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Definition and research agenda

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An integrative literature review of prototyping in management research: Definition and research agenda

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ABSTRACT

Recent years have seen the proliferation of approaches in management featuring prototyping as a central component and vehicle to facilitate interaction with stakeholders. Yet, despite the extensive engagement with prototyping, vocabulary and conceptualizations of the phenomenon still vary and research remains fragmented, hampering empirical and conceptual development. In this paper, we address this by exploring the concept of prototyping in management research. Through an integrative literature review, the study contributes with an inductively developed definition of prototyping that stresses the representational nature of prototyping. Based on the definition, we organize the diverse, fragmented, and eclectic body of work into seven distinct themes. We then compare and elaborate these themes and organize them into three aggregate dimensions to offer an initial sketch of how prototyping materializes from cognitive externalization to conative interaction an how these interdependent processes creates various organizational outcomes. Finally, we suggest future avenues for examining the integration of the fragmented themes and for exploring research opportunities between and within the them.

1. Introduction

Over the past decade, different forms of prototyping have become increasingly popular among practitioners and researchers in the broad field of management (Bland & Osterwalder, 2019; Felin et al., 2020; Hampel et al., 2020; Ries, 2011; Thomke, 2020; Thomke & Manzi, 2014). This is evident in practitioner models of lean startup with its minimum viable products, design thinking, and sprints with their use of rapid prototyping, as well as a host of other frameworks such as pretotyping, science fiction prototyping, and discovery-driven planning (Bland & Osterwalder, 2019; Blank, 2013; Johnson, 2011; Knapp et al., 2016; Liedtka & Ogilvie, 2011; Mansoori & Lackéus, 2019; Ries, 2011; Savoia, 2011). The use of prototyping is further induced by the emergence of new technologies making technically demanding experimentation with physical and digital prototypes widely available (Anderson, 2012; Browder et al., 2017; Camburn & Wood, 2018; Rayna & Striukova, 2016, 2021) as well as accelerators, fablabs, and makerspaces with facilitated processes featuring some form of prototyping (Cohen et al., 2019; Mansoori, 2017; Browder et al., 2017; Cartel et al., 2018).

While prototyping has been given some coverage in management research, no coherent, shared, and explicit research agenda has emerged. Consequently, we see diverse, fragmented conceptual vocabularies and disconnected research streams potentially hampering theoretical and empirical development of our understanding of prototyping in organizations and how it can help achieve managerial objectives. In this paper, we address explore the concept of prototyping in management research through an integrative literature review as we attempt to synthesize knowledge from multiple communities of practices and redirect it to juxtaposition for potentially fruitful, integrated avenues of research (Cronin & George, 2023; Toracco, 2005).

This review offers an initial insight into the heterogeneity of prototyping. Our aim is to organize and redirect knowledge by conceptualizing the various aspects of prototyping explored in the literature as processes that activate cognitive externalizations and conative interactions. The contributions of this approach are threefold. First, we contribute with a definition of prototyping to serve as reference point for management research on prototyping – a conceptualization that emphasizes the representational nature of prototyping. Second, based on this conceptualization, we identify seven themes from the diverse, fragmented research on prototyping: reification, visualization,

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boundary spanning, testing, exploration, organizational learning, and process coordination and momentum. We then, thirdly, aggregate the themes into the three dimensions of cognitive externalization, conative interaction, and organizational outcomes and set the themes in motion by organizing them into a conceptual overview of prototyping.

Our paper thus contributes to the advancement of prototyping research in management by showing how prototyping, as a representational function, is grounded in cognitive externalization (Lim et al., 2008), is inherently forward-looking and intentional (Selden & Fletcher, 2019), and has important organizational outcomes (Carlile, 2002; Hargadon & Sutton, 1997). This research agenda emphasizes the importance of taking a process perspective exploring new mechanisms across themes, as well as contextualizing these in various domains. Our ambition is to redirect the research agenda by providing both a valuable (and needed) conceptual foundation to the extensive use of prototyping in management research and practice as well as a solid platform upon which to build further theorizing on prototyping and generating important research questions.

