Design Science

Reviewing the concept of design frames towards a cognitive model

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Abstract

This paper critically reviews literature about design framing to clarify an understanding of what is meant by the construct of a *design frame*. It describes the origins of the term design frame and characterises three distinct definitions that can be found within the literature. It reviews empirical studies of design framing to highlight definitional confusion between studies. It discusses the significance of Dorst's propositional model of design frames and juxtaposes design frames with other related constructs. It clarifies ways that the resolution of nomenclature for describing design framing might lead to a more coherent body of empirical research into this topic. It suggests that there is value in developing a better cognitive model of design framing and outlines potential steps towards such a model.

Keywords: design frame, framing, design cognition, grounded cognition, cognitive model

1. Introduction

A common adage in design is that solving the right problem matters. It has become a cliché to begin articles about design framing with Einstein's quote, that 'if I were given one hour to save the planet, I would spend 59 minutes understanding the problem and one minute resolving it' (e.g., Spradlin 2016; Henriques 2018; Münch, Trieflinger, & Heisler 2020). The intimation is that once a useful understanding of a problem has been developed, then a solution – or a suitable design candidate – is often readily available. Articles use this quote from Einstein because it speaks to the importance of framing for problem-solving and design activity. Framing is understood to be the 'core of design thinking' (Dorst 2011) yet the essence of design frames – how to distinguish them, how to speak about them – remains ambiguous.

This review paper is motivated by a perceived mismatch between, on the one hand, the widespread usage and utility of the construct *design frame* and, on the other, the lack of definitional clarity currently available. The term *framing* has gained significant usage within design cognition literature. In a widely cited paper, Dorst (2011) has argued that framing is the 'core of design thinking'. Frames have been studied empirically for at least three decades (e.g., Schön & Wiggins 1992; Valkenburg & Dorst 1998; Kvan & Gao 2006; Hey, Joyce, & Beckman 2007; Zahedi & Heaton 2017; Mcdonnell 2018; Silk *et al.* 2021; Chandrasegaran, Lloyd, & Akdag Salah 2022). The notion of framing has been applied to diverse areas of design such as social policy innovation (Van Der Bijl-Brouwer 2019), engineering design (Rodriguez & Benavides

2021), and product design (Hey *et al.* 2007) as well as to design research methods (Bailey *et al.* 2018) and design pedagogy in higher education (Gray 2019). Yet the terms design framing and design frame still lack any consensus definition.

This paper is concerned with reviewing the term *design frame* and it takes the form of a critical review in that it considers the literature that is most salient to the topic, uses a conceptual mode of synthesis, and analyses the literature aiming for a conceptual or theoretical contribution (Grant & Booth 2009); it is not an exhaustive review of the topic. It reviews the origins of the term frame to show that three different definitions can be found within the literature. It then reviews empirical studies of design framing to show that a range of these three definitions is utilised. It discusses the significance of the propositional model of design frames (Dorst 2011) and contrasts design frames with related constructs. It concludes with a discussion of pathways that might advance the study of design frames.

2. Definitions of design frames

2.1. The origins of the term frame

The origins of the term *frame* can be approached through the question: what is the relationship between a person's ability to *reason about the world* and to *have sensory experiences in the world*? This question was salient in the 18th century in attempts to reconcile rationalist and empiricist notions of epistemology (Markie & Folescu 2004). On the one hand, new knowledge can be developed through the use of reason, such as through logical inference. On the other hand, sensory experiences within the world can also lead to new understandings. These two understandings are now recognised as complementary parts of an interdependent system of concepts and experiences.

The *concepts* that a person holds about the world influence the ways in which sensory experiences occur; what they think about the world changes what they attend to, what they sense, and the interpretations that they produce. Similarly, the *experiences* that someone has in the world can change those concepts to reflect reality in what is commonly referred to as learning. Early work exploring these notions looked at the nature of concepts and the existence of selective attention (James 1890) as well as the constructive nature of memory (Dewey 1910; Bartlett 1932). It was observed that *problems* (including but not limited to design problems) serve to trigger a '…survey and recall of the past to discover what the question means and how it may be dealt with' (Dewey 1910, p. 207). Although neither James nor Dewey used the term *frame*, their work underpins the modern understanding of a frame as being an internal conceptual structure that guides the ways in which aspects of experience occur. Schön (who did use the term frame) explicitly refers to the influence of both James and Dewey on his thinking.

The word frame began to be used widely following the publication of Erving Goffman's book *Frame Analysis* (Goffman 1974). Goffman drew upon these philosophical underpinnings from Dewey and James (Verhoeven 1993) as well as the phenomenological ideas of Bateson (1972) and Schutz (1962). He defined frames as follows:

> I assume that definitions of a situation are built up in accordance with principles of organization which govern events—at least social ones—and our subjective involvement in them; frame is the word I use to refer to such of these basic elements as I am

able to identify. This is my definition of frame. My phrase 'frame analysis' is a slogan to refer to examination in these terms of the organization of experience. (pp. 10–11)

For Goffman, people organise experiences through frames, and those frames can be analysed. Frames are the way that people make sense of circumstances, the story that they might tell you if you were to ask them 'what is going on here?'

