergence-related properties without being influenced by material inconsistencies or manufacturing limitations. The prototype was rendered in multiple configurations to illustrate its adaptability and the emergent qualities of its modular assembly (*see appendix nr.2*).

6.2.2 Modularity and Emergent Properties

The modular lamp consists of eight pieces: a base and seven interchangeable light modules. Each module is uniquely shaped, allowing for various configurations that influence both aesthetic and functional outcomes. The magnetic attachment system enables seamless rearrangement, with the potential for **47,293** (*see appendix nr.1*) unique configurations, reinforcing the concept of systemic emergence. Users can experience cognitive emergence as they experiment with different spatial arrangements, discovering new visual and functional qualities through interaction with the system.



Figure 1: Lamp in exploded view orthographic



Figure 2: Lamp in use (split)

These renders show the lamp in its separate parts, and in its scattered constellation. If assembled as a tower with all segments being stacked on top of each other, the number of different variations is $7! = 5040$.

6.3 Design Language and Aesthetic Cohesion

The modular lamp employs a cohesive design language that is guided by the principle of aesthetic unity through form and materiality. The decision to exclusively utilize rounded geometries across all components ensures a visual consistency that reinforces the perception of the lamp as a singular entity, despite its modularity. Each individual piece—whether the vase-shaped modules, the flattened elliptical plates, or the elongated rod—adheres to a soft, curved morphology that fosters a sense of organic fluidity in any configuration. This design approach aligns with the emergent nature of the lamp, where individual elements seamlessly integrate into a greater whole without jarring transitions. Below, three variations of the lamp are shown to exemplify this:



Figure 3: Three modular lamp combinations

A key element in grounding the modular composition within its physical environment is the base, which takes the form of a pressed-down half-cylinder with a flat bottom. Functionally, this stabilizes the lamp in various configurations, but it also serves an aesthetic role by providing a clear visual anchor. The contrast between the base's solid presence and the more delicate light modules enhances the perception of balance, ensuring that even the most asymmetrical arrangements retain a harmonious visual weight.

The attachment system is also an integral part of the lamp's aesthetic and interactive language. Around each magnetic connection point, a subtle silver ring frames the junction, both signalling attachment locations and reinforcing the modular system's precision. These rings serve a dual purpose: they provide a visual guide for users as they assemble and reconfigure the lamp, while also subtly highlighting the connection points as intentional design elements rather than functional necessities alone. This careful integration of form and interaction ensures that user engagement with the lamp remains intuitive while maintaining the overall aesthetic cohesion.

By adhering to a unified vocabulary of rounded geometries, grounding the structure with a well-defined base, and incorporating subtle visual cues for interaction, the modular lamp achieves a design that is both functionally adaptable and visually cohesive. This approach not only enhances the perception of the lamp as an emergent system but also strengthens its capacity to integrate seamlessly into diverse interior environments.

6.4 Colour

The colour selection for the modular lamp plays a crucial role in reinforcing its aesthetic and conceptual grounding. Central to this approach is the contrast between the deep, dark blue of

the base and the warm, pale lemon-yellow glow of the light modules. This pairing is not only visually striking but also functionally necessary, serving to anchor the ethereal, modular elements within a defined spatial presence.

From a theoretical perspective, the combination of dark blue and warm yellow follows principles of colour harmony as outlined by Wada (2011). In his work, he highlights the effective pairing of Dark Tyrian Blue with Pale Lemon Yellow, a combination that balances richness and warmth, creating a dynamic yet cohesive visual experience. In the case of the lamp, the dark blue base absorbs and stabilizes the composition, while the luminous yellow modules provide a sense of lightness and adaptability. This interplay between depth and radiance enhances the perception of the lamp as both a sculptural and functional object, oscillating between a structured system and an emergent, user-defined composition.

Beyond colour theory, the choice of dark blue for the base was an intuitive decision aimed at firmly rooting the lamp within the tangible world. The modular light elements, with their soft yellow glow, possess an inherent weightlessness, reinforcing the concept of fluid reconfigurability and adaptability. However, without a contrasting element, the design risked becoming too abstract and unimaginable in a physical setting. The base, through its deep hue and defined form, serves as a counterbalance to this lightness, ensuring that the lamp remains visually and functionally grounded. It acts as an anchor, providing a point of stability that allows the modular system to exist not as a fleeting concept but as a tangible, interactive object in real-world environments.

By integrating principles of contrast, harmony, and grounding, the lamp's colour scheme enhances its emergent qualities while ensuring coherence between form and function. The dark blue base does not merely serve as a foundation in a structural sense but also operates as a visual and conceptual stabilizer, allowing the modular lamp to occupy a space where dynamic configurability meets aesthetic clarity.

6.5 Material Considerations

A key objective of the realisation phase was to explore material choices that align with the principles of sustainability and aesthetic longevity. The primary challenge was identifying materials that provide the necessary rigidity and translucency while being environmentally responsible.

6.5.1 Design Philosophy

Given the project's focus on ecological design, bio-based polycarbonates and reinforced bioplastics were considered for the light modules. These materials offer light diffusion properties while reducing reliance on petroleum-based plastics. Traditional resins were avoided due to their environmental impact. The base of the lamp was designed using metal coated with a deep blue paint that gradually chips over time, revealing the metal underneath—a feature inspired by the design philosophy outlined by Moggridge (2007). This approach fosters a stronger emotional connection between the user and the object, as the lamp acquires character through use.

