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MITIGATING DESIGN FIXATION WITH EVOLVING EXTENDED REALITY TECHNOLOGY: AN EMERGING OPPORTUNITY

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Abstract
Design fixation refers to the designers' inability to avoid becoming stuck with preexisting ideas in order to generate new ones. With the recent fast advancements and developments, XR has emerged as a powerful promising technology that can shed new light on this issue. Consequently, this paper aims at: (1) investigating the underlying mechanisms of design fixation as reported in literature; (2) exploring the state-of-art in the use of XR technology in design; and (3) identifying ways to mitigate design fixation by employing XR technology.

Keywords: creativity and ideation, design creativity, design cognition, virtual reality (VR), augmented reality (AR)

1. Introduction

Design fixation has been a long persisting problem that bothers designers. Fixation refers to a phenomenon in the design process during which designers consciously or unconsciously adhere to prior ideas and their variations, while they are unable to generate new ones. This notion, that was first proposed by Jansson and Smith in 1991, refers to situations where designers blindly stick to certain features of the design and reuse them in suboptimal ways, even when they are deliberately instructed to avoid doing so (Crilly and Cardoso, 2017; Jansson and Smith, 1991). Fixation caught the attention of design researchers due to its impedance to idea generation in the conceptual stages of the design process. Evidence from different academic fields suggests that design fixation is rooted in human's intrinsic cognitive mechanisms, such as conflicts of mental processes and sunk cost (Gabora, 2002; Viswanathan and Linsey, 2011). Although the study of design fixation was prolific in the last two decades, further efforts should be undertaken in order to gain a deeper insight into this phenomenon and mitigate it. In this sense, the use of Extended Reality techniques has brought forth new and promising opportunities in offsetting the negative impacts of the fixating design mindset.

Extended Reality (XR) fuses the concepts of Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). Their common origins can be traced back to Ivan Sutherland, who fifty years ago proposed the idea that having '*a computer display could create a simulation of the physical world with which the operator could interact directly by means of the senses'* (Schroeder, 1993, p.964). The main differences among these three subclasses of XR reside in how they balance virtual elements and reality. Whereas VR aims to completely immerse people into a computer-generated three-dimensional virtual environment for interaction (Schroeder, 1993; Milgram and Kishino, 1994), AR is at the opposite extreme. A main feature of this technique is that it overlays virtual elements on top of the real world for an augmented live view, but the interaction with reality is rather limited (Arth et al., 2015). On the other hand, MR integrates the features of both techniques, in a way that '*real world and virtual world objects are presented together within a single display*' (Milgram and Kishino, 1994, p.3), while users can interact with both real and virtual elements (Figure 1). Supported by the revolutionary technological progress, XR techniques are pushing the boundaries of human-tech interaction nowadays (Jain and Werth, 2019; Kwintiana and Roller, 2019)

Figure 1. The genesis of extended reality

With the use of XR technologies, opportunities in settling persisting problems in the design process have emerged, especially those concerned with the mitigation of design fixation. For example, Gibson et al. (1993) applied immersive VR for assisting designers with a more natural ideation process. More recent attempts also adopted the strategy of replacing the unnatural computer-aided design (CAD) tool with more flexible and intuitive XR techniques. Dorta (2007) pointed out that low usability of CAD tools turned design tasks into software operation tasks and severely challenged designers in expressing creativity. Thus, he recommended designers to use a more intuitive design tool that would enable them to focus on design. Instead of traditional CAD tools, this researcher proposed the use of a hybrid 3D immersive environment in support of the sketching of ideas for interior design spaces. A similar approach can be found in the Virtual 3D Sketching interface proposed by Rahimian and co-workers in the engineering design domain (Rahimian et al., 2011). Flexibility and intuitiveness in interacting with XR - considered as crucial for designers to naturally reflect on the ideation process - were common aspects in these studies. Although important advances were made in the field, gaps related to technological developments that limited prior research from achieving its full potential, still exist. Furthermore, most studies carried out on XR are based on insights and experiences from professional designers mainly focusing on technical and practical issues, but disregarding important aspects related to design. This offers an opportunity to inspect the cognitive and behavioural mechanisms that are critical to understand the effect of XR on design fixation, specifically.