2. Prototyping in management research

Prototyping has long and widely been acknowledged in management research as an activity undertaken by managers to achieve various organizational objectives. References to managers, entrepreneurs, innovators, engineers, and designers using prototyping to develop new products, services, and business models are familiar sights in management research. In the absence of a coherent and explicit research agenda on prototyping in management research, the field has developed different vocabularies to explain and discuss it and the role it plays in managerial processes in relatively isolated conversations around for example the development of new products, services, and business models in different types and sizes of firms (BenMahmoud-Jouini & Midler, 2020). The fragmented character and lack of knowledge syntheses is accentuated by the multiple communitites of practices involving different professions, including engineers, designers, and entrepreneurs, as well as multiple domains of management research including innovation management (Auernhammer, 2020; Auernhammer & Roth, 2021; Yu et al., 2018), new product development (Hargadon & Sutton, 1997; Thomke et al., 1998; Thomke & Bell, 2001), entrepreneurship (Frederiksen & Brem, 2017; Koning et al., 2022; Wessel et al., 2022), and organization (Carlile, 2002; Comi & Whyte, 2018; Coughlan et al., 2007), for example. Notably, in the present integrative literature review, we also found many instances of prototyping as concerns secondary to other research interests and theoretical contributions in studies of experimentation (Murray & Tripsas, 2004; Thomke et al., 1998; Wouters & Roijmans, 2011), boundary objects (Carlile, 2002; Hargadon & Sutton, 1997), boundary spanning (Bogers & Horst, 2014; Pershina et al., 2019), epistemic objects (Ewenstein & Whyte, 2009; Jarzabkowski et al., 2013), and mobilization (Comi & Whyte, 2018; Mueller et al., 2012), for instance.

While literature reviews of prototyping have been published, these have primarily focused on engineering (Jensen et al., 2016), information systems (Beynon-Davies et al., 1999; Naumann & Jenkins, 1982), or design (Camburn et al., 2017; Menold et al., 2017) with a narrow scope seeking to identify critical variables for prototyping strategies (Camburn et al., 2013; Christie et al., 2012; Doke & Swanson, 1995), reviewing specific techniques, such as virtual prototyping (Cecil & Kanchanapiboon, 2007; Wang, 2002), rapid prototyping (Brooks & Aitchison, 2010; Freitas et al., 2020; Yan & Gu, 1996), business process modeling (Stein Dani et al., 2019), and sketching (Eppler & Pfister, 2011), examining tools such as Raspberry Pi or Arduino (Kondaveeti et al., 2021; Saari et al., 2017), or focusing on specific contexts or issues, such as service design (Blomkvist & Holmlid, 2011), policymaking (Villa Alvarez et al., 2020), or prototyping outsourcing (Liao et al., 2010).

However, none of these literature reviews attempted to list potential thematic categorizations, bridge the different thematic conversations, or synthesize common themes from the multiple communities of practice (Cronin & George, 2023). This is problematic for several reasons. First, the increasing focus on prototyping in practitioner frameworks intensifies the need for a thorough, comprehensive empirical and theoretical understanding of prototyping in different managerial and organizational settings. Without this, there is a risk of potentially promoting modes of organizational development that lack a foundation in critical empirical research (Berglund et al., 2018). This is even more concerning when prototyping is treated as a secondary research interest. Second, as a consequence of the fragmented and incoherent nature of existing research, findings remain unconnected, and knowledge accumulation and theoretical advancement is curbed by the lack of a thematic synthesis (Cronin & George, 2023).

This literature review seeks to address these issues by attempting to lift the topic of prototyping out of its fragmented state by synthesizing common themes from across communities of practice and creating a conceptual framework that not only highlights the relationship between themes but also considers how their interrelationships coalesce into higher order categories (or aggregate dimensions) in an emerging conceptual framework.

3. Methods

As prototyping has been given very different empirical treatments and conceptualized very differently in the management field, a complete and exhaustive review based on a systematic search of databases with specific predefined and generally agreed upon keywords – as is the template of systematic literature reviews (Rauch, 2020; Tranfield et al., 2003) – is unlikely to provide a useful initial overview of the knowledge base (see Günzel-Jensen et al., 2014, for a similar point). Instead, the need to bridge multiple communities of practice through the synthesis of knowledge as well as the need to redirect research suggests an integrative literature review (Callahan, 2010; Torraco, 2016, 2005; Cronin & George, 2023). The purpose of this form of literature review is to synthesize, integrate, and critically explore representative literature to establish new frameworks, perspectives, and knowledge on a given topic (Elsbach & van Knippenberg, 2020; Macpherson & Jones, 2010; Torraco, 2005; Cronin & George, 2023). Thus, integrative reviews are particularly useful for studying "new or emerging topics that would benefit from a holistic conceptualization and synthesis of the literature to date" (Torraco, 2005, p. 357). Moreover, the approach has been praised for its usefulness in developing new insights in the face of varying terminology and disciplinary arenas (Post et al., 2020; Snyder, 2019).

An integrative literature review uses an inductive approach, where the scope of the literature search, the definitions of key terms, and the analytical themes are not set a priori but developed from expansive and in-depth analysis of the fragmented literature studied. The final boundaries and analysis of the integrated review are thus set, not by predefined search strings and definitions, but by theoretical saturation, as in an inductive approach (Gehman et al., 2018; Gioia et al., 2013). Thus, our aim is, as advocated for integrative reviews (Whittemore & Knafl, 2005), to identify and integrate representative findings on the topic of prototyping from the broad management research field into a new framework that accentuates and critically examines the core issues and insights of the research in order to produce a new framework and a "research agenda that flows logically from the critical analysis of the literature" (Torraco, 2005, p. 363).

