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Towards a Framework

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Quantum Mechanics, Ambiguity and Design: Towards a Framework

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ABSTRACT

Quantum Mechanics could have fundamental impact on design models and measurement. Quantum mechanics allows us to fill in the blanks of classical models of design, through its ability to explain ambiguous states of design. An ambiguous state is where design exists in between two binary states, as a superposition. Designers are most likely to be unfamiliar with quantum mechanics, as well as the subject of quantum mechanics being complex and sometimes contradictory to human scale mechanics. By discussing the opportunities of quantum mechanics for design, we are proposing a framework to model and measure ambiguous dimensions of design through quantum superpositions. The proposed framework includes the dimensions for the directionality of design (convergence or divergence), the degree of design embodiment (from low to high) and the decision-making of the designer (yes to no). Once the designer attempts the measurement of a superposition, a binary state can be distilled. For the act of designing, filling in the blanks is equal to sculpting away superposed states. In this philosophy, to design is to measure. This early stage research raises areas of opportunities and suggests further research directions for quantum mechanics and design.

CCS CONCEPTS

• **Human-centered computing**; • **Interaction design**; • **Interaction design theory, concepts and paradigms**;

KEYWORDS

quantum, creativity, design process, ambiguity

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1 INTRODUCTION

Quantum mechanics are fundamental laws of nature that describe the interaction of the atomic and subatomic scale of the universe. Important fundamental knowledge from the quantum realm includes the quantization of energy [17], wave-particle duality [12, 16, 18], the uncertainty principle [49] and the correspondence principle [17]. Currently, quantum mechanics are being used to describe fundamental phenomena, with most recent Nobel prize contributions of (quantum) physics for Parisi (2021) and Penrose (2020).

In general, designers and creatives are not trained in understanding, nor applying quantum mechanics. In this paper, we aim at bridging the gap by introducing designers to the quantum world, and take this opportunity to propose a framework to apply quantum mechanics to creativity, cognition and design. Although in its early stage, our research aims at contributing to the ongoing discovery of the quantum mechanics of memory functions and brain activity in ideation and creativity. Creativity and the quantum have been philosophically linked in research as early as 1996 [7]. Quantum perception/cognition research plays a role in answering unexplained phenomena outside "classical" mechanics, such as for the cognition of ambiguous Figures [37]. Furthermore, recent research points towards quantum being a driving force for design in the way ambiguity invokes creativity [14] and musical creativity [50], as well as human expertise, knowledge and problem-solving [8].

This paper aims to explore the fundamentals of quantum mechanics to provide and inspire a new way of looking at the designer's journey from abstraction to concretization [1], concept generation to concept selection [23, 51] or challenge to outcome [52]. First, design's quantum behavior is explored using familiar terms and models in design. Then, the quantum state of designs is framed as superposition of binary states. The aim is to display the opportunities for creating models of design using descriptions provided by quantum mechanics. Overall, we hope to spark discussion and research ideas, as well as applications of quantum mechanics in design, creativity and cognition.

2 BRIDGING THE GAP FROM QUANTUM MECHANICS TO "EVERYDAY DESIGN"

Our everyday world of interaction, as perceivable by our senses, is of classical scale. A single electron or photon, and its quantum mechanics, are of negligible influence to our human perception. Our human scale and mass rule our ways of perceiving interactions. However, important links for the investigation of consciousness may be found in the interplay of scale between quantum mechanics' and classical mechanics' facilitated by the microtubules inside each cell of the synapses in the brain. [9, 30].

Quantum mechanics have been of great success in explaining real-world phenomena [32]. Quantum mechanics have been an enabling technology for all modern and dated digital electronics and communication technology in the form of the transistor [8, 53]. Quantum concepts and methods for probability have been used to explain human phenomena such as cognition and decision making

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[13, 31, 34, 35, 37, 54], common sense [36], consciousness [30, 38], causal reasoning [39] and episodic memory [15].