Consequently, by addressing the above identified gaps, this study aims to: (1) investigate the underlying mechanisms of design fixation from the literature; (2) explore current state-of-the-art in the use of Extended Reality in design from the perspective of cognitive and behavioural issues; and (3) identify possible directions to mitigate design fixation by employing this technique. This article contributes to: (1) integrating previously scattered knowledge about cognitive mechanisms behind design fixation; (2) providing solutions to mitigate the design fixation phenomenon; and (3) proposing future directions for incorporating XR techniques in design. By presenting these unattended gaps and opportunities, this study aims to inspire design researchers and technology developers on the above-mentioned novel and unique design research methods to consider design and XR technologies.

2. Design fixation

2.1. Design fixation phenomenon

Generally speaking, design fixation refers to the situation where designers adhere to existing ideas and cannot switch to new ones. This phenomenon was originally defined by Jansson and Smith (1991) as *'...a blind adherence to a set of ideas or concepts limiting the output of conceptual design'* (reported by Crilly and Cardoso, 2017, p.3). In the experiments they conducted, Jansson and Smith showed the participants bad examples and required them not to include those features. Such an explicit warning did not prevent the participants from reusing those features in a suboptimal way (Crilly and Cardoso, 2017; Jansson and Smith, 1991). Design fixation became an issue of concern in design research. However, while a plethora of works expanded the state-of-the-art on the topic, interpretations about fixation made by different fields caused confusion. Youmans and Arciszewski (2014) argued that researchers from different disciplines used the term design fixation to describe distinctive situations, even when the reasons for fixating were dissimilar. Psychologists, for example, mostly use this term to refer to unaware adherence to primed features, while engineers sometimes employ this term to refer to a deliberate unwillingness to replace a previous successful solution with a new one. Design fixation, however, does not always negatively affect outcomes in all contexts, as industrial professionals sometimes prefer reusing existing ideas to reduce risks and investment (Youmans and Arciszewski, 2014). Nevertheless, difficulties in overcoming the inability to generate new ideas still bother designers and researchers. Consequently, it is still worthy of further investigation. As a way to frame this problem, Youmans and Arciszewski (2014) specified three different kinds of design fixation: 'unconscious adherence', 'conscious block', and 'intentional resistance'. Unconscious adherence is close to Jansson and Smith's definition of design fixation, which refers to the situation where designers are influenced by previously exposed information without awareness. Their blindness to the situation might result from inherent human cognitive mechanisms. In the case of conscious block, designers are *'frustratingly aware of their inability to avoid fixed thinking'* (Youmans and Arciszewski, 2014, p.132). Intentional resistance can happen on an individual or an organizational level. It refers to '*a prevailing attitude that a previously successful solution is preferable to that of a novel solution'* (Youmans and Arciszewski, 2014, p.133). Other studies have suggested that a fixated idea may not necessarily be unsuccessful, but can be effort-consuming (Viswanathan and Linsey, 2011).

2.2. Mechanisms underlying design fixation

Youmans and Arciszewski's categorization frame is straightforward and insightful as it succeeds in reviewing the principles underlying design fixation. By exploring and cross-comparing literature from a variety of domains, several cognitive and behavioural mechanisms were identified and are presented below. They not only map the three categories of design fixation, but also reflect the multi-faceted nature of this phenomenon.

2.2.1. Sunk cost

Sunk cost refers to the resources that are spent and not possible to recover. Rational decision-making strategy should take future cost, instead of previous cost, into consideration as the latter has no real impact on upcoming events. Yet designers frequently show reluctance to deviate from the current path of action due to their unwillingness to waste the invested time, resources, and efforts. This is believed to be related to a psychological phenomenon called 'loss aversion', known as the tendency of humans to prioritise avoiding loss over obtaining equivalent gains. Sunk cost was often considered as the main encumbrance for innovation in industries and organisations. Recent studies demonstrated its negative impact on the design process, and showed how this phenomenon contributes to induce a fixated mind (Viswanathan and Linsey, 2011).