Accordingly, structuring and defining the scope of the search and analysis becomes an integral part of the literature review, rather than predefining these (Elsbach & van Knippenberg, 2020). This is necessary for our study, as no generally accepted definition or established conceptualization of our focal topic prevails (Torraco, 2016). As such, rather than using or constructing a predefined definition – operationalized as a set of keywords for use in database searches seeking to establish a complete sample of papers – we need to follow an inductive

template of letting conceptualization and delimitation of the topic emerge in the analysis as part of an iterative process that goes back and forth between data and analysis (Gehman et al., 2018; Glaser, 1965; Glaser, 1967; Saldana, 2015).

Following the directives of an integrative literature review and an inductive approach, it is not our aim to provide a complete overview of a defined body of work on a clearly and singularly defined research topic, as in a systematic literature review approach. Instead, we adopt an approach similar to that in inductive qualitative empirical research (Gehman et al., 2018; Gioia et al., 2013). This means that we: (i) allow for the sample of the literature review to evolve dynamically as we explore the field, rather than delineate it before data collection, (ii) allow for the topic and conceptualization of our study to emerge and be changed iteratively as we adopt a constant comparison approach where analysis emerges from a dynamic iteration between findings and data, and (iii) generate findings through explorations of patterns of similarities and differences within the data (Miles et al., 2013). This approach gives priority to depth and serendipitous findings at the expense of completeness in coverage.

3.1. Literature search

As outlined above, the sample for our review developed inductively as we engaged in our exploration of the topic of prototyping in management research. Rather than starting from an inherently problematic predefined set of parameters, we initially deployed two snowballing techniques. One was direct consultation with numerous expert colleagues in management research undertaken to identify studies of particular interest and relevance to prototyping and prototypes in management research. Specifically, we engaged with experts in the management field with specializations in the domains of design, engineering, entrepreneurship, innovation, and organization to identify particularly important and relevant studies and papers, as defined by their engagement with prototyping within empirical domains of management.[1] This move also helped expand the scope and initial framing of the research topic beyond the expertise of the authors, who are all originally trained in the area of entrepreneurship. The other snowballing technique was the use of the reference lists of selected papers to identify other papers of interest. These activities expanded our sample, but importantly, as we worked our way through papers, our conceptualization and definition of prototyping in management was sharpened and became clearer, which again allowed us to stringently expand the sample.

The primary advantage of the snowballing approach was the ability to identify what Toracco (2016, p. 405) refers to as representative contributions, that is, contributions that are influential, highly original, controversial, or provocative. Furthermore, the approach allowed us to navigate the significant differences in the sprawl of management research. Notably, publication patterns vary among specializations, where conferences and academic handbooks make up important publication outlets for management researchers studying engineering, design, and human–computer interaction, while journal publication is the standard for others in entrepreneurship, organization, and innovation, for example. Moreover, different specializations infuse 'prototyping' with different understandings and use various terms, such as mock-up, simulation, model, object, artifact, and sketches and drawings (BenMahmoud-Jouini & Midler, 2020). Some thus use the descriptive terminology of "prototypes" and "prototyping" while others address similar empirical phenomena using theoretical vocabulary such as "boundary objects" or "epistemic objects" (Ewenstein & Whyte, 2009; Carlile 2002). While not all boundary objects, epistemic objects, artifacts, or strategy tools are prototypes, many are, as we quickly discovered. Our inductive approach allowed us to navigate and analyze such important differences while uncovering underlying theoretically informative and empirically enlightening issues that span different research, terminology, and publication traditions. In total, 175 papers were identified in the inductive sampling. The search was concluded as we reached thematic saturation, meaning that no further themes and findings were generated with new inclusions in the sample (Glaser, 1967; Miles et al., 2013).

To further ensure against substantial omissions of papers and streams of research in our sample, we added a SCOPUS database search. Using the central concepts from the definition of prototyping developed (see Section 4.1 below for the detailed definition), we formulated a search string[2] to find additional papers related to prototyping as a representational activity. The abstracts of the new additional papers were browsed, and 42 new papers were selected for inclusion in the final sample. However, these papers added no substantial new themes, indicating that a satisfactory level of theoretical saturation was achieved in the inductive sample. Where there was not an overlap between the papers of the inductive sample and the systematic search, most of the added papers were applications of concepts and theories already prevalent in the initial sample.