2.1 Ambiguity in design, designs overlap in quantum mechanics

According to the Cambridge Academic Content Dictionary (CACD), ambiguity is "a situation or statement that is unclear because it can be understood in more than one way". However, ambiguity in design is more broadly viewed as both the CACD definition and a creative resource [55]. In this respect, product or representational ambiguity acts as a glitch that can manifest at a perceptual (i.e. inherent properties), cognitive (i.e., conceptual associations) and emotional (i.e., conflicting responses) level [56]. For design in particular, it has been suggested that the process of the perception of visual ambiguous Figures appears to follow quantum mechanics [37]. This is supported by research on how ambiguity invokes creativity [14]. Souparno and colleagues [14] suggest it is reasonable to inspect the tolerance of ambiguity [21, 22] to consider its importance for creativity and its role in divergent production.

In the auditory domain, it has been shown that any sound phenomenon can be potentially expressed and described as the evolution of a superposition of psychoacoustic states, i.e., low-high pitch, dull-bright turbulence, and slow-fast pulsations [48]. Further, the perceptual ambiguity of Shepard-tone [45] music has been recently explained in terms of quantum measurement (i.e., listening) and superposition of quantum states [43], whose behavioral evidence has been linked to pupil dilation [44].

In this respect, we could rephrase the afore-mentioned CACD definition of ambiguity as follows: "a quantum state of the design representation that is unclear because it can be perceived in more than one way".

However, according to the quantum view of Penrose [19][30], it is not the act of viewing Schrödinger's cat inside the box that determines whether it is dead or alive. Our viewing of a complex quantum system of weather on a far-away planet, does most probably not influence the weather itself on this planet: **The quantum state of the weather however, influences us, to view it in a reduced state**. What this means for Schrödinger's cat, is that it is both dead and alive at the same time, an ambiguous state of 50/50 probable existence [10]. This is, until we take a measurement of the state of Schrödinger's cat, to reduce the state to a binary measurement of being perceived as either dead, or alive.

This means that we need to twist the rephrased definition of ambiguity to a quantum correct notion of ambiguity. Therefore, ambiguity in quantum and design is the fundamental multiple ways of designs existence, that can be perceived as unclear.

2.2 Examples of ambiguity in quantum mechanics

In the realm of quantum scale, particles are behaving fundamentally ambiguous. This is for instance accepted in the duality of behavior for a wave-particle such as a photon or an electron [12, 16, 18]. Quantum particles, such as photons or electrons, behave both as a wave movement, as well as an energized particle. This can be seen by shooting photons or electrons at a screen as done according to two-slit experiments for photons [57] and electrons [46] and

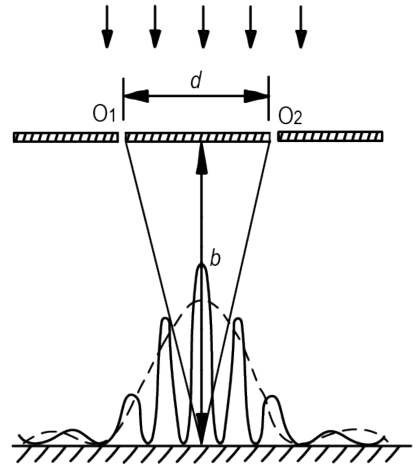

Figure 1: Quantum wave interference in Young's two-slit experiment. The dotted curve represents the diffraction fringes, while the solid line represents the interference fringes. Adapted from Thomas Young and the Concept of Coherence of Light. Kipnis, 1983.

measuring their location of arrival behind the screen. Even though photons and electrons are particles, as "energy packets", the double slit experiments result in a wave-interference pattern of photons and electrons, as can be seen in Figure 1. The wave movement measured in the quantum interference pattern behind the two slits shows the ambiguous quantum mechanical quality of an electron or photon being both a wave-motion, as well as a particle-motion.

The uncertainty principle [49] formulates that we can either measure the position of a quantum particle with a high amount of certainty, or the momentum of the particle with a high amount of certainty. This means that we fundamentally cannot measure both the position and the momentum of a quantum particle, with a high certainty at the same time. Our way to view a photon, or electron, is fundamentally uncertain, not because of the measuring apparatus, but because of the uncertainty principle [49] as a law of nature. This is an important principle to quantum mechanics for design, as we need to choose what to measure from a quantum state, in order to reduce to a classical state. The uncertainty of position and momentum is another duality in the behavior of quantum particles, commonly known as entropy in quantum terms, which is known in design as the term ambiguity.