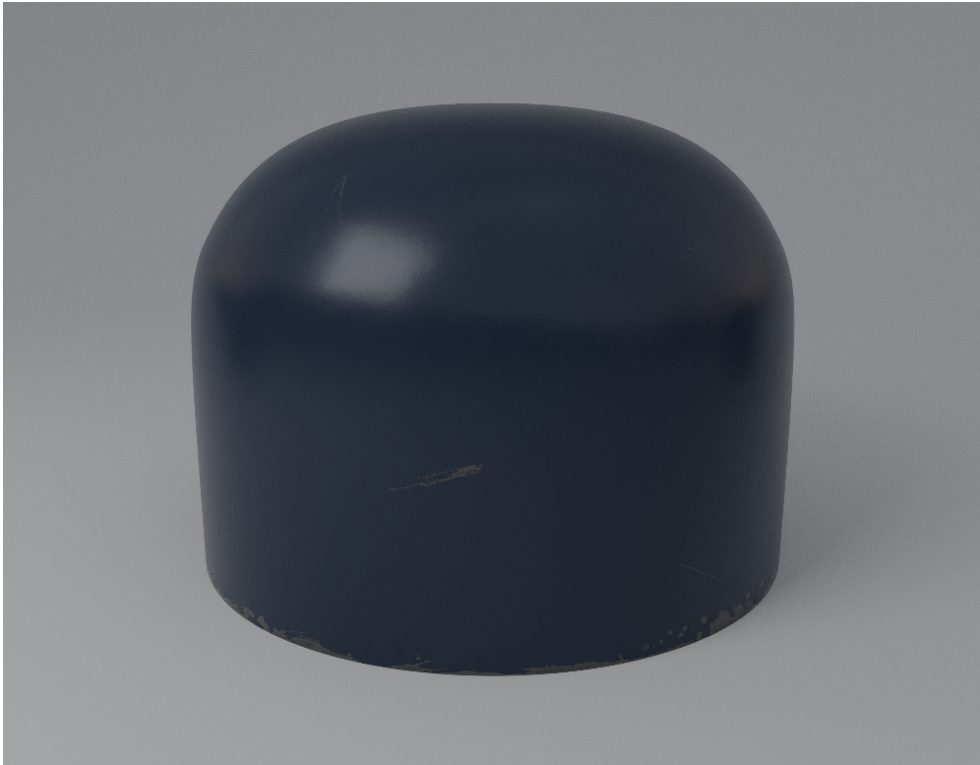


Figure 4: Base of the lamp close-up

6.5.1 Sustainable Material Alternatives

Considering the notion that emergence may lead to more sustainable design, this was reflected in the deliberation of sustainable alternatives to the materials used in the lamp, primarily resin. Traditional petroleum-based resins, while widely used for their durability and ease of manufacturing, pose significant environmental challenges due to their reliance on fossil fuels and limited end-of-life recyclability. In selecting a material for the light modules, two primary concerns had to be addressed: **translucency**, ensuring effective light diffusion, and **durability**, allowing the lamp modules to withstand repeated handling and reconfiguration.

Bio-based transparent wood bio-composites, created by impregnating delignified wood with limonene acrylate, offer high optical clarity and structural resilience, making them a viable alternative (Maiti et al., 2022).

Even though these bio-composites are not biodegradable, they are bioderived. Further research could identify materials which do not compromise on sustainability or structural rigidity and other material functions. If possible, utilizing more sustainable materials would align the prototype more closely with environmentally responsible design principles.

6.5 Digital Representation and Evaluation Preparation

Since physical prototyping was not within the scope of this study, the realisation phase focused on creating photorealistic renders to communicate the lamp's emergent properties effectively. The renders highlighted various configurations and lighting conditions, allowing participants to assess the lamp's adaptability and interaction potential. The digital prototype was prepared in multiple states to showcase:

- Different spatial distributions of the light modules
- The impact of individual vs. collective illumination
- The interplay between modularity and holistic form

6.5 Conclusion

The realization phase successfully translated the theoretical framework of emergence into a modular lighting system that embodies adaptability, interaction, and sustainable material considerations. The prototype's digital representation serves as an effective tool for evaluating emergent design principles, offering insights into user perception of modularity and reconfigurability. The next phase of this study focuses on the evaluation process, where participants will analyse the rendered images and provide feedback on the emergent qualities observed in the lamp's design.

CHAPTER 7

7. EVALUATION

7.1 Introduction

The evaluation phase aimed to assess the effectiveness of the designed prototype in conveying emergent properties and its ability to enhance user understanding of emergence in industrial design. Through structured user testing, participants were presented with rendered images of the prototype, asked to engage with a questionnaire, and provided qualitative feedback on their perception of emergence. This chapter presents the key findings from the evaluation, reflecting on user responses, the degree to which the prototype aligns with the theoretical definition of emergence, and potential areas for future refinement.

7.2 Methodology

The evaluation was conducted through a structured user study involving two participant groups. The primary objectives of the study were:

1. To determine whether the prototype successfully embodies emergent properties as defined in the thesis.
2. To assess whether viewing the prototype enhances participants' conceptual understanding of emergence.
3. To explore how participants imagine potential applications or interactions with the design.

Participants were first asked pre-exposure questions to gauge their prior understanding of emergence. They were then shown a definition of emergence before being presented with the prototype through a series of rendered images. Following this, participants completed a Likert-scale and open-ended questionnaire designed to evaluate their perception of the prototype's aesthetic cohesion, functionality, and emergent qualities.

Data collection included both qualitative insights (via open-ended responses) and quantitative data (from Likert-scale ratings). Thematic analysis was used to categorize recurring participant observations, while statistical analysis was applied to Likert-scale results to measure overall trends in perception, including mean values, standard deviation, and variance.

7.3 Key Findings

The findings of this study (*see appendix 3*) suggest that emergence in industrial design is best understood as an iterative process, shaped by both design intent and user interaction. Previous theoretical discussions (Bar-Yam, 2004) emphasize unpredictability as a defining characteristic of emergence, yet insights from practitioners suggest that while unpredictability remains a factor, emergence can be fostered through intentional design strategies. One expert noted that "testing configurations in real-world contexts provides the only reliable means of validating emergent properties," reinforcing the need for empirical validation alongside theoretical modelling. This suggests that the integration of emergent properties into design is not purely a conceptual exercise but a practice-oriented methodology requiring iteration and adaptation.

7.3.1 Perception of Emergence in the Prototype

Analysis of participant responses indicates that the prototype successfully demonstrates emergence. When asked whether the design aligns with the given definition of emergence, the majority of participants (80%) responded positively, citing characteristics such as "unified yet evolving structure," "unexpected coherence from individual parts," and "dynamic interplay of form and function."

Likert-scale data aimed to answer the following four key evaluation questions:

1. To what extent does the design exhibit aesthetic cohesion?
2. How functional do you find the design?
3. To what extent did viewing the prototype enhance your understanding of emergence?
4. To what extent does the design align with the concept of emergence?

The mean scores across ten participants were:

- **Q1: 4.5**
- **Q2: 4.7**
- **Q3: 4.6**
- **Q4: 4.9**

These high ratings suggest a strong alignment between the intended emergent qualities and user perception.

7.3.2 Influence on Understanding of Emergence

Prior to viewing the prototype, participants provided varied definitions of emergence, often describing it in abstract or theoretical terms. However, after engaging with the prototype, 80% of participants reported that the design helped solidify their understanding of emergence, with many emphasizing that visual representation made the concept more tangible.

The Likert-scale rating for "extent to which the prototype helped understand emergence" averaged **4.6/5**, indicating that the design positively influenced comprehension. One participant remarked: "To be honest, the term sounded very abstract at first, and it's hard to imagine what an actual product might look like. Seeing the elements come together and all the different parts of the definition makes it more graspable."