The origins of framing are further complicated (Borah 2011) by parallel uses of the term – beyond Goffman's sociological account – within artificial intelligence (Minsky 1974) and psychology (Kahneman & Tversky 1984). Recent reviews focus on framing in product innovation (Hey 2008), framing as a reflective conversation (Dorst 2015), and a sociological review of framing (Snow 2007). In later work on the subject, Rein and Schön (1996) discuss four ways of looking at frames as scaffolds (inner structures that support further building; a Minsky-like perspective), as boundaries (like picture frames; a Goffman-like perspective), as schemata that support interpretation (a Piagetian perspective), and as diagnostic/prescriptive stories (the view that Rein and Schön support).

2.2. Frames in design

The notion of *framing* entered the field of design through the writing of Schön (1983).[1] For Schön, framing happens when we *name* the things that we are interested in (internally recognising them through selective attention) and *frame* the context in which we understand them:

> When we set the problem, we select what we will treat as the 'things' of the situation, we set the boundaries of our attention to it, and we impose upon it a coherence which allows us to say what is wrong and in what directions the situation needs to be changed. Problem setting is a process in which, interactively, we name the things to which we will attend and frame the context in which we will attend to them. (p. 40)

He gives the example of a studio master, Quist, and a student, Petra, engaged in a reflective conversation. Schön describes the conversation as having 'local experiments' that contribute to the 'global experiment' in which master and student work together to reframe the problem. These common origins of frames – especially the work of Schön – are referenced throughout the literature that looks into empirical studies of framing in design (Schön & Wiggins 1992; Valkenburg & Dorst 1998; Kvan & Gao 2006; Zahedi & Heaton 2017; Van Der Bijl-Brouwer 2019).

The idea of a *frame* has been useful at least since the time of Schön as a way of resolving the interdependency of internal and external worlds of cognition and is a useful construct for the study of design. Frames have been used to provide narrative accounts of how designers change their conception of a design problem (Schön 1983). They have been used in the analysis of design discourses to distinguish where designers are naming, framing, moving, and reflecting during episodes of design (Valkenburg & Dorst 1998). They have, more recently, been used in an applied way to suggest a process for working towards better understandings of a problem (Dorst 2015).

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[1]Schön cites James and Dewey in his notes, in *The Reflective Practitioner*, writing 'Dewey proposed that problems are constructed from situations of indeterminacy, problematic situations, that we apprehend through the experience of worry, trouble, or doubt' (p. 357).

2.3. Design framing

The activity that leads to the creation of a design frame is referred to as design framing. An understanding of how design framing is discussed in the literature provides a useful context for defining design frames. Designers face a well-recognised challenge, that they can only ever design within their own interpretation of the problem that is to be addressed (Schön 1983; Gero 1990; Dorst 2011, 2015) and design framing is the process of constructing an understanding of the problem that is to be solved. Design problems are not 'out there' waiting to be solved, and even a design brief requires interpretation (Sosa, Connor, & Corson 2017). The term framing was introduced to design by Schön (1983) with the observation that:

> When ends are fixed and clear, then the decision to act can present itself as an instrumental problem. But when ends are confused and conflicting, there is as yet no 'problem' to solve. A conflict of ends cannot be resolved by the use of techniques derived from applied research. It is rather through the non-technical process of framing the problematic situation that we may organize and clarify both the ends to be achieved and the possible means of achieving them. (p. 41)

The goal, or the 'ends', for any design problem needs to be invented by each designer approaching that problem. Designers make moves in the context of their understanding of a design problem, where 'the very invention of a move or hypothesis depends on a normative framing of the situation, a setting of some problems to be solved' (Schön 1984, p.132).

It is significant that the understanding of a design problem is rarely set in stone. Throughout designing, the designer's understanding of the task is ongoingly revisited and the understanding of a problem evolves in parallel with the understanding of potential solutions (Poon & Maher 1997; Dorst & Cross 2001). Framing is thus an ongoing activity throughout the design process and is sometimes referred to as *reframing* following an initial framing (Paton & Dorst 2011; Stompff, Smulders, & Henze 2016).

2.4. Three definitions of design frames based on where they are found

A significant part of the ambiguity around frames is that definitions tend to focus on what frames do rather than what they are. A prerequisite for understanding what design frames are is understanding *where* they are located in relation to a designer. In reviewing the broader literature, three definitions of design frames can be described based on where frames are located. For some, frames as located within the internal world of cognition, while, for others, they are a type of representation and are external to cognition. For a third group, frames are tools for thinking that are defined by their ability to move between representation and cognition. This distinction relies upon the useful shorthand of 'internal' and 'external' (in relation to a designer) to avoid the philosophical arguments (which are ongoing) about where exactly this distinction lies (e.g., Williamson 2006).

First, a design frame can be thought of as internal to an individual designer and part of their cognitive structure. Multiple strands of design cognition literature posit this notion using a variety of different terms, such as *mental models* (Dong, Kleinsmann, & Deken 2013), *situations* (Gero & Kannengiesser 2004), *design*

prototypes (Gero 1990), and *object worlds* (Bucciarelli 1994). The notion that design frames are conceptual structures is implicit in the literature on *problem and solution spaces* (Dorst & Cross 2001), the seeing-moving-seeing of *reflection-in-action* (Schön & Wiggins 1992), and *design metacognition* (Ball & Christensen 2019). For Schön, the nature of these cognitive structures is as sensemaking narratives (Schön & Rein 1994).