2.3 Familiarity of quantum in design

In its most classical reduced form, design can be regarded as a linear process of creation from vague to concrete. This is akin to a painter starting with a blank canvas, a sculptor with a chunk of wood or marble and the designer, with an empty sketch book. However, what happens in addition to this linearity is iteration. The theory of design thinking [1, 4] regards design as perpetual cycles of analysis, synthesis, evaluation and communication that take place in order to achieve an iteration from abstract thoughts and ideas to concrete models, products and services (Figure 2).

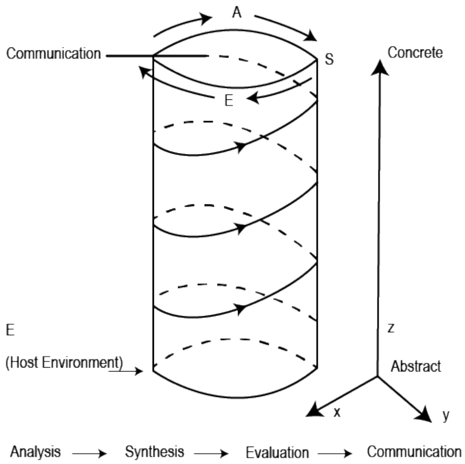

Figure 2: Design is shown as perpetual cycles of analysis, synthesis, evaluation and communication, progressing from abstraction to concretization (adapted from [1])

An alternative way of describing the conceptualization of design processes is through a design funnel [23], where the designer's journey funnels towards a selection of a concept. This is done by applying iterations of convergence and generation to move to a higher degree of embodiment (Figure 3) [40, 51].

Other commonly used terms for "funneling" in order to move to a higher degree of embodiment and concretization, are divergence and convergence, as popularized in the double diamond model [52]. The double diamond model consists of two iterations of divergence and convergence, in the form of discover, define, develop, deliver [52], as shown in Figure 4.

3 MODELLING DESIGN WITH QUANTUM MECHANICS

3.1 The wave-particle duality of design

In its simplest configuration, the cyclical or iterative nature of designing can be represented as a periodic oscillation. Sine waves are a function of a cyclical motion in time. Therefore, we can create a simplified model of design as a cyclical process of diverging and converging (Figure 5). We can substitute "time" with the degree of embodiment, to show the progression from abstraction to concretization [1] (Figure 6).

Additionally, we can view the design process not as its wave-state, but as its particle state of decision making in one moment of time, as a thought, or idea. Here, we view the design process as a moment of decision making of a binary yes (+) or no (-) to form an outcome to a challenge, or in other words a solution to a problem (Figure 7).

Thus far, our wave-particle model of design is based in the classical realm of mathematics. However, in design and creativity, cycles are noted to be happening in a fuzzy or chaotic way [3, 5, 6]. This means that iterative cycles for design in practice, will only partially happen perfectly linearly and circularly, as visualized in "jumps" back into the double diamond model (Figure 6). Moreover, for perception and problem solving, our brain faces a quantum perception [37]. Our rationality is faced with answering perception of a challenge with the choice of yes (+), no (-), or an ambiguous combination of the two, maybe (+/-) [37], as shown in Figure 8. This is where quantum mechanics may help us combine the theory and reality of a design process.

3.2 How to model classical binary data to a quantum bit

In quantum mechanical computation, we use qubits to simulate the ambiguous states of the quantum world. This is for instance done in quantum computers by superposing the spin of electrons [24, 25], nuclear spin [26] or nuclear magnetic spin [27]. By superposing a particle state such as the spin of an electron, we are not sure of the position of the spin. When measuring the spin of a perfect superposition, there is a theoretical probability of 50% for measuring the spin "up" or "down". By writing spin-up as yes (+) = $|Y\rangle$ for the eigenvector value [0,1] and spin-down as no $(-) = |N\rangle$ for [1,0], we can formulate any ambiguous state of spin as a combination of the amount of Up-spin / Yes and Down-spin / No at the same time creating Maybes (+/-).