Viswanathan and Linsey (2011) demonstrated that designers exposed to a condition characterised by high sunk cost presented more fixated ideas. In their experiment, these researchers prepared two kinds of materials: metal materials that are easy to reshape and plastic materials that require more effort to use. The result indicated that the group which built the model with plastic material had highest fixation. Moreover, another group that was instructed to imagine designing with the plastic materials and draw their ideas by hand sketching, showed a similar fixation effect. This suggested that it is not only the use of effort- and time-consuming materials that reduces the novelty and variety of ideas, but also mentally processing the design with higher sunk cost can lead to similar results (Viswanathan and Linsey, 2011).

2.2.2. Conflict in design mental process

Design ideation, especially in its early stage, is often described as a transitional phase where ideas rapidly collide and combine. Sophisticated design support tools can facilitate this process and enhance the novelty and creativity of ideas. However, as pointed out in previous studies, most prevalent design tools, i.e., CAD do not contribute to generate novel ideas. A main reason is that cognitive processes related to idea generation conflict with the nature of CAD systems. The complex and counter-intuitive operations of CAD tools have turned the design task into a software task manipulation. Consequently, designers can design what the software allows them rather than what they want to. This phenomenon is of major concern in technological-related design fixation research.

In 1993, Gibson and colleagues identified the need for a design that *'could retain their excellent automotive and interactive properties, whilst adding advanced graphic definition and sculpture tools'* (Gibson et al., 1993, p.115). Although these researchers insightfully proposed VR as a mitigating solution, they were constrained by the limitations of the technology available two decades ago. A more recent study from Dorta (2007, p.252) further specified how conflicting mental tasks cause designers to lose the directness in expressing their ideas: *'Computers have their own logic and language…'* As he pointed out, *'Some computer interface commands have so many preconceptions about how the design process should be... The time spent by users to configure and deal with computer requirements deters them away from design thinking to digital representational or programming model thinking'* (Dorta, 2007, p.252). Moreover, Rahimian et al. (2011) also pointed out the inherent problem of CAD in obstructing the natural flow of the design process, and hindering the designer's spatial cognition. They empirically compared a design task under three experimental conditions that included: a full manual designing, a full digital designing, and a combination of both. Results indicated that whereas CAD tools significantly hindered design creativity in the first two conditions, the opposite occurred in the combined group. Hence, these researchers recommended the use of more flexible and intuitive design tools in the early design process.

2.2.3. Interconnected nature of memory

Human memory is interconnected and associative in nature. Humans can hardly activate target memory episodes without evoking related ones. Memories are stored in the form of neuron connections and distribute equivalently across the brain cortex (Squire, 1986; Thompson, 1986). In this process, each memory episode is stored across multiple locations, while each memory location contributes to the storage of multiple memory episodes (Gabora, 2002). The highly interconnected configuration of memory allows humans, and designers in particular, to link irrelevant or remotely related items together, which represents a common source of creative and novel ideas.

However, a main issue is that neuron connections are dynamic and susceptible to recent neural activation. Reactivating a memory episode strengthens connections between the corresponding neurons, which in turn makes such an episode easier to be accessed (Youmans, 2011). This may serve to explain the blindness of adherence effect observed in design fixation scenarios. Moreover, it may shed light on why strategies like brainstorming, mode switching, or even just stopping work on a task can help mitigate design fixation. The shared logic of these strategies is to stop activating the same neural pathway in order to avoid strengthening the fixated connections while attempting to catch 'new combinations of properties by reconstructing unusual blends of stored items' (Gabora, 2002, p.130).

2.2.4. Monotonous stimulus

Due to the interconnected structure of memory, a stimulus from the external environment is often needed to initiate the knowledge retrieving process (Surprenant and Neath, 2013). What designers perceive determines which neural pathways will be activated, and what information will be accessed. In other words, the richer the types of information a designer can retrieve from the stimuli provided, the more distinct ideas he or she will generate. Thus, stimuli in the external world play an important role in design ideation.