Second, a design frame can be understood as an external representation, such as when a designer uses speech, sketching, or diagrammatic representations to reveal aspects of their internal understanding (see examples in Dorst 2015, Sosa *et al.* 2017). Requirements in a design competition might be considered an external representation of a frame. A designer can describe what they are trying to do in a way that might be said to 'capture the design frame'. Laursen and Haase (2019) provide examples of this kind of 'problem framing'. In the example cited earlier, Schön states that 'Quist criticizes [Petra's] framing of the problem' based upon seeing her actions and hearing what she says, implying that frames are externalisable.

Finally, design frames can be understood as tools that exist within the liminal space between the internal and the external. An understanding of a design problem can be represented externally and can cross and re-cross the intrinsic-extrinsic divide. Dorst (2015) adopts this third notion in defining frames as '…tools that exist within a world of actions and intentions' and that 'whether some metaphor or pattern of relationships can be called a 'frame' is completely defined by its use' (p. 65). In this view, a frame that has been represented externally can be used as a 'tool for thinking' about the design problem. It is not just the internal structure held by an individual, nor is it a single explicit representation such as a set of statements. It exists in the relation between the two as a synthesis of an external representation and the way that this representation is interpreted and used. For example, design teams iteratively share and interpret representations of a design problem to develop shared mental models (Dong *et al.* 2013), and this view of design frames is useful for understanding how teams of designers share norms (Hey 2008; Zahedi & Heaton 2017).

These three different locations of design frames, combined with prior understandings of what framing does, can be used to synthesise three definitions for an answer to the question of *what are design frames?* that are implicit within the literature:

(i) Design frames are conceptual assemblages: Designers, when addressing a design problem, conduct some cognitive activity that leads them to develop a set of concepts (where, following Chandrasegaran *et al.* 2022, that term includes values, beliefs, propositions, objects, symbols, etc.). A design frame is the singular name given to that conceptual structure, which is revealed through design moves/actions or utterances/representations.

(ii) Design frames are externalised representations of an understanding: Designers, use their understanding of a design problem to develop externalised representations of that understanding, such as speech or sketching. These representations of 'how this problem might be understood' are design frames and can exist independently of any designer.

(iii) Design frames are tools for thinking: Designers, use their understanding of a design problem to develop representations of that understanding, such as

through speech or sketching. These representations of 'how this problem might be understood' do work in the world as tools for thinking (either for oneself or for other designers). It is the combination of the representation and the moves/actions in relation to it that constitute the design frame.

3. Design frames in empirical studies

These three definitions can be put to work in identifying confusion within the literature. Table 1 lists seven selected empirical studies of design framing, which cover over almost four decades. These studies all purport to be studying this same phenomenon – design framing – yet utilise different definitions of what are meant by frames and framing and use methods that demonstrate this confusion.

For Kvan and Gao (2006), problem framing is 'the act of problem definition' (p. 246) and is 'a developmental process involving systemic transformation' (p. 247). They identify framing as a design process that involves activities of conjecture, setting rules, and planning. In their method, framing activity is inferred from a design protocol when a designer identifies a new design problem or interprets further from the design brief. They make an implicit commitment to the first definition of design framing.

In contrast, Silk *et al.* (2021) state that 'While a problem can be reframed in multiple ways, individuals' interpretations of a framing can vary considerably' (p. 6). For Silk *et al.* (2021) frames are external and need to be interpreted by designers, much like a design statement. The method in their study is described with students being assigned to, or receiving, either innovative or adaptive frames. In this way, they adopt the second of our three definitions of framing.

The third definition of design frames is best characterised by Valkenburg and Dorst (1998), who pioneered the approach of identifying (within the discourse of a design protocol) the places where a team of designers are verbally *naming* the features of attention and creating a *frame* for action; then conducting design *moves* and *reflecting* upon those moves and their consequences. They recognise that 'a designer is actively constructing a view of the world based on his/her experiences' (p. 251), forming the frame internally; yet it is through sharing the frame with the team that it can be the basis for 'move-testing experiments (involving action and reflection)', what Schön (1984) refers to as frame experiments.

There is some recurring slippage between the second and third definitions of design frames. Valkenburg and Dorst (1998) go on to say that 'When the team frames a (sub)problem or (partial) solution to explore further on, then we code the context as a "frame"' (p. 255). This introduces some ambiguity: a 'frame' is something that a team holds, the (imputed) shared context for their actions, rather than an indication of the view of the world of any one designer.