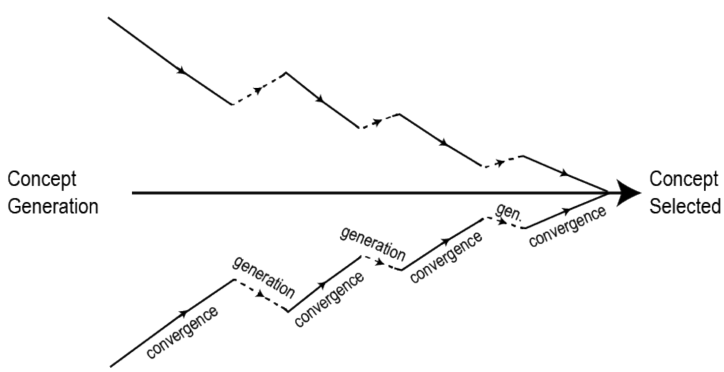

Figure 3: Progressing from concept generation to concept selection by applying three iterations through funneling by three cycles of convergence and generation. (adapted from [51])

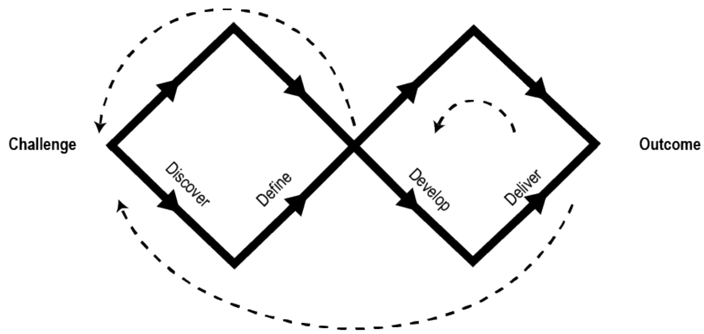

Figure 4: Evolved Double Diamond Model, British Council of Design, 2019. Progressing from Challenge to Outcome, according to four stages of Discover, Define, Develop and Deliver. Visualized as two cycles of diverging and converging, with occasional jumps back in steps. (adapted from [52])

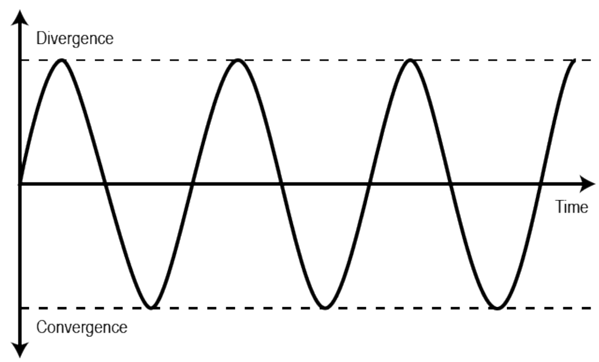

Figure 5: Simplified model of a design process as a periodic oscillation of diverging and converging over time.

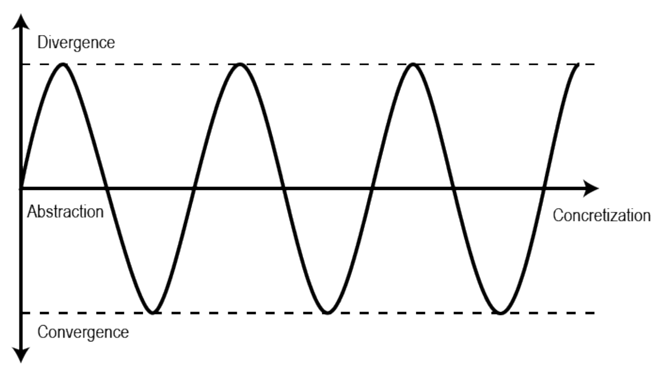

Figure 6: Simplified model of a design process as a periodic oscillation of diverging and converging over time.

4 DISCUSSION

4.1 Describing the particle state of design

We can model any maybe (+/-) as a combined state vector $|\varphi^{\circ}\rangle$ of the amount (α *or* β°) of "yes" and "no" of a "maybe" (Figure 8), which results in the following formula.

$$|\varphi\rangle = \alpha\,|0\rangle + \beta\,|1\rangle$$

We can measure design in any moment of time, in large scale, or in a single second, including its chaotic, fuzzy and irregular states through superpositions. We can regard the act of designing as taking probabilistic measurement of superposed states.