The full list of the papers included in the review can be found in appendix A and an overview of the search process in appendix B. Importantly, our review makes no claim to completeness in terms of coverage of management research on prototyping but seeks to synthesize, integrate, and combine the heterogeneous research landscape into a platform to inspire future research in line with the integrative literature review approach (Elsbach & van Knippenberg, 2020; Snyder, 2019; Torraco, 2005; 2016).

3.2. Literature analysis

Analysis of the literature was initiated in parallel with the formation of the inductive sample of papers and followed an inductive approach as discussed in the methods section. The cycles of coding followed a conceptual movement from lower to higher levels of theoretical abstraction, yet in reality, the process was highly iterative and concurrent with the literature search – similar to a grounded theory approach (Gehman et al., 2018; Gioia et al., 2013). Thus, the analysis involved going back and forth between the cycles as the sample was developed. This process proceeded until theoretical saturation was complete (Miles et al., 2013).

Our initial open first-order coding of the literature revealed a large and heterogeneous landscape of different prototyping activities, all with their different purposes, artifacts, processes, etc. We identified a central pattern of similarity, which was used to develop a common conceptualization of prototyping (presented below in Section 4.1). Patterns of difference were then identified in second and third cycles of coding (presented below in Fig. 1 and Section 4.2). Finally, on the basis of our data structure, we organized the themes into a theoretical framework allowing us to progress from a description of the literature to an integrative conceptual framework (presented below in Section 4.3). This allowed us to establish three central contributions. First, our analysis uncovered a shared pattern in the conceptualization of prototyping centering on representation as its functional core. We outline this pattern in the findings section on conceptualizing prototyping for management research. Second, patterns of variation running through all

[1] A stream of literature exists that uses the notion of prototypes in relation to cognitive processes where objects are assessed cognitively based on their being "prototypical." This stream of research was excluded from our search as it is a distinct stream of research connected to our focal research only by using the same word to designate different and unrelated empirical phenomena.

[2] The full search string for the search in the SCOPUS database was: (TITLE-ABS-KEY (prototyp*) AND TITLE-ABS-KEY (object* OR artifact* OR artefact* OR representa*) AND NOT TITLE-ABS-KEY (prototypical*)) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SUBJAREA , "BUSI")

First-Order Codes	Second-Order Categories	Themes (Aggregate Dimensions)
• Material nature of prototyping • Building to think • Cognitive partners and physical aids to thought • Making as a language for thinking, dwelling, tinkering, and thinging	Reification	Cognitive externalization
• Visual nature of prototyping • Visualizing the mind's eye and abstract imaginings • Externalizing knowledge and ideas to overcome fixation and cognitive limitations • Benefits of ambiguity and openness to multiple perspectives • Generation without regard to material and physical constraints	Visualization	
• Integrative devices that mediate interaction and joint problem-solving in boundary encounters • Facilitate and guide interaction, involvement, and knowledge sharing • Bridging knowledge and thought worlds to create shared understanding • Enhance communication, presentation, and demonstration • Communication mediums to share information and qualify design inputs	Boundary spanning	Conative interaction
• Experimental components and embodiments of hypotheses • Experimentation and systematic testing • Refining technical elements of solution • Gather feedback and data on focal parameters • Promote iterative and adaptive development	Testing	
• Deepen understanding of problems and user needs • Experiencing current and future scenarios • Provoke imaginative discussions and speculate about fictional futures • Generative windows to imagined futures • Explore interrelation between problem and solution spaces	Exploration	
• Mediate collaborative learning and unlearning • Generate new knowledge or validate existing knowledge • Establish the strategic space and direction of emerging solutions and business models • Induce adaptive, trial-and-error learning and exploratory user engagement • Inferencing about the strengths and weaknesses of ideas and solutions, and identifying new directions	Organizational learning	Organizational outcome
• Coordinate activities and link knowledge throughout the prototyping process • Increase the commitment and creative ability of participants • Break down larger problems to simplify work complexity and support actors in dealing with uncertainty and fuzziness • Reduce confusion and support conflict management • Increase the momentum, commitment, and creative ability of participants through incremental progress and small wins	Process coordination and momentum	

Fig. 1. Data structure.

three coding cycles were summarized in seven conceptually distinct prototyping themes. Third, we organized the seven themes into three aggregate dimensions and set the themes in motion by interrogating (potential) relations between them and advancing a future research agenda (Torraco, 2005, 2016).

4. Findings

4.1. Defining prototyping for management research

In the literature reviewed no established, unified, or broadly accepted definition of prototyping was prevalent. Indeed, prototyping has become a catch-all notion with varying definitions and understandings (Beaudouin-Lafon & Mackay, 2003; BenMahmoud-Jouini et al., 2014; Lauff et al., 2018; Ravn et al., 2016), depending on who uses them and for what purposes they are generated (Alavi, 1