Yang et al. (2018) showed that monotonous stimuli lead designers to explore a narrower solution space. In their study, participants were asked to design a wearable device under different design conditions that included: i) a 2D human body image printed on a paper and ii) a 3D human body model in an immersive virtual environment. Findings indicated that under the immersive VR condition more diverse designs were produced, while in the 2D condition solutions were highly repetitive and similar to existing products. Results also emphasised the role played by the stimulus in the 3D

environment. In this condition observations of the model were made from different perspectives that inspired the generation of unique ideas. Participants also benefited from a digital brush mimicking the effect of a variety of materials, which can be found in the real world, that helped to mitigate fixation and contributed to enhance idea generation.
Moreover, the lack of variety in stimuli also reflects the absence of sensory modalities other than visual in support of the design process. Engaging multi-sensory modalities while designing proved to be an effective strategy for enhancing creativity (Merter, 2017, p.86). However, current design tools almost exclusively rely on visual stimulus modality. The identification of this gap offers new research opportunities for the future.

2.2.5. Individual differences

Individual differences are reported to play a role in design fixation. Bellow and colleagues found that people characterised by low working memory capacity dealing with tasks under quiet and interruptive conditions, tend to present more design fixation than those with higher working memory capacity (Bellows et al., 2012). They proposed that working memory capacity is related to the ability to filter irrelevant features from stored information (Bellows et al., 2012).
Another individual-based factor was 'Need for Closure', with reference to the psychological need of bringing an ongoing process to an end and to rush to a conclusion. Lai and Shu found that people with higher 'Need for Closure' showed more fixation in their design tasks, and this was attributed to their tendency to make quick decisions and a consequent fixation on the available information (Lai and Shu, 2017).

3. Extended reality

3.1. An outlook of XR

The story of extended reality techniques (XR) starts with 'The Sword of Damocles', the first Virtual Reality (VR) and Augmented Reality (AR) device. Ivan Sutherland (1968) invented this device in order to present users with an immersive and interactive computer-generated environment. This name was inspired by the look of the mechanical arm that was used to connect users' head-mounted display and other parts of the machine via the ceiling. The objective of this device perfectly aligns with the modern definition of VR, while its reliance on the movement tracker and see-through head-mounted display shares the common feature with modern AR. This invention was hence considered to be the origin of both techniques.
The evolution of VR and AR diverged since then. For the next decade, VR was mainly researched by the military for simulation training and space-related studies. VR embraced its first important development in the late 1980s, when Jaron Lanier created the term Virtual Reality to address this technique. The idea of interacting in a virtual world, where users' capabilities can be extended while the real-world obstacles can be excluded, amazed the world with its potential in reshaping how humans interact with the world. Unfortunately, many insightful theories and predictions could not be verified with the technologies available thirty years ago. It was only after progress in computing power and algorithms that VR achieved more functions, and returned to the vision of the public.
The modern definition of AR proposed by Tom Caudell and David Mizell in 1992 refers to *'overlaying computer-presented material on top of the real world'* (Arth et al., 2015, p.3). While achieving very different goals, AR was considered as a variation of VR in its early phase (Azuma, 1997). The boundary between VR and AR became clear when lightweight devices enabled users to apply AR techniques to the broad real world, rather than in artificial environments such as the lab. The first mobile AR system was invented in 1997, and it was already able to accomplish the majority of the tasks that AR can achieve nowadays (Arth et al., 2015). The blossoming of smartphones allowed the general public to become familiar with this technique. The mobile-phone-based AR has been extremely successful in enhancing daily life experiences. The future of AR research seems to depend on its integration with wearable devices.
Mixed Reality (MR) is a relatively new concept to the public. This technology is often vaguely defined as the merging of the real and virtual worlds or simply as 'the combination of VR and AR'.

Milgram and Kishino (1994, p.3) clarified this definition from the technical perspective: '*[In MR] real world and virtual world objects are presented together within a single display*'. To make sense of the concept, a popular interpretation is that MR mixes two specific features of VR and AR: immersive and real. MR and VR are both immersive because the entire space around the users is a part of the interactive environment, while MR and AR both integrate real-world elements and virtual objects. This explains how MR 'mixes' the reality with the virtual.