Further confusion is found in the most recent studies. Chandrasegaran *et al.* (2022) refer to the notion of a design team having a 'primary frame within a design conversation' (Ibid, p. 13) and also to the ability to see 'frames interacting' within a protocol. This implies a view of a team as having multiple frames. Yet the nomenclature is lacking: there is discussion of multiple frames and a primary frame, but no recognition that individual team members might have different design frames. They define frames as 'social or rhetorical constructions that allow different perspectives to be explored in designing. These perspectives include values, beliefs, propositions, objects, symbols, etc. and they are explored through

Table 1. Selected empirical studies of framing organised chronologically, with methods of identification and cognitive commitments

Reference and genealogy	Motivation	Method	Where frames are located, and key assumptions made about frames
Schön (1984)	'I want to explore what happens in design inquiry when there is a conflict of frames and perspectives… How does an individual shift from one frame or perspective to another?' (p. 132)	Case study of architectural design with two designers. Analysis of design protocol, sketches and participant response to a video of the design session. Qualitative analysis of how each designer framed the problem and shifted their frame	Not explicitly stated in this paper. Designers demonstrate how they understand the problem and their dialogue reveals that one suggests a 'frame experiment' to the other. Implicit assumption that the researcher can impute some understanding of a frame (as an internal conceptual construct) from protocol/ artefacts/recall
Valkenburg and Dorst (1998), building on Schön	'to provide team members and team leaders with tools and guidelines to improve their [design] practice' (p. 250)	Study of two design teams in a design competition. Analysis of design protocol and artefacts by identifying naming, framing, moving and reflecting. Coding through: 'When the team frames a (sub) problem or (partial) solution to explore further on, then we code the context as a 'frame'. The frame is a context for the next activities; something to hold on to and to focus on while designing. Therefore a frame is mostly only recognisable through the following activity' (p. 255)	Frames are held by a team. Analysis of protocol/ artefacts are sufficient to identify the team's frame(s) and changes to that frame. 'the team not only tries to solve the problem, but at the same time also explores the suitability of the frame' (p. 255) '[the design team] develop that single frame throughout the design project' (p. 267)
Kvan and Gao (2006) building on Schön	'It is necessary for us to investigate the relationship between design tools and the design process' (p. 260)	Comparison of problem framing activities with paper-based and digital-based settings. Protocol analysis with linkograph and	Design is a cognitive process that occurs through cyclical phases of framing, moving, and reflecting as 'consecutive design

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Table 1. Continued

Reference and genealogy	Motivation	Method	Where frames are located, and key assumptions made about frames
		statistical analysis. 'The coding schema is based on Schön's 'framing', 'moving', 'reflecting' design process and has been described in detail elsewhere' (p. 249). Framing is defined as 'identify a new design problem' and 'interpret further from the design brief'	activities' (p. 260). Framing is seen as the cognitive activity of problem definition. It is recognised as being influenced by memory and environment. No commitments to where frames are located or what they are
Hey et al. (2007) building on Schön	'We identified core framing activities of design teams and propose a framing cycle of pseudo-frame setting, making individuals' frames explicit, making frame conflicts salient, and building a common frame' (p. 79)	Mixed methods study of 22 multidisciplinary design teams in the early stages of new product development. An 'operational definition' of frames as including: (a) a desired end state or goal; (b) relative importance and relevance of features; (c) boundaries, through problem scope, solution scope, resource constraints; (d) criteria for evaluation (p. 81)	Frames are cognitive constructs held by individuals: 'Frames are cognitive and thus are held implicitly by individuals. Even though they are not readily observable by others, frames can be more or less shared as a team frame to the extent to which the individual members' frames overlap or align' (p. 81)
Zahedi and Heaton (2017) building on Valkenburg and Dorst (1998)	'How do ideas evolve in the context of collaborative design? This research explores the framing strategies and tools involved in the co-construction of a shared understanding in the early stages of a design project' (p. 8)	Qualitative analysis of protocol and artefacts from an industrial design students' workshop. Coding for 14 designerly actions and analysis of relationships between these actions and naming, framing, moving, and reflecting	No explicit commitment to what a frame is. Implicitly a tool for thinking 'With a 'given' problem, students are unaware of the need to construct a frame, consider the context or see the project holistically. Ideally, by accepting ambiguity, design students become aware of the frames and limitations of projects, see the possibility of alternative frames and tackle the project

Table 1. Continued

Reference and genealogy	Motivation	Method	Where frames are located, and key assumptions made about frames
			through cycles of problem-setting' (p. 10)
Silk *et al.* (2021)	'In this study, we aimed to better understand relationships of problem framing and cognitive style to student designers' perceptions of their own idea generation outcomes' (p. 1).	'…we conducted an experiment that controlled for the types of problem frames that novice designers received and compared these problem frames with their cognitive styles and perceptions of their ideation outcomes. We analyzed these data quantitatively…'. The study included 102 engineering and industrial design students	The design frame is analogous to a problem statement '…the way a problem is described and the information included within a problem statement which constitute the 'problem frame' are compounding factors in designers' approaches to ideation and their ideation outcomes' (p. 2). Frames are interpreted by designers 'While a problem can be reframed in multiple ways, individuals' interpretations of a framing can vary considerably' (p. 6)
Chandrasegaran *et al.* (2022)	'Our hypothesis is that the words associated with a (successful) frame will be repeated and adopted by other interlocutors in a design conversation' (p. 4) and 'We have attempted in this paper to develop a more robust method for identifying 'framing talk' in design conversation' (p. 13)	Use of computational linguistics to develop methods that might help identify framing talk within design discourse. N-Grams are labelled with a scores for mutual information (ratio of significance of words being used together compared to words being used separately), frequency, and unique speakers. They identify three kinds of N-Gram indicative of framing based on these scores	'Frames are not objective, rational ways for assessing evidence and making decisions, but social or rhetorical constructions that allow different perspectives to be explored in designing' (p. 3)

a process of "moving" or "action"' (Ibid, p. 4). Yet is this a definition of what it is that the team shares? Does the team's 'primary frame' include beliefs and values, or are they held by individuals within the team, overlapping to differing degrees? Hey *et al.* (2007) grapple with this same issue:

> Frames are cognitive and thus are held implicitly by individuals. Even though they are not readily observable by others, frames can be more or less *shared* as a team frame to the extent to which the individual members' frames overlap or align… no single method has been able to reliably tease apart individual frames from team frames, or to examine the differences between individual members' frames. (pp. 81–82)

In their view, frames are held by individuals (are internal) and can come to be shared by members of a design team (where those frames overlap or align). However, they are basing their analysis on the method employed by Valkenburg and Dorst (1998) which leads to methodological challenges that are explicitly recognised:

> Even with this multitude of data, finding framing is challenging: frames are cognitive, often implicit, and reside in the minds of individuals. For teams to negotiate a shared frame, an individual's frame must be shared explicitly or otherwise suggested through interactions and behaviours. Thus in our observations, we looked for activities and interactions that either: (a) revealed an individual's implicit frame to others; (b) made discrepancies between individuals' frames visible or salient; or (c) engaged the team in explicitly negotiating among individual frames and constructing a shared frame. (pp. 84–85)

This extract suggests a need for a more effective nomenclature for frames; a way to differentiate between internal design frames ('frames are cognitive'), how they are represented externally ('an individual's frame must be shared explicitly…'), and the way that frames move around as tools for thinking and come to be shared by teams.

This brief review of selected empirical studies of design framing reveals the present state of confusion. There has been consensus about the phenomenon of framing in designers and in design teams since Schön's work in 1983: it is that part of designing concerned with setting the context within which design activity takes place. However, it is not clear what frames themselves are: where they are found and how to research them in ways that lead to valuable insights.

4. Reviewing perspectives on design frames

This review of design frames has demonstrated that (a) there are at least three different definitions of design frames in the literature and (b) these definitions have led to a range of applications of the term in empirical studies. Yet the construct of a *design frame* is demonstrably useful for design research. This section reviews a propositional model of what design frames do that articulates the importance of design framing and discusses design frames in relation to the constructs of object worlds, situations, mental models, and problem spaces.

4.1. A propositional model of what design frames do

A widely adopted understanding of the importance of design framing is described by Dorst (2011) as the 'the core of design thinking'. This can be considered as a *propositional model* for what design frames do. This model involves three parts: there is a **WHAT**, those things that are being attended to by a designer, a **HOW,** as

a hypothesis or working principle for designing, and a **VALUE**, which is the designerly goal of this **WHAT** and **HOW**. This leads to Dorst's formulation that:

$$\underset{\text{(thing)}}{\textbf{WHAT}} + \underset{\text{(working principle)}}{\textbf{HOW}} \quad \text{leads to} \underset{\text{(aspired)}}{\textbf{VALUE}} \tag{1}$$

The crux of design problems is that neither the **WHAT** nor the **HOW** are given to a designer: designers have the goal that they are working towards, but an incomplete sense of what they need to attend to for achieving that goal (**WHAT** is unknown); and no hypothesis for how to realise this goal is inherent in the problem (**HOW** is unknown). This is what Dorst refers to as Abduction-2 or design reasoning, where both the **WHAT** and the **HOW** are unknown: in such situations, it is unclear how a designer is able to commence doing anything towards realising the value:

$$??? + ??? \text{ leads to} \textbf{VALUE} \tag{2}$$

This distinction between two types of abduction – Abduction-1 and Abduction-2 – is useful for understanding how designers escape this bind. In Abduction-2 both the **HOW** and the **WHAT** are unknown; as distinct from Abduction-1 in which just the **WHAT** is unknown. This notion of different types of abductive design reasoning has a history in the literature, as surveyed by Koskela, Paavola, and Kroll (2018). Abductive reasoning was formulated in the philosophy of C. S. Pierce (1839–1914), and brought into the design literature by March (1976) through his discourse on design reasoning and by Coyne *et al.* (1990). It was Roozenburg and Eekels (1995) who emphasised the distinction between exploratory abduction (Abduction-1) and innovative abduction (Abduction-2) as being of importance for design.

Designers escape the bind of Abduction-2 (Equation 2, with two unknowns) through adopting a design frame, following Schön (1983). A design frame, in propositional terms, is defined by Dorst as encompassing both the **HOW** and the **VALUE**:

> Frames are… very complex sets of statements that include the specific perception of a problem situation, the (implicit) adoption of certain concepts to describe the situation, a 'working principle' that underpins a solution and the key thesis: IF we look at the problem situation from this viewpoint, and adopt the working principle associated with that position, THEN we will create the value we are striving for. (p. 525)

Often a designer knows what they are trying to achieve, and by adopting a particular way of understanding the problem – a frame that includes both **HOW** and **VALUE** – they are then able to work on the problem. By adopting a frame, a designer no longer requires Abduction-2; they are in a position of using Abduction-1, in which a working principle can be combined with a goal to start thinking about a **WHAT**. The challenge is to adopt the right design frame to permit useful design activity – something that expert designers seem to be good at, and a form of expertise that remains poorly understood.