4.2 Modelling design with qubits

The addition of superposed states for design provides a rich way for conserving the relativity of design. This means that in theory, we can describe the iterative nature of design despite its chaos, fuzziness and irregularities. We base the following dimensions on the wave-particle behavior of design described in Section 3.

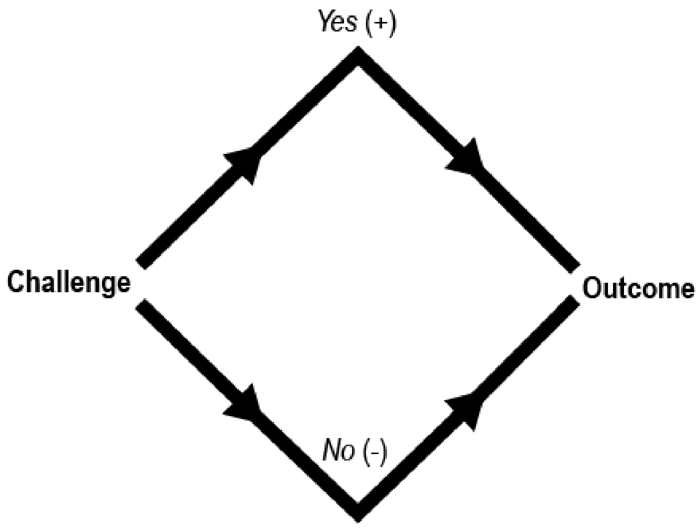

Figure 7: Simplified model of a designer's decision-making process as a simplified binary yes (+) or no (-) choice.

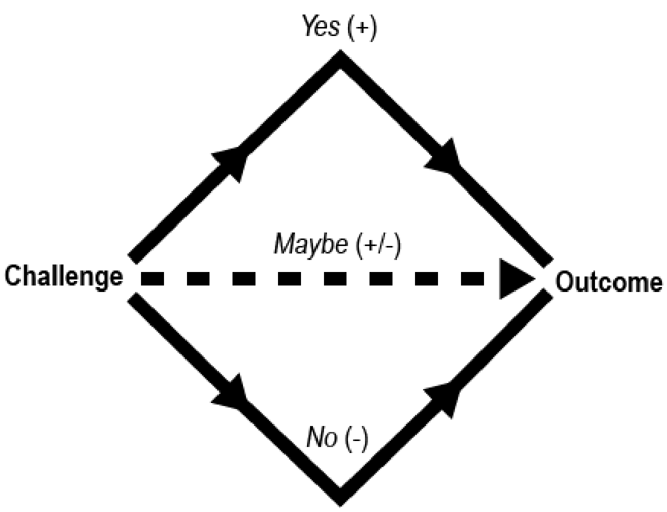

Figure 8: The designer's decision making modeled as a qubit with range of possible states yes (+), no (-) or superposed maybe (+/-).

$|0\rangle X|1\rangle$ for X ranges from the amount of Convergence to Divergence

$|0\rangle Y|1\rangle$ for Y ranges from the amount of abstraction to concretization in the form of Low embodiment to High embodiment.

$|0\rangle Z|1\rangle$ for Z ranges from No to Yes decision making of the designer

These dimensions mapped to a Bloch sphere [41] can be illustrated as follows (Figure 9).

The superposed states between the eigenvectors are fundamental for the design framework. The framework proposes a state to be in superposition, until measured in a probabilistic outcome, meaning that the designer makes measurements of the superposed state, in the act of designing. By placing a measurement, we can distill a probabilistic state in a moment in time. The framework can describe large time scales, such as weeks and months, as well as small scales such as seconds by words of dialogue or thoughts in a string.

4.3 "Measuring" design conversations with qubits

As an illustrative example of application of our proposed framework, we make use of a short excerpt of a design protocol of sound design session, represented in Figure 10 as a linkograph with the corresponding design moves [42, 58]. The episode sees a sound manager (P1), a sound engineer (P2) and a sound designer (P3) intent in discussing the sound quality of an electric car engine, by alternating verbalizations and vocalizations, transcribed as utterances.