3.2. XR's benefits for design and design fixation

XR technologies are evolving fast and gradually approaching their full potential. Recent breakthroughs in computation have enhanced VR's level of immersion, which provided users with a more realistic and accessible virtual scene with a lower perceivable delay. On the other hand, the progress in wearable devices expanded the possibility of interaction methods, especially in better supporting body movement recognition and engaging multi-sensory perception. Consequently, new opportunities in supporting design with XR have emerged. Some of the aspects that design would benefit from when XR techniques will reach maturity are:

- Flexible and Intuitive operation:

In current practice, VR and AR have already provided the most natural and intuitive ways of operation among all 3D design tools. On the one hand, inputs from these technologies rely on body movement and gesture recognition, with either digital pointer or hands, which can be seen as a most common and natural way for designers to express and communicate their ideas ever. On the other hand, VR and AR systems impose minimal preconceptions in the interfaces about 'how the design process should be', hence allowing designers to conceive and develop their ideas with maximal freedom. Since designers are not distracted by the technical aspects of the tool, they can largely focus on the design task itself. In this sense, flyingshapes is a recently launched VR-based CAD software that emphasises the intuitive and seamless experiences in operating this product for design, an aspect that was appreciated by both designers and XR developers (https://www.flyingshapes.com/). This constitutes another proof that flexibility and intuitive operation of VR are the keys to overcome the raised issues and concerns.

- Recovery: easy redo and undo

Enabling easy redo and undo is not a unique feature for XR, as it is a common benefit of all digital tools (Dorta, 2007). However, it makes a difference if the tool under consideration is also intuitive to use. A dilemma for designers was whether to maintain the natural flow in the design process, or to ensure that each detail can be retrieved and stored. Both traditional and earlier digital design tools can only achieve one of these two requirements. XR, however, can free designers from making such a decision. By supporting natural interaction and easy retrieval of the previous work, XR techniques can reduce both psychological and sunk costs characteristic in the design process.

- Embodied cognition

Embodied cognition refers to the phenomenon in which humans' physical perception can influence cognition via a body-mind link. The information sensed by the human body intertwines with the ongoing cognitive process and shapes the thoughts (Shapiro, 2019, p.86). For example, it has been observed that by physically embodying abstract metaphors, such as 'being open' or 'breaking the wall', designers are able to enhance the novelty and originality of their ideas (Malinin, 2019). Leung et al. (2012) have shown that walking freely or walking out of a room during the ideation process, which served as an embodied metaphor of 'thinking out of the box', have been observed to promote the creativity of designers. A unique value of XR is that it is possibly the only design tool of its kind supporting embodied cognition during the design process.

- Extendibility

XR has great potential in incorporating other advanced techniques and further extending their capabilities. Fast advances in sensor research that are taking place these days will enable XR to support the design process through the interaction of all five senses. As envisioned by Sutherland (1968), a promising direction consists of engaging different multi-sensory modalities in support of the design activity. XR techniques already provide richer auditory and haptic feedback compared to other visually-focused design tools, and much more can still be achieved in the near future. Besides supporting the design process through the interaction of all five senses, future XR technology will be able to simulate real-world features, such as texture, temperature, movement, and weight in a finer level of detail.

- Rich stimuli

As discussed above, what designers perceive in the ideation process to a great extent decides what knowledge and experience can be retrieved, and in what direction their ideas will go. Thus, designers need richer stimuli for generating more diverse ideas. In this sense, XR has already outperformed other design tools in supporting multi-sensory stimuli. Moreover, the immersive XR environment will enable designers to notice more details and make observations from different perspectives.

- Change in perspectives

Enabling designers to observe the world through others' eyes will be another singular advantage of XR techniques. Previous research already showed that VR can promote empathy and understanding (Herrera et al., 2018) while reducing the stereotypes and wrong knowledge of outgroup members (Yee and Bailenson, 2006). Furthermore, a fully functioning virtual environment could be devised to replicate the world as perceived by different types of users. Consequently, designers could immerse themselves in different worlds, such as that of the elderly, infants, athletes, office staff, etc. This may allow them to gain a deeper understanding about the users' needs in their real contexts. Universal design will especially benefit from this possibility.