7.3.3 Aesthetic and Functional Cohesion

The evaluation also examined whether participants perceived the prototype as a balanced design in terms of aesthetics and functionality. The aesthetic cohesion of the prototype received an average rating of **4.5/5**, with users highlighting the seamless integration of elements and an overall sense of unity.

In terms of functionality, the prototype was rated **4.7/5**, with some participants suggesting that additional interactive elements could further enhance its demonstration of emergence. Nonetheless, respondents acknowledged the clarity of its functional logic, particularly in how individual elements contribute to a cohesive whole.

A participant stated: "I really like the design! It really stands out to me that you can split up the lamp into different parts, and it still works beautifully."

7.3.4 Statistical Analysis of Responses

To assess the reliability of the quantitative responses, standard deviation and variance were calculated for each question:

- **Q1: Standard Deviation = 0.52, Variance = 0.28**
- **Q2: Standard Deviation = 0.48, Variance = 0.28**
- **Q3: Standard Deviation = 0.52, Variance = 0.27**
- **Q4: Standard Deviation = 0.32, Variance = 0.10**

A normality test was performed, indicating that the data closely follows a normal distribution. This supports the consistency and reliability of participant responses, with relatively low variance across answers.

7.3.5 Interpretation of Statistical Results

The statistical results reinforce the robustness of the user evaluation. The low standard deviation values suggest that responses were relatively consistent, indicating strong agreement among participants. The low variance, particularly for Q4 (**0.10**), implies a high degree of confidence that participants perceived the prototype as aligning with the concept of emergence. The slightly higher variance in Q3 (**0.27**) suggests that some participants may have had a broader range of interpretations regarding how the prototype influenced their understanding of emergence. However, the overall trend indicates that the design effectively conveyed emergent properties.

These statistical findings further validate the qualitative feedback, showing that both objective ratings and subjective insights support the conclusion that the prototype successfully demonstrates emergence in industrial design.

7.3.6 Co-Creation and Potential Applications

A key aspect of the evaluation was exploring how participants imagined interacting with the prototype in novel ways. Participants were asked how they could see the design being used or adapted, and responses included:

"I can imagine using this lamp in my shared flat because I really like the dynamic of how I could use it. One idea I had was to split up the lamp with my flatmates so everybody can have one part in their room, and when we meet together in the common rooms, we could bring our little lamp and create different lighting depending on who is in the room."

"I think, I would like to use it for a candlelight dinner without candle lights. I would illuminate the room in a soft romantic light.

Or I can imagine using it for a garden party. I would spread the little lights all over the flower beds. That would be a nice effect for a grill party."

"I can imagine using this lamp design to light up a very large room, a room used for a party, or, if the elements are separate parts of a smart home network, to lighten up hallways when triggered by a motion sensor. The smaller modules could also easily be carried from one room to another, like a modern-age lantern. If the modules are waterproof and light enough to float, they could be used to illuminate a garden or even a pond."

"At night when you don't want to open too much light because you're still half-asleep, and you need to go to the bathroom, you can just take a smaller piece with you. This makes it so portable and convenient, also as a night light for reading or seeing behind areas where there is not a lot of light. Instead of picking up a whole-ass lamp, I can just take a piece with me."

The variation in these responses shows just how much user input can add to the functionality and usability of a product. One takeaway when going into the manufacturing of the lamp would be that the components should be water-/ or splash proof to allow for more outside use cases. Furthermore, these inputs demonstrate that the prototype invites user imagination and engagement, reinforcing its emergent nature beyond passive observation.

7.4 Reflection on Evaluation Method

The evaluation method effectively captured user perception and understanding of emergence, validating the prototype's alignment with theoretical principles. The combination of qualitative and quantitative methods provided a nuanced understanding of how emergence is perceived and conceptualized in design.

However, certain limitations should be noted. Given that participants only viewed rendered images rather than interacting with a physical or digital model, their ability to fully experience emergent properties was constrained. Given the limited scope of the study with only 10 participants, the statistical validity of the results is also uncertain. Future studies could integrate augmented reality (AR) or interactive digital models to enhance engagement and capture a broader range of participants in a quantitative manner.

7.2 Systematic Comparison: Prototype vs. Definition of Emergence

A critical aspect of the evaluation was determining whether the modular lamp prototype meets the definition of emergence as established in this thesis. According to the working definition, emergence in design occurs when individual components interact to create a unified whole that is distinct from its parts, embodying novel properties through user engagement or systemic integration. The following structured argumentation breaks down the definition into three core elements:

7.2.1 Interaction Among Individual Design Elements or with User

The first component of the definition states that "**individual design elements—whether material, functional, or aesthetic—interact with each other or the user.**"

The modular lamp consists of distinct elements - vase-shaped pieces, plate-like forms, a base, and connectors - each designed to function independently or in unison. The use of magnetic connections allows users to create new arrangements. Therefore, the modular lamp inherently fulfills this criterion as the user actively interacts with the separate parts to create new configurations. The magnetic connections between modules allow them to attach, detach, and rearrange in multiple ways, demonstrating clear interaction between components and the user.

It could further be argued, that the prototype meets not just the or criteria but all the elements of this part individually. There is an interaction on all three – material, functional, aesthetic – levels. In which these elements interact with either each other or the user to form a whole. The material interaction occurs mainly in the base of the lamp, where the interaction of the user with the lamp creates a different appeal and texture based on the material choice. Functional interaction can be found in the discussed magnetic connection and interaction of the lamp parts, as well as in the interaction with the user to place the lamp sections individually, thereby altering the lighting concept of the room – a function. Finally, interaction of aesthetic elements can be found in the distinct shapes the prototype can take on when re-arranged. The aesthetic difference and weight of the individual parts allow for vastly different silhouettes to be created by the user according to their input.

7.2.2 Formation of a Unified, Innovative, and Irreducible Whole

The second component of the definition states that a "**unified, innovative, and irreducible whole**" should be formed.

The lamp exhibits coherence in its assembled states, with each configuration producing a visually harmonious and functional lighting object. This was further affirmed by users in the evaluation who rated the design as visually coherent. The system's flexibility allows users to generate novel and innovative designs beyond a static form.