We show how the verbal utterances in the linkograph can be mapped and interpreted as measurements of quantum states of designs, in Figures 11(a, b, c):

- Figure 11a - State of design conversation visualized on a single Z-axis of yes (+) and no (-), starting from the question posed at line 336 "if you add an electric motor", to which line 337 is a measured yes response. The Z-axis measures $|Y\rangle$ accordingly, with the sonification: "Wiinrg wriin wriiing touc touc touc touc";
- Figure 11b - Addition of X-axis by line 337 starting a divergence of 3 links (Figure 10), therefore pointing towards $|D\rangle$ and line 338 changing the measured $|Y\rangle$ for the electric motor to $|N\rangle$ "the electric motor is too much modulated". Following, there is a new superposition of the Z-axis with "maybe something smoother". We now have a 2-dimensional framework;
- Figure 11c - Addition of Y-axis with line 339 with the addition of specific asset of "higher frequency" for the sound, the Y-axis is measuring a higher degree of embodiment for the to be designed sound $|H\rangle$, the X-axis is resting at $|N\rangle$ for the modulation. The next state will be measuring $|Y\rangle$ for "a continuous sound" and we are at the point of heading

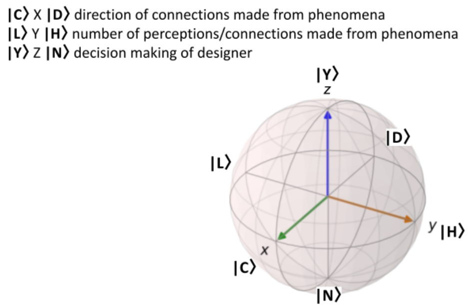

Figure 9: Bloch sphere for measuring the state of design. The axes of the Bloch sphere consist of |C⟩ x |D⟩ for x ranges from the amount of Convergence to Divergence. |L⟩ y |H⟩ for y ranges from Low embodiment to High embodiment in design. |N⟩ z |Y⟩ for z ranges from No to Yes decision making of the designer.

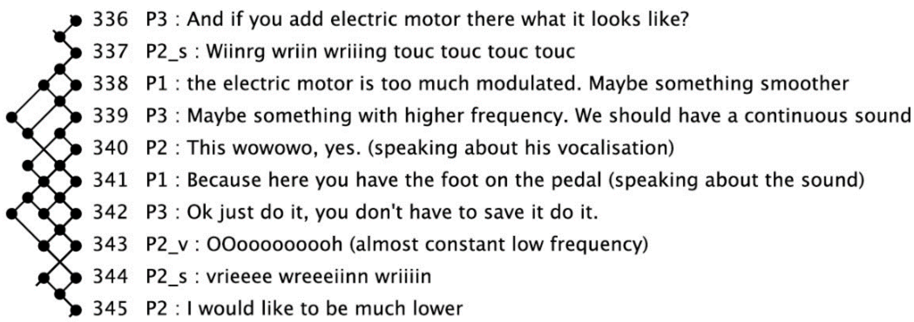

Figure 10: Linkograph of an excerpt of 12 moves. Forelinks denote acts of synthesis and divergent thinking, backlinks are associated to evaluation and convergent thinking.