4. Discussion

In this section, we debate further on how designers will benefit from XR, and how this technology will help mitigate design fixation. We first elaborate on what features of XR will contribute to this aim, and thereafter we identify gaps between existing XR-based solutions to design fixation and the capabilities of XR technology.

4.1. Mitigating design fixation with XR

We analysed the cognitive and behavioural mechanisms of design fixation, and the benefits that XR will bring to design. From these, we propose that XR techniques can help to mitigate problems identified with design fixation, while providing fundamental support to the designers.

4.1.1. XR and sunk cost

Due to sunk cost effect, design fixation is likely to be responsible for the designers' unwillingness to waste their time and effort while dealing with a design task. In order to tackle this issue, the intuitive and flexible interaction maintained with XR devices during the process can help to reduce potential frustrations. Moreover, the easy retrieval of previous works allows designers to resume from any stage without worrying about wasting the invested resources. The less demanding the design process may be, the less aversive designers may feel when abandoning an idea. In this regard, the powerful functions of XR are effective in reducing the time and effort required to solve a task, and hence they contribute to diminishing the actual sunk cost.

4.1.2. XR and conflict in the mental process of design

XR can be seen as a suitable solution for dealing with conflicting situations generated in the design process. The natural and intuitive way of interaction facilitated by this tool contributes to reducing conflicts derived from design manipulations during the task. Humans have limited attentional resources and an unnatural interface of the design tool may demand additional attention from the designers. In consequence, designers may not have adequate mental resources available for the design task. However, the interaction with XR devices relies on hand controllers that enable designers to easily use natural gestures and body movements to represent their ideas. In this regard, ergonomics research suggests that tasks that are processed by different cognitive channels interfere less with each other. Both CAD operations and design tasks require intensive visual resources. An advantage of XR techniques is that they rely on spatial and manual resources, which helps to reduce mental competence between different operations and tasks, and thus prevent design fixation.

4.1.3. XR and the interconnected nature of memory

As discussed above, memories associated with the overly activated neural pathways tend to occupy the mind and induce fixation. Thus, a solution to this problem could be to reduce the unnecessary priming element to a minimum, and inspiring designers with enriched stimuli. For example, tutorials and guiding projects impose a deep impression on novice designers and hence lead them to fixate on the exposed features (Georgiev and Milara, 2018). An advantage of XR's flexible and intuitive mode of operation is that it supports dealing with design situations in such a straightforward way that it does not need too much guidance. Moreover, allowing the brain to switch its attention between different mental processes is also an effective strategy in finding alternatives to release the overly activated neural pathways leading to fixation; and this is what XR techniques are good for. XR's great extendibility, rich information output, and ease in changing perspectives about the design situation can lead designers to temporarily set aside fixated ideas and to explore new design opportunities.

4.1.4. XR and monotonous stimuli

By integrating multi-sensory modalities and embodied cognition, XR technology will significantly enrich the types of stimuli in the design process, and this will help reduce the effect of monotonous stimuli.