Although, the transformations remain within the scope of predefined modular configurations. Unlike biological or algorithmic emergent systems, the lamp does not generate entirely unforeseen outcomes. This might go against the irreducibility of the whole. However, while the configurations are bounded, the concept of modular emergence in design does not necessitate infinite unpredictability. The ability to adaptively reconfigure the system introduces an irreducible design quality, wherein the final outcome cannot be solely explained by its components in isolation. Finally, by enabling co-creation, the potential outcomes become even more irreducible from the specific lamp prototype, the proposed use cases that users mentioned in the evaluation e.g.: "I can imagine using this lamp in my shared flat because I really like the dynamic of how I could use it. One idea I had was to split up the lamp with my flatmates so everybody can have one part in their room, and when we meet together in the common rooms, we could bring our little lamp and create different lighting depending on who is in the room." (see *appendix 3*) confirm this by establishing rituals or other experiences which act as a whole that cannot be reduced to the specific prototype.

7.2.3 Distinction from the Properties of Individual Parts

The final part of the definition states that **the whole "differs from the properties of the individual parts."**

The holistic lighting effect created by assembling multiple pieces exceeds the function of any single module. Users report perceiving the lamp as a coherent entity rather than a collection of separate objects, supporting the idea that the emergent whole differs from its constituent parts.

The individual modules retain their fundamental lighting properties even when assembled. The emergent effect is largely perceptual rather than functionally transformative.

The perceptual transformation is a core aspect of emergence in design. The way in which light disperses, interacts with surrounding space, and shifts based on arrangement exemplifies emergent behaviour through aesthetic and functional integration. Another argument can be made on an ontological level, wherein the lamp prototype can fill different light functions from floor lamp, to ambient, or reading light. Since we generally distinguish between those types of lamps, it can be inferred that the functionalities of the prototype would also be distinct from each other or at least their different configurations.

7.3 Conclusion

7.3.1 Comparative Discussion

The discussion of the modular lamp prototype in relation to the definition of emergence highlights its ability to embody key emergent principles through interaction, adaptability, and systemic composition. The evaluation demonstrates that the prototype effectively facilitates interaction between individual elements and the user, enabling diverse configurations that contribute to a unified and irreducible whole. While certain constraints, such as the structured nature of modular interactions, limit the degree of unpredictability, the prototype still illustrates how emergence can be intentionally fostered within a design system. These findings reinforce the potential of modularity as a vehicle for emergent behaviour in industrial

design.

7.3.2 User Evaluation

The results from the user evaluation affirm that the prototype successfully demonstrates emergence in industrial design and serves as an effective tool for enhancing user understanding of the concept. The findings support the theoretical framework established in this research, indicating that emergence can be meaningfully embedded in design through intentional structuring of elements. Additionally, the study highlights the prototype's potential for broader applications, particularly in adaptive systems and educational contexts. Future work should explore interactive implementations and real-world testing to further substantiate these findings.

CHAPTER 8

8. DISCUSSION & FUTURE WORK

8.1 Discussion

The findings of this study confirm that emergence, as applied in industrial design, is not merely a theoretical construct but a tangible and influential design principle. Through structured user evaluation, the modular lamp prototype demonstrated emergent properties in both form and function. Participants widely recognized the interplay between individual components and their contribution to a cohesive whole, reinforcing the conceptual foundation of emergence in design.

A significant insight gained from this study is that emergence is closely tied to user interaction and perception. The ability of participants to explore various configurations of the prototype led to a more intuitive understanding of how emergent properties manifest in modular design. This supports prior theoretical claims that emergence is best understood through experiential engagement rather than purely abstract explanations.

Another key takeaway is the balance between modularity and integration. While the modularity of the prototype allowed for significant configurational flexibility, the structural cohesion of the design ensured that no single component felt isolated. This aligns with systemic emergence principles, which emphasize the interdependence of components in producing a unified outcome. However, some participants expressed that additional interactive features, such as real-time adaptability or dynamic material responses, could further enhance the demonstration of emergence.

The evaluation also revealed that emergence in design extends beyond mere aesthetic or functional considerations. Several participants noted that the lamp could serve as a conceptual model for adaptive design, applicable in various domains such as architecture, interactive installations, and sustainable product development. This suggests that emergence, when embedded in modular systems, has broader implications for future design methodologies.

Despite these positive outcomes, certain limitations must be acknowledged. The study relied on rendered images rather than physical interaction with a tangible prototype, which may have constrained participants' ability to fully engage with the emergent properties of the design. Additionally, the evaluation did not incorporate long-term user engagement, which could provide deeper insights into how emergent properties evolve through continued interaction.

8.2 Future Work

Building on these findings, several avenues for future research and development can be identified:

8.2.1 Physical Prototyping and Real-World Interaction

While the current study focused on a digital prototype, future work should prioritize the development of a physical model to explore the full experiential dimension of emergence. A tangible prototype would allow users to engage with the design dynamically, providing richer insights into the ways emergent properties manifest in real-world settings. The integration of responsive materials or sensor-based interactions could further enhance the prototype's adaptability.

8.2.2 Interactive Digital Models and AR Implementation

To overcome the limitations of static image-based evaluation, future studies could incorporate interactive digital models or augmented reality (AR) applications. These technologies would allow users to manipulate and reconfigure the modular components in real time, fostering a more immersive understanding of emergent design principles.

8.2.3 Expanded User Testing with Longitudinal Studies

Future research should extend beyond a single-session evaluation to assess how user interaction with an emergent design evolves over time. Longitudinal studies could track how users adapt to and reinterpret the modular configurations over extended periods, providing deeper insights into the role of emergence in sustained engagement.

8.2.4 Application of Emergent Principles in Sustainable Design

The findings suggest that emergence has strong potential for sustainable design applications. Future research could explore how modularity and adaptability contribute to circular design principles, such as reusability, repairability, and material longevity. Investigating bio-based or self-healing materials within an emergent design framework could also advance sustainability efforts in industrial design.

8.2.5 Cross-Disciplinary Exploration of Emergence

Given the interdisciplinary nature of emergence, future work could explore its applications in fields beyond industrial design, such as computational design, interactive environments, and urban planning. Collaborations with researchers in artificial intelligence, architecture, and material sciences could yield innovative approaches to embedding emergence in complex systems.

8.2.6 Refinement of Emergent Design Methodologies

A structured methodological approach to designing for emergence remains underdeveloped. Future studies could focus on formalizing a framework that guides designers in embedding emergence into modular systems effectively. This could involve establishing design heuristics, testing computational models, and developing toolkits for emergent design processes.

8.3 Conclusion

This chapter has outlined the implications of the study's findings, highlighting both the strengths and limitations of the approach. While the research successfully demonstrated the applicability of emergence in modular design, further exploration through physical prototyping, interactive evaluation methods, and expanded user studies will be essential in solidifying its practical relevance. By advancing the integration of emergence into sustainable and adaptive design strategies, future work can contribute to a more responsive and resilient design paradigm.