Why the propositional model of framing matters

This propositional model of design frames does the work of uniting two threads within the design literature. First, Schön (1983) described frames in the context of

design as a reflective practice: designers have a design frame and conduct moves as 'experiments' that are reflected upon, and the frame changed based on those experiments. Second, March (1976) and others have looked at the abductive logic inherent in design reasoning. Dorst's propositional model combines the two and this understanding has been used to identify framing strategies that are used by expert designers (Dorst 2015). This in turn has led to articulation of a series of activities that are useful to undertake when wanting to refine a design frame (e.g., analysing the *history* of the problem owner and the initial formulation) (Dorst 2015). These can be understood as high-level strategies that are associated with what expert designers do. The propositional model is a clear explication of the well-recognised cognitive property of design: that designers are able to commence design activity without knowing either what they need to do or how they need to work.

The case studies described by Schön (1984), Schön and Wiggins (1992), Akin and Akin (1996), Valkenburg and Dorst (1998), Suwa, Gero, and Purcell (2000), and many others since have demonstrated explicit occurrences of phenomena in which *changing the frame has a significant change to the space of possible designs.* Returning to the Einstein quote that opened this paper, design problems often have clear solutions once a 'satisfactory' frame has been found.

4.2. Disambiguation from related constructs

The construct of design frames can be further understood by juxtaposition with other constructs within the design literature that are related. This section reviews the constructs of object worlds, situations, mental models, and problem spaces and describes how each relates to design frames.

Bucciarelli (1994) introduced the term *object world* to recognise that different designers have 'different competencies, skills, responsibilities and interests, [and] inhabit different worlds' (Bucciarelli 2002, p. 220). Any two people have different internal worlds or *umwelts* (Von Uexküll 1957) based on their sensory experiences of the world. The object world is an extension of the umwelt, where each designer also has their own technical competencies, and their own internal language for design (Bucciarelli 2002). This can be observed when studying a design team, where multiple designers might be working on the same object, yet each does so from within their own object world: 'the ways of modeling, thinking about the design, the questions one raises, the way they are framed, the resources one has to call into play in response, all of this is in accord with the paradigmatic technique which provides the basis for thought and practice within that world and differs from that of another participant… There is one object of design, but different object worlds' (Bucciarelli 2003, p. 222). Design frames are, for Bucciarelli, one part of the totality that makes up the object world of a designer: a design frame is a part of an object world and is brought into being within an object world.

Situated cognition recognises that concepts are tied to the *situation* within which they are used: the environmental, social, and cognitive contexts for learning and knowledge use (Brown, Collins, & Duguid 1989; Clancey 1997; Barsalou 2016). The idea of design as a situated activity has been used to describe certain design phenomena (Gero 1998; Suwa *et al.* 2000; Gero & Kannengiesser 2004; Kelly & Gero 2017). A situation as taken to be an emergent cognitive construct, a conceptual assemblage that is composed of perception, proprioception, introspective

states (e.g., emotions), and environmental settings (Barsalou 2016, p. 627). Design frames are, similarly, conceptual assemblages yet a design frame is just one part of a situation (which is in turn the present-moment construct of an object world): those parts concerned with the interpretation of the problem and conceptions for ways of working.

The term *mental model* refers to the conceptual constructs and relationships between them that model the world and permit deductive reasoning about it (Johnson-Laird 1983). Mental models have been used within the design literature to explore the way that members of design teams come to share the same understanding of a problem (Dong *et al.* 2013; Xiang *et al.* 2015). Design frames can be talked about as *mental models* of a design problem, yet this latter view can be reductive in that it neglects a situated understanding of conceptualisation; the term often entails a commitment to a classical understanding of concepts as ungrounded, amodal representations.

The notion of *problem spaces* within the design literature (Poon & Maher 1997; Dorst & Cross 2001), as distinct from solution spaces, is relevant to design framing. This is an understanding that 'the problem space and the solution space co-evolve together, with interchange of information between the two spaces' (Dorst & Cross 2001, p. 434). However, the bifurcation of the internal world of a designer into two distinct parts, although useful in discussing designing, is contrary to contemporary understandings of human cognition as single system of conceptualisation (e.g., Barsalou 2016). From a grounded cognition perspective, both problem and solution space are emergent features of a situation that includes a design frame.

5. Discussion

This review paper has described multiple origins of the term *frame* within sociology, artificial intelligence, psychology, and traced the path of the term *design frame* into design literature. It has described confusion around the location of design frames, where they are variously considered as being internal (to designers), external, or liminal tools that cross this internal/external divide. It has shown that this lack of clarity has resulted in a history of empirical studies that purport to be studying design frames yet that hold different accounts of what design frames are meant to be and where they are located. It has reviewed Dorst's propositional model of design frames and shown how the term relates to relevant constructs within the literature. This section considers the nomenclature of design frames, suggests that it would be valuable to develop a cognitive model of design framing, and looks towards further research into design framing that may lead to the development of such a situated cognitive model.