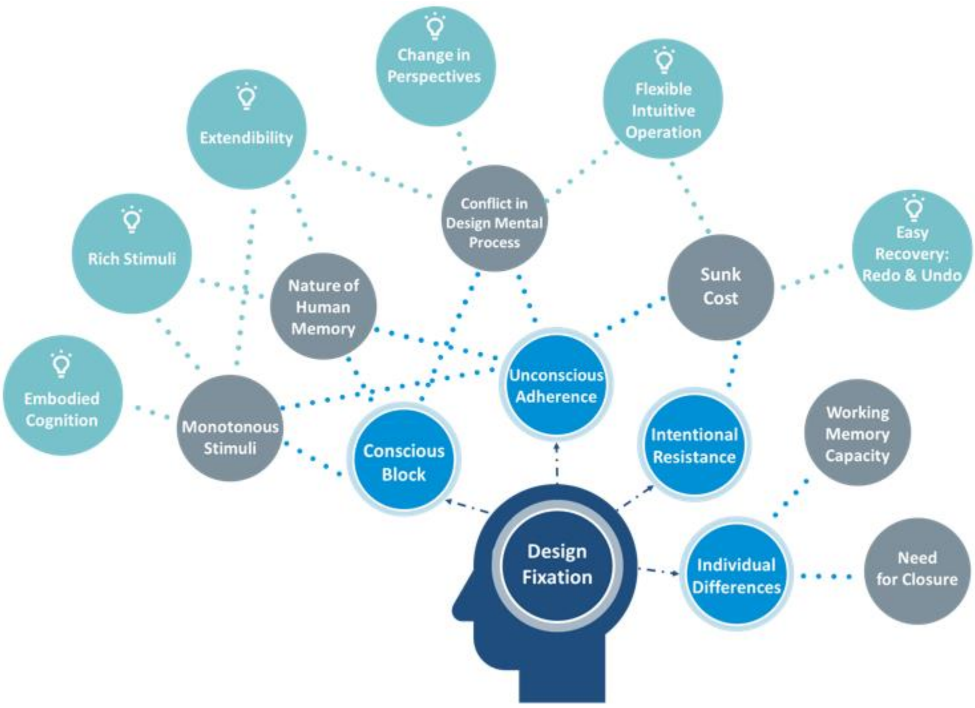

Figure 2. Maps of identified problems and mitigations

4.2. What are the gaps?

4.2.1. XR technologies and design fixation

Through a cross-domain literature review, we identified existing gaps between XR-based solutions aimed at dealing with design fixation, and what XR can achieve nowadays. Existing XR-based solutions were roughly classified into two categories: 3D sketching and digital clay approaches. While details of 3D sketching approaches varied, the motivation behind them is identical: enabling designers to use natural methods such as hand sketching in building 3D models. Dorta (2007), for example, proposed an AR-based solution approach for interior design problem solving, which provides a spherical graphic template for drawing and projecting drawings on a surrounding spherical screen that creates a 3D effect. In this way, designers can visualise how their projects would be perceived in reality. A similar approach was proposed by Rahimian et al. (2011), during which the designers' manual sketching process was tracked and converted into a virtual 3D model depicted on a computer screen.

While both examples were seen as practical and insightful, there were important gaps that these tools could not address, most of which were related to constraints imposed by the technology available then. A common limitation of these solutions was that although design outcomes were converted into 3D, the design ideation process itself was not conceived in 3D.

The logic behind digital clay is similar: avoid fixation caused by low-usability software and support the natural design process. But the strategy that this technology represented was about providing tangible clay with sensors. Whereas designers moulded the clay, sensors would synchronise the design shape to the computer in order to convert it into a 3D model. In its time, this technological solution was considered to be very sophisticated and enabled the use of traditional design methods for 3D modelling. However, the extendibility of this technique was a major gap, considering that it was hard to integrate with other senses. Another concern was that externalising concepts and ideas too early may lead designers to fixate on their ideas, as shaping the clay requires ideas to be externalised from the beginning.

Overall, the existing solutions focused on mitigating design fixation due to conflicting mental process issues. Together with these, gaps between existing solutions and currently available XR techniques mainly rest on: (1) low extendibility to other beneficial features; (2) inadequate utilisation of the immersive 3D environment; and (3) inability to address other types of design fixation. These are some of the features that should be specifically addressed when developing future XR-based design tools.

5. Conclusion

In this article, we elaborated on the notions of design fixation, and the cognitive and behavioural mechanisms characterising this phenomenon. Moreover, we explored the state-of-art of extended reality techniques and evaluated opportunities for employing these tools to mitigate design fixation. While gaining insights onto the powerful functions, great extendibility compared to other techniques, and huge potential of these emerging tools, we propose that XR will effectively contribute to dealing with and mitigating the main causes of design fixation discussed in this work. Identifying existing gaps between previous technologies and XR, and testing them in practice will be beneficial to the development of this tool. Hence, in a future work we plan to carry out a series of empirical studies that will enable us to explore the potential of XR techniques in the design process, especially in utilising the operational flexibility and stimulus-richness to offset humans' intrinsic tendencies in fixating on past ideas. We also plan to deal with additional problems and challenges associated with design fixation and cognitive load.

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