CHAPTER 9

9. CONCLUSION

9.1 Restating the Research Problem

This thesis set out to define and explore the concept of emergence within the design space, focusing on its role in industrial design. The study aimed to establish how emergent properties arise from modular systems and how designers can intentionally leverage emergence to create adaptable, engaging, and sustainable designs. Through a literature review spanning philosophy, systems theory, gestalt psychology, and industrial design, this work sought to synthesize existing perspectives into a coherent framework that designers can utilize.

9.2 Key Findings and Contributions

The research has demonstrated that emergence is not merely an abstract theoretical construct but a tangible and applicable design principle. Key insights from the study include:

- **Emergence as a Design Tool:** The study found that emergence can be harnessed in design by emphasizing modularity, adaptability, and user interaction. The modular lamp prototype served as a case study, demonstrating how different configurations produce distinct aesthetic and functional experiences.
- **Co-Creation:** The research reinforced that emergent properties often arise from interactions with the user rather than from isolated components. These co-creation

principles can be applied across the design process – whether during prototyping, user testing, or in the final product – to enable emergent principles.

- **User Perception of Emergent Design:** The user study provided empirical evidence that users recognize and engage with emergent properties in modular design. Participants reported increased conceptual understanding of emergence after interacting with the rendered prototype, indicating that emergent design can serve as an educational and interactive tool.
- **Sustainability Implications:** The findings suggest that emergence has strong potential in sustainable design. Modularity and reconfigurability support extended product lifespans, reducing material waste and encouraging circular design principles.

9.3 Summative Answer to Research Questions

To explicitly address the research questions:

1. What are the defining characteristics of emergence within design?

- Through the literature review a cohesive definition of emergence in design was established as: "a process where individual design elements—whether material, functional, or aesthetic—interact with each other or the user to form a unified, innovative, and irreducible whole that differs from the properties of the individual parts". In the evaluation, Participants consistently recognized the interplay between the elements, reinforcing that emergent properties arise when components interact beyond their isolated functions.

2. How can the implication of emergence impact design disciplines?

- The study suggests that embedding emergence in design can positively impact user experience, adaptability, and sustainability. Participants viewed the modular prototype as a potential model for sustainable and customizable design, demonstrating that emergence can play a role in responsive environments and interactive installations.

3. How can the concept of emergence be effectively communicated through a design artifact?

- The prototype successfully conveyed emergence through modular reconfigurability and user interaction. The evaluation highlights that allowing users to engage with an emergent system - whether physically or visually - enhances their understanding of emergent principles.

9.4 Significance and Relevance

The study contributes to industrial design by providing a structured approach to integrating emergence into design practices. This is particularly relevant for:

- **Adaptive and Interactive Design:** Emergent principles can enhance user-centred and adaptive design methodologies, particularly in areas such as interactive installations, architecture, and product design.

- **Sustainable Design Strategies:** Emergent properties in modular systems align with circular economy principles, promoting reusability, repairability, and customization over time.
- **Future Design Methodologies:** This research underscores the need for a formalized framework that guides designers in embedding emergence into their work, fostering innovation and deeper user engagement.

9.5 Limitations and Future Work

While this research successfully outlined emergence in design, several limitations should be acknowledged:

- **Lack of Physical Prototyping:** The study relied on rendered images rather than tangible prototypes. Future work should explore how physical interaction influences the perception and evolution of emergent properties.
- **Limited Longitudinal Studies:** This study assessed immediate user responses, but further research should examine how user engagement with emergent designs evolves over time.
- **Material Considerations:** While the study explored sustainable alternatives, additional research is needed to evaluate the feasibility and impact of biodegradable or bio-derived materials in emergent systems.

9.6 Final Remarks

This research has established a foundational understanding of emergence in design, highlighting its practical significance beyond theoretical discourse. By integrating emergent principles into modular systems, designers can create objects that are both aesthetically engaging and functionally adaptable, contributing to more sustainable and responsive design solutions.

The study demonstrates that emergence is not merely an abstract concept but a tangible principle that can be embedded through interactive and systemic design methodologies. Practitioners in behavioural modelling emphasize the necessity of user engagement in validating emergent properties, while researchers in design adaptability highlight modularity as a key driver of emergent behaviours. These insights suggest that designers can actively cultivate emergence by designing for adaptability, user interaction, and configurational flexibility.

As the field of design continues to evolve, emergence presents a compelling avenue for innovation, sustainability, and dynamic user experiences. Future research and practical applications will be instrumental in further refining and validating the emergent design paradigm.

AI DISCLOSURE STATEMENT

During the preparation of this study, ChatGPT (model 4o) was used to improve the readability and structure of the content. After using this tool, the authors have reviewed and edited the content as needed and take full responsibility for the publication's content.

APPENDIX 1 THROUGH N

1. Full calculation of number of lamp combinations

The steps follow the formulas and operations outlined by Bagui & Mehra (2024)

Step 1: Formula

To count the number of ways to arrange 7 distinct objects into k groups (where $1 \leq k \leq 7$), and order matters within each group.

The formula to count this is:

$$\sum_{k=1}^7 S(7, k) \cdot k!$$

Where:

$S(n, k)$ is the Stirling number of the second kind, which counts the ways to partition n elements into k non-empty subsets.

$k!$ accounts for the fact that each group can be ordered in any sequence.

Step 2: Compute $S(7, k)$

With the formula:

$$S(n, k) = k \cdot S(n-1, k) + S(n-1, k-1)$$

Where:

$S(n-1, k)$ extends an existing partition by adding the new element to one of the k groups.

$S(n-1, k-1)$ starts a new group with the new element.

Using this, we get:

$$\begin{aligned} S(7, 1) &= 1 \\ S(7, 2) &= 63 \\ S(7, 3) &= 301 \\ S(7, 4) &= 350 \\ S(7, 5) &= 140 \\ S(7, 6) &= 21 \\ S(7, 7) &= 1 \end{aligned}$$

Step 3: Multiply by $k!$

Multiplying each $S(7, k)$ by $k!$:

$$\begin{aligned}S(7,1) \cdot 1! &= 1 \cdot 1 = 1 \\S(7,2) \cdot 2! &= 63 \cdot 2 = 126 \\S(7,3) \cdot 3! &= 301 \cdot 6 = 1806 \\S(7,4) \cdot 4! &= 350 \cdot 24 = 8400 \\S(7,5) \cdot 5! &= 140 \cdot 120 = 16800 \\S(7,6) \cdot 6! &= 21 \cdot 720 = 15120 \\S(7,7) \cdot 7! &= 1 \cdot 5040 = 5040\end{aligned}$$

Step 4: Summing all the terms

$$1 + 126 + 1806 + 8400 + 16800 + 15120 + 5040 = 47293$$

Thus, the final result is:

47,293

2. All final prototype renders

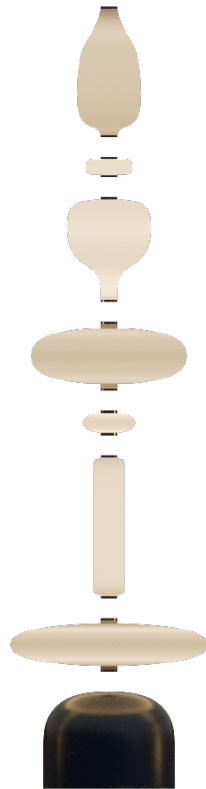


Figure 5: Lamp in exploded view orthographic



Figure 6: Three modular lamp combinations



Figure 7: Lamp in use (whole)



Figure 8: Lamp in use (split)



Figure 9: Lamp split close-up

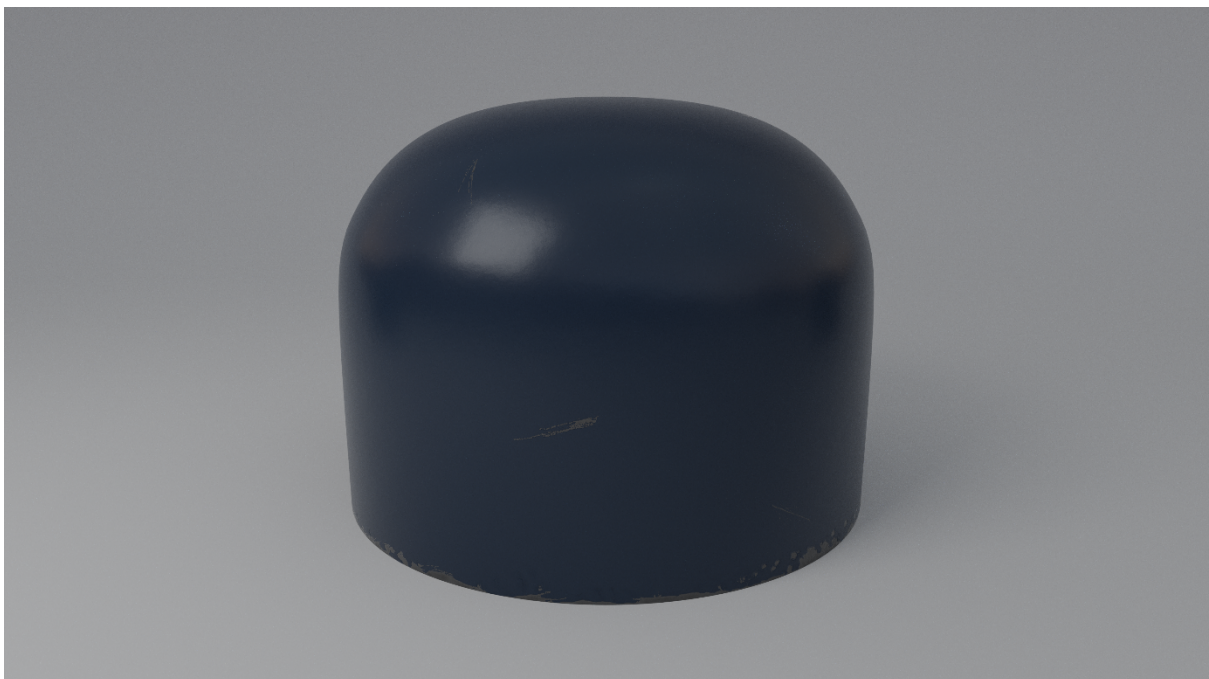


Figure 10: Base of the lamp close-up

3. Evaluation responses from all participants

Pre-Prototype Questions

1. "What does the term 'emergence' mean to you in the context of design?" (Open-ended):

Participant 1:

Emergence means that a design is made from multiple parts which have none or a different purpose as standalone parts.

Participant 2:

For me, it means that one piece, one artifact, is multifunctional. Not only for one handling or in one context. Several pieces can be used together or separately.

Participant 3:

Emergence is a phenomenon that occurs when different parts of a thing or an idea come together and then something new or bigger or better emerges.

Participant 4:

It doesn't mean much to me. Maybe something interactive.

Participant 5:

Emergence for me is the way something connects with another. The way things merge together in a way.

Participant 6:

I understand emergence as the phenomenon where individual parts, when combined, exhibit new properties or create something entirely new.

Participant 7:

Emergence is the arising of a new category (for an intended purpose).

Participant 8:

Emergence is when simple elements or rules interact to create complex functions that go beyond the individual parts.

Participant 9:

Okay, so, I never heard of the term used this way. Either it comes from emergency or that something appears.

Participant 10:

Something that 'emerges' or comes unexpectedly from somewhere.

Definition-Based Question

"Here is one definition of emergence in the context of design:

'a process where individual design elements - whether material, functional, or aesthetic - interact with each other or the user to form a unified, innovative, and irreducible whole that differs from the properties of the individual parts.'

2. Do you think this definition makes sense? Why or why not?" (Open-ended):

Definition: 'A process where individual design elements—whether material, functional, or aesthetic—interact with each other or the user to form a unified, innovative, and irreducible whole that differs from the properties of the individual parts.'

Participant 1:

Yes, it makes sense because this definition covers all possible elements that could be incorporated into a product.

Participant 2:

It makes sense because there is a relation between the single pieces of the design element and a relation between the design element and the user.

Participant 3:

It does make sense, because it describes (in a good way) what I experience in design.

Participant 4:

Yeah, it seems like it makes sense. Well, the term interaction is included.

Participant 5:

Yes, this definition does make sense as it speaks about interaction.

Participant 6:

I think it makes sense, because only with all the elements together a new object can be created.

Participant 7:

The definition makes sense. However, the term 'innovative' is subjective.

Participant 8:

Yes, because it aligns well with the definition I had in mind before.

Participant 9:

The definition makes sense, but why is it called emergence and not something like 'combination'?

Participant 10:

I mean, it does in the sense of 'a new meaning emerges' when parts come together.

Prototype Evaluation Questions

3. "What is your first impression of this design? Describe any standout features." (Open-ended):

Participant 1:

The design is elegant and beautiful. The light radiating from each element of the lamp is different.

Participant 2:

It looks like a candlestick, ancient with scrolls and rounded edges. You can put the single parts together differently.

Participant 3:

The design in the middle reminds me of a candle. It impresses me how many lamps you can make from it.

Participant 4:

With the term emergence in mind, it makes sense because all the individual parts are there but have different forms.

Participant 5:

It's very aesthetically pleasing, it makes me want to be creative.

Participant 6:

Wow, I really like the design! It really stands out to me that you can split up the lamp into different parts.

Participant 7:

The design is sleek, and I appreciate the harsher character added to make the design more realistic.

Participant 8:

The modularity and practicality were the first things I noticed. It's organic-looking.

Participant 9:

I really like it, first of all. What I like most is that you can put it into separate places and when you go to sleep you could just put it back together.

Participant 10:

I like the design, also the shapes you chose for each part.

4. "Do you think this design demonstrates emergence as defined earlier? Why or why not?" (Open-ended):

Participant 1:

Yes, it exemplifies the emergence definition in that the final product consists of several elements (a base and seven glass-like elements) that, placed on top of each other, form a light-emitting sculpture.

Participant 2:

Yes, I think so, because you can individualize the lamp. It looks different when you change the different parts. Also, you can separate the pieces and then you have more than one light. So, you can brighten the room in a special way. For a nice lighting concept, you need 5 or 6 light sources. With the artifact, you can brighten the room with one lamp, or you can put the different pieces of the lamp in the room to get a special comfortable effect.

Participant 3:

Yes, it does demonstrate emergence, because it has individual design elements consisting of the light elements and base. The elements also differ in their material, function, and aesthetics. According to the definition, they also interact with each other or the user to make different lamps of different sizes. So, all in all, I think it demonstrates it well. A single part might be used as a 'torch' and I could take it to bed to read or whatever, but you can also arrange them in a final design.

Participant 4:

I kind of explained it in the answer before. Well, it matches the definition in the sense that you have these different parts, and they come together or interact to form this lamp.

Participant 5:

Yes, I do think it demonstrates emergence, as the user who owns this lamp would be interacting with the lamp in different ways for the same purpose of providing light, which gives the purpose excitement and more connectivity to the object itself.

Participant 6:

I think it does, because all the little lamps together don't just form a "big lamp" but create a different vibe or style of lamp – which they can only do together in their specific constellation. Each different set of little lamps together shapes a different vibe of a new lamp.

Participant 7:

Yes, I think that design is in line with the definition in two main ways. 1) The lamp design itself is innovative by combining different textures and aesthetics. 2) The individual parts of the lamp can be switched; this interactive part of the design allows for multiple interpretations of the work and thus creates way more opportunities for emergence than simply a new lamp design.

Participant 8:

Yes, because, although each individual part can be used as a lamp, the one that emerges when combining the parts into one big- or multiple lamps, allows for different use cases compared to just having one standalone lamp.

Participant 9:

Yes, because you have differently shaped parts, and they can be combined to give you a new aesthetic. For example, going back to the chess analogy, the parts themselves don't necessarily look like a chess piece, but combining them gives this new characteristic shape.

Participant 10:

I think it does in the sense that: Still, you will have a lamp at the end, so all parts are lamps, but the way you use them is different. For example, if you use the whole lamp, it's kind of like an artistic sculpture, but if you split them, you can use them to make different atmospheres. In one of the renders, the lamp was separated, and this can make for interesting atmospheres that you can curate as you like.

5. "Rate the aesthetic cohesion of the design on a scale from 1 (fragmented) to 5 (highly cohesive)."

Participant	1	2	3	4	5
P1					x
P2					x
P3				x	
P4				x	
P5					x
P6					x
P7				x	
P8					x
P9				x	
P10				x	

6. "Rate the functionality of the design on a scale from 1 (not functional) to 5 (highly functional)."

Participant	1	2	3	4	5
P1					x
P2					x
P3				x	

P4					x
P5					x
P6					x
P7				x	
P8					x
P9					x
P10				x	

7. "Does seeing this design help you understand how emergent properties arise? If yes, how?" (Open-ended):

Participant 1:

Yes, in that it is clearly demonstrated how each element is different from the others. Each element has a functionality of its own, and yet, if some or all of the elements are combined, they form a new object with its own purpose.

Participant 2:

Yes, it helps me, because it is a little bit like water: one drop is like a pearl. Many water drops form a river, a cloud, a puddle. And the artifact can be used in a straight way, as one light. Or in a concept. Then there is a flow of light, which brightens the room in a cozy way.

Participant 3:

Yes, the picture of the prototype in three different forms shows perfectly how emergence arises. I can still see the different parts of the prototype, and at the same time, completely different aesthetic silhouettes arise— 'emerge.'

Participant 4:

To be honest, the term sounds very abstract at first, and it's hard to imagine what an actual product might look like. Seeing the elements come together and all the different parts of the definition makes it more graspable.

Participant 5:

Yes, it does, because the idea of moving around the shape of the lamp and being able to take the individual light parts around really shows how a simple thing such as a lamp can be made more interactive and really give you a different experience. Which, from my understanding, is quite emergent.

Participant 6:

It does because it visually demonstrates how a new object with a new style or new vibes can be formed out of different parts.

Participant 7:

The interactive design motivates the user to alter the meaning of the lamp. Not only allowing for multiple interpretations of the lamp, but also subtly nudging the user towards a more intercontextual way of thinking.

Participant 8:

Yes, because lamps are a very intuitively understandable artifact. It's easy to imagine how the individual pieces can be used or compared to the full lamp.

Participant 9:

Yeah, I mean, it was pretty clear from the definition, but it's kind of like an example so it helps.

Participant 10:

Yes, it does. It's similar to before. The combination of the single elements can create a different outcome. Not only that you create a single lamp, but you also can arrange it differently every time.

8. "Rate how well this design helps you understand emergence on a scale from 1 (not at all) to 5 (very well)."

Participant	1	2	3	4	5
P1					x
P2					x
P3				x	
P4					x
P5				x	
P6				x	
P7				x	
P8					x
P9					x
P10					x

Question 9: "In what ways can you imagine using this design? Are there interesting or unconventional applications you can think of?" (Open-ended):

Participant 1:

I can imagine using this lamp design to light up a very large room, a room used for a party, or, if the elements are separate parts of a smart home network, to lighten up hallways when triggered by a motion sensor. The smaller modules could also easily be carried from one room to another, like a modern-age lantern. If the modules are waterproof and light enough to float, they could be used to illuminate a garden or even a pond.

Participant 2:

I think I would like to use it for a candlelight dinner without candle lights. I would illuminate the room in a soft romantic light. Or I can imagine using it for a garden party. I would spread the little lights all over the flower beds. That would be a nice effect for a grill party.

Participant 3:

So, I can imagine that this prototype or this lamp would be an important part of my household, as I can use it to design different light atmospheres. And it's great because it doesn't have a cord, so I only need one plug but still have several light elements. Plus, it's probably cheaper overall vs. buying several different lamps.

Participant 4:

It would be nice to put it in front of my window to read because the individual light elements don't require a charger. Also, it's nice to be able to create different light settings and move the parts around in the room – a functionality which normally requires multiple lamps – with this one product.

Participant 5:

At night when you don't want to open too much light because you're still half-asleep, and you need to go to the bathroom, you can just take a smaller piece with you. This makes it so portable and convenient, also as a night light for reading or seeing behind areas where there is not a lot of light. Instead of picking up a whole-ass lamp, I can just take a piece with me.

Participant 6:

I can imagine using this lamp in my room in my shared flat because I really like the dynamic of how I could use it. One idea I had to think of was to split up the lamp with my flatmates so everybody can have one part (because actually we are 8 people living in the house atm.) in their room, and when we would meet together in the common rooms, we could bring our little lamp and create different lightings depending on who is in the room. Also, I just like the idea of us bringing different parts of the lamp to places we want to light up in the moment (for example, in different places in the garden), so it just brings a dynamic and interactive action into the lighting situations.

Participant 7:

I would put the small lamp on top, so I could easily get hold of it and use it as a little reading lamp. If all of the lamps are shared over the rooms, I could also imagine using the base as an improvised footstool.

Participant 8:

So, the scenario I could imagine is as follows: You have your friends over, and in the beginning, the lamp is standing as the 'full' lamp, and then you decide you want to watch a movie, so you shut off all the other lights and spread this lamp across the room, and the only

light sources now are the single light sources sitting on the ground or on pieces of furniture. This would make for a more subtle light that makes for a good 'movie watching' atmosphere.

Participant 9:

If I had one, I would just use it in a room and then figure out different spots across the room where the lights look good. And then put them back together at the end of the day. I'm not sure about the efficiency, but you could also use some parts to light up certain places of the house when you're there. So, when moving to a different part, you can just take them with you.

Participant 10:

I can imagine this, for example, in social settings, such as in a museum, not necessarily as the attraction but as a decoration. It can also be helpful for workshops where each of the people can have one piece of the lamp, so instead of, for example, candles, they would have the lamp pieces. It might also be nice in a yoga or meditation vibe. I see it more as an artistic piece, so its purpose does not have to be to light a room but more to change the vibe of the room. So, you should maybe not use this as a normal lamp. The use cases might be more in line with social settings or artistic exhibitions.

10. "Overall, rate how well this design aligns with the concept of emergence on a scale from 1 (not at all) to 5 (perfectly)."

Participant	1	2	3	4	5
P1					x
P2					x
P3					x
P4					x
P5					x
P6					x
P7					x
P8					x
P9					x
P10				x	

4. Full coded expert interviews

Theme	Subcategory	Perspective from Expert 1	Perspective from Expert 2

Definition of Emergence	Whole vs. Sum of Parts	Emergence in design is when a concept arises from elements but is more than just the sum of those elements. It has properties and functionalities that individual components do not possess.	Emergence in industrial design is a comprehensive and dynamic process involving a complex system, where product functionality emerges through user interaction with the environment.
Definition of Emergence	Functionality and Adaptability	Emergence solves a problem or serves a purpose that individual elements alone could not achieve. Recognition of this functionality is key.	The key to emergence is flexibility and adaptability – products should evolve based on user needs and context.
Predictability and Irreducibility	Unpredictability	Predictability is not a necessary component of emergence. Designers may put elements together and something unexpected emerges that they could not have foreseen.	Emergence is unpredictable because user behaviour is unpredictable. Designers may have intentions, but users might use the product in unexpected ways.
Predictability and Irreducibility	Irreducibility	Reducibility is linked to the configuration of elements. The overall shape and structure determine the emergent properties, not just the individual parts.	Irreducibility matters when emergent properties cannot be traced back to individual components, as seen in statistical modelling and behavioural interactions.
Role of User Interaction in Emergence	User Validation	User interaction is crucial in validating emergent properties. Emergence only becomes apparent when users engage with an artifact and recognize its function.	Co-creation plays a major role in emergence, where users contribute to shaping emergent properties through interaction and adaptation.

Role of User Interaction in Emergence	Co-Creation & Stakeholder Involvement	Testing an emergent design is akin to a 'litmus test' – it must be evaluated in real-world conditions to determine whether emergence has occurred.	Stakeholder involvement and real-world testing are essential in identifying emergent behaviours that designers may not have considered.
Examples of Emergent Design	Adaptive Design	Emergent properties can be observed in successful design projects, where new solutions arise that did not exist before.	Modular furniture and Lego bricks serve as clear examples of systemic emergence—individual parts gain new meanings when combined.
Examples of Emergent Design	Unexpected User Behaviours	Inexperienced designers often fail to achieve emergence, as they merely combine elements without creating a truly new entity.	Unexpected user behaviours often reveal emergent properties that designers did not initially anticipate, leading to new applications or refinements.
Ontological Emergence	Levels of Reality & Complexity	Ontological emergence is linked to the idea that emergent properties exist at different levels of reality. The interactions between components create properties that are not reducible to lower levels.	Emergence at an ontological level involves hierarchical structures where properties emerge that cannot be deduced from their parts, much like statistical models that describe aggregate behaviour without isolating individual contributions.
Gestalt Psychology and Emergence	Gestalt Perception	Gestalt principles explain how users perceive a unified whole rather than separate elements. This is critical for emergence in perception-based design.	Gestalt perception helps users see the whole rather than just the sum of parts, reinforcing emergent recognition in visual and cognitive design.

Systems Thinking in Emergence	Systems Thinking vs. Statistical Modelling	Systems thinking supports emergence by emphasizing interactions between components at different hierarchical levels, leading to higher-order properties.	Statistical modelling approaches emergence differently, focusing on how composite variables interact within a system rather than looking at individual components.
Design Methods for Emergence	Minimalist Design Approach	A minimalist approach helps foster emergence by focusing on the fewest elements necessary to achieve a functional whole.	Interactive prototyping, such as experiments with robotics and human-robot interactions, helps uncover emergent behaviours through real-world user interaction.
Design Methods for Emergence	Iterative Prototyping & Testing	Iterative prototyping allows designers to refine configurations, adding or removing elements to discover the minimal conditions required for emergence.	Observational studies, such as testing asthma inhalers for children, reveal emergent properties based on unexpected user interactions, guiding iterative design improvements.

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