5.1. Nomenclature for design frames

As has been noted, there is ambiguity around the location of design frames: whether they are internal, external, or liminal to a designer. There is a need for nomenclature to make it possible to speak precisely about design frames as occurring within a designer's cognition (what we are referring to as 'internal') and design frames as externalised ('external'). This is necessary for talking about teams framing design problems and coming to shared understandings (e.g., Zahedi & Heaton 2017) or tracing the development of design frames through time. Table 1

demonstrates some of the contortions that can arise without this clarity. Clear nomenclature could allow for delineation between design frame as 'implicit within a designer' and design frame as 'explicit within design actions/utterances'.

One option for more precise nomenclature could be through developing a convention that a *design frame* is the implicit, conceptual assemblage that represents the frame within cognition; and that such frames are then made explicit (such as through speech) in what are *representations of a design frame*. An example of the utility for this nomenclature is to return to the idea of 'individuals' interpretations of a framing' (Silk *et al.* 2021) which is an ambiguous construction when contrasted with the idea that 'Frames are cognitive and thus are held implicitly by individuals' (Hey, Joyce, & Beckman 2007). The latter already fits within the proposed nomenclature while the former could perhaps be rewritten as 'individuals within a design team each interpret the shared representation of a design frame'.

Further ambiguity is found in the verb *design framing* which is now taught in some places as a skill in which designers can gain expertise (Dorst 2015; Sterling *et al.* 2018) and is also analysed as something naturally occurring within design protocols (e.g., Valkenburg & Dorst 1998). This leads to confusion around the distinction between design framing as a conscious metacognitive strategy or as a phenomenon intrinsic to design activity. Many expert designers do not consciously 'do' design framing so much as intuitively change the frame in useful ways (based, perhaps, upon well-developed metacognitive skills).

One way to avoid such ambiguity may be by adopting nomenclature to distinguish these two different bases for a change of frame. One option would be to refer to *design framing* as the conscious deployment of metacognitive strategies associated with useful development/refinement of a design frame. This can be distinguished from *changes to a design frame* as a term that external observers use when identifying the phenomena when observing designers. If such nomenclature were to be used, then the term *reframing* becomes unnecessary, a construct that confuses rather than clarifies.

5.2. Formal and cognitive models of design framing

Models of design processes that aim to represent design framing can be grouped into formal and cognitive models of design framing. A limitation of formal models is that they do not claim to represent human design cognition. There is an absence of cognitive models of design framing within the literature.

The phenomenon of design framing can be explained by some formal models of design (e.g., those reviewed by Hatchuel *et al.* 2011, Rodriguez & Benavides 2021). Formal models of design processes are those that describe a set of constructs and the functions through which those constructs result in design phenomena. For example, in C-K theory (Hatchuel & Weil 2009), design is modelled as the generative interaction between two kinds of expansion (Hatchuel *et al.* 2018), one relating to logical propositions and another relating to conceptual (nonlogical) propositions. Rodriguez and Benavides (2021) formally model design framing using C-K theory and provide a 'preliminary model for ranking [engineering design theories and methods] for framing, according to three characteristics' (p. 284) of a problem domain independence, generativity, and a formal definition of valuable outcome or process.

The constructs proposed within cognitive models of design processes have the added requirement of being plausible representations of how human cognition functions (Hay *et al.* 2017). Recent decades have seen widespread acceptance that human cognition is grounded, embodied, and situated both within cognitive science (Barsalou 2008) as well as design cognition (Gero 1998; Hay, Cash, & Mckilligan 2020). Cognitive models of design processes are open to critique on the basis that they are often difficult to falsify. While the methods available to empirically investigate cognitive models of design processes remain limited, the methods available in future are expanding (Gero & Milovanovic 2020; Hay *et al.* 2020). Future combinations of design cognition and design neurocognition methods (e.g., Hu *et al.* 2022; Manandhar *et al.* 2022) may lead to the possibility of experiments that test detailed hypotheses about design framing phenomena using methods outlined by Gero and Milovanovic (2020).

5.3. Towards a cognitive model of design frames

There remains an absence of detailed, contemporary cognitive models for design framing; this is surprising given the importance of the phenomenon. There is a rich vein of cognitive theorising about design framing at a high level of abstraction, from Schön (1983) through to Dorst (2015). Yet attempts to understand how conceptual co-ordination within a contemporary understanding of cognition leads to design framing phenomena cannot be found within the literature. A cognitive model of design framing would include a commitment to what is meant by the construct of a design frame. This section reviews some ideas within the literature that we believe would be useful in developing such a cognitive model of design frames.

A situated understanding

The understanding of cognition as situated conceptualisation has some explanatory power for the phenomenon of design frames. There is a shift from traditional 20th century understandings of cognition in that 'cognition doesn't exist as an independent symbolic module in the brain, but critically depends on the modalities, body, and environment… cognition emerges as the brain, body, and environment coordinate situated action' (Barsalou 2017). The contribution of situated cognition is to recognise that concepts are always used within a situation, which is to say in the presence of other concepts, perceptual information from an environment, and influence of emotions.