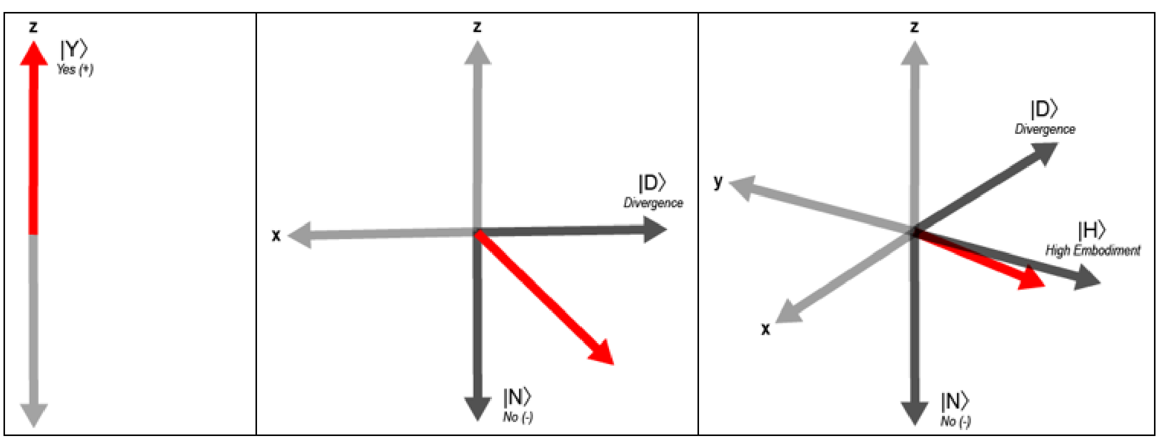

Figure 11: a. State of design conversation visualized on a single z-axis of yes (+) and no (-), moves 336 → 337. b. Addition of X-axis by line 337 starting a divergence of 3 links (Figure 10). c. Addition of Y-axis with line 339 with the addition of specific asset of "higher frequency" for the sound.

towards convergence according to the linkograph (Figure 10). We now have the complete 3-dimensional framework.

An interesting observation is that protocol analysis studies such as linkography [42] (Figure 10), discard the role of time in design. This in contrast to the proposed quantum framework, which is for Figure 11a, 11b and 11c explicitly used in a sentence-to-sentence scale of time.

4.4 Design as a sculpting process of superpositions

Quantum mechanics brings novel opportunity to view design through a quantum lens.

A designer starts with a blank sketch book, the design itself exists only in absolute abstraction, just as ideas. For the act of designing, filling in the blanks is equal to sculpting away the superposed. Quantum mechanics provide a way to model the blanks of classical frameworks as a combined state between two binaries. The design process can be regarded as reducing binary states from superposed ambiguities, such as reducing yes (+) or no (-) from superposed maybes (+/-), convergence or divergence from superposed directionality, and abstraction and concretization from superposed embodiment. The act of designing can be regarded as the designer placing measurements on the superposed, to in turn, reduce binary states.

As long as we can measure design even retrospectively in binary states, we can create theoretical superpositions of different phenomena to measure design. However, superpositions of binary states need to be formulated, in order to model these using qubits. This means that there are opportunities for exploring real world design phenomena such as the co-evolution of problem solution space [2, 28], or stuckness [29], through a new lens of quantum entanglement.

This paper provides a real-world touchpoint for quantum theory to approach the measurement of everyday design. For future research, measurement of design-process-in-the-wild is of most interest for the design community. Therefore, the aspect of real-world design measurement modeled by quantum mechanics and qubits requires elaborate exploration and research documentation in order to bring validation from the design world together with quantum theory for design and creativity.

5 CONCLUSION

The mechanics of the design process with converging and diverging certainty in design communication and the mechanics of quantum physics seem like two linked fields of research through the fundamentals of creativity, cognition and ideation. Through the deepening journey of this research exploration, the bonds between the field of quantum mechanics and design are perhaps as fundamental as classical mechanics or frameworks with which to describe design. This is most noticeable in the quantum mechanics that lend itself to describing the complex mechanics of a design-process, as well as the possibilities to model and measure design according to simulated quantum mechanics such as creating a quantum system using superposed binary states of design. Due to the classical mechanical frameworks of design, we can retrieve fundamental binary states of design such as directionality (convergence & divergence), embodiment (abstraction & concretization), and the designers decision making (no & yes), to create superpositions and model the blanks in design practice. Besides the theoretical implications of quantum mechanics for design, there are opportunities to measure design in the "real world" using quantum mechanical models simulated with quantum circuits and measurements on qubits. We suggest future research to be aimed at explaining real world design phenomenon such as the co-evolution of problem-solution space and stuckness using quantum entanglement. Furthermore, there is a significant research opportunity in quantum mechanics for design, such as entropy and uncertainty, which may have implications for defining uncertainty in design communication. Additionally, quantum leaps and "jumps" or fuzziness in a design process may have interesting coherence to examine. Most importantly, we want to focus on the application of quantum mechanical measurements, to spread quantum mechanics for design and its opportunities throughout the design world.

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