The situation within which a concept is used changes how that concept is used. Concepts should not be thought of as discrete atoms of knowledge that can be 'used'; the computational analogy of 'retrieving something from memory' is misleading. A more useful analogy is of a good architect who knows how to design houses; each time they respond to a brief, the house that they produce will be site-specific and inhabitant-specific – they have no ability to design some 'canonical house' which embodies their house-designing ability. So it is with concepts, which are used within situations. This situated nature of concepts is supported by empirical studies that showing a range of phenomena relating to priming effects and the constructive nature of memory (Barsalou 2016).

Concepts for conceptual development

For Dorst (2015) a design frame is a 'very complex sets of statements that include the specific perception of a problem situation, the (implicit) adoption of certain concepts to describe the situation, a 'working principle' that underpins a solution and the key thesis' (p. 525). What is the cognitive model of processes that are able to generate these very complex sets of statements?

One cognitive component of design frames may be that they include some conceptual representation of a goal state. As this is design activity, the goal state relates to a concept that does not presently exist in the world of the designer. This goal state also needs to have some kind of perceived value for the designer, following March (1976), Coyne *et al.* (1990), and Dorst (2011), as a definitional part of design activity – this is the motivation for design activity that persists even as the conception of the goal state changes.

A second component of design frames may be that they include a recursive conception of *plans for how to test the design frame*, which Schön refers to as frame experiments. This might be concepts for actions that aim to develop the goal state (e.g., ideation activities), actions that develop the conception of value (e.g., design research), or actions that aim to understand future actions (e.g., a design process).

How design frames change

It is clear that design frames change as a part of design activity. A grounded cognitive model of design frames could be useful for hypothesising different reasons why and how changes to design frames occur. Four examples of how this may occur can be hypothesised as follows:

(i) *Endogenous, to the design frame:* The design frame may, as a part of the frame for action, require changes to the situation.

(ii) *Endogenous, to the situation:* The situation, as a complex conceptual structure, may become incoherent in some way (e.g., self-contradictory), leading the conceptual system to change its structure.

(iii) *Endogenous, to the person:* Some form of hedonic reward for a certain level of novelty may make static situations an unlikely prospect due to innate pleasure in a changing situation (e.g., Saunders & Gero 2004). Other emotional/embodied responses to a situation (e.g., disgust) might lead to a changing situation.

(iv) *Exogenous:* Perceived changes in the environment may introduce new concepts into the situation. This may include interactions with other beings, interpretation of representations, or any other environmental trigger.

Conceptual distance and framing

There are moments where a designer – to an external observer – appears to have radically changed their understanding of a problem (Akin & Akin 1996; Suwa *et al.* 2000). Yet there are also many moments where a designer may only be subtly changing the design frame in ways that are tangential to the problem. It may be useful to the study of designers to distinguish between the two.

The notion of *conceptual space* has been posited by Gärdenfors (2004) as a way that concepts might be represented in such a way that the notion of distance becomes applicable. Examples have been given in prior work of ways in which conceptual spaces may be brought together within situations in a way that makes

distance a situational phenomenon (Kelly & Gero 2017; Perišić, Štorga, & Gero 2019; Gero & Milovanovic 2022). It follows that there may be a way of comparing the design frames of a designer at different points in time and being able to calculate some meaningful measure of distance between design frames, expressed as a unit within conceptual space.

Current research using natural language processing techniques (NLP) to analyse design protocols can be understood through this lens. Such work starts with externalisations of design frames (utterances) and creates statistical models from these words (using models of natural language) that can be seen to change over time. The distance between statistical models at different points of time then becomes a proxy for changes to a design frame.

Design frames within a team

Each member in a design team can be considered to have their own situation, and (in designing) their own design frame(s). It follows that it may be possible to speak of some *degree of coherence* between design frames of the members in a design team. This idea has been discussed at length within the literature. Bucciarelli (2002) observed that 'engineers designing…are faced with the task of frequently bringing the results of their object world efforts, which no doubt will conflict, into coherence if design is to proceed – and they must do this without a shared proper language' (p. 228). There is a thread in the literature exploring how this coherence is achieved, such as the work by Dong *et al.* (2013) combining latent semantic analysis and reflective practice analysis to show how team mental models come to be shared over time. The definition of design frames in this paper may contribute to this thread by providing a more precise way of investigating coherence in design frames within a team over time – perhaps through application of graph analysis of conceptual maps and/or through distance measures within conceptual space.

6. Conclusion

This paper has reviewed some of the ambiguity around the concept of *design frames*. It has discussed the origins of the term frame and how it came to be used in design studies. It has clarified three different definitions of design frames within the literature and has reviewed empirical studies of design framing to demonstrate contradictions between studies. It has reviewed Dorst's propositional model of design frames and the value that it serves and positioned design frames in terms of related concepts within the design literature. It has discussed the value of having a grounded cognitive model of design frames and provided some directions that may be fruitful to achieve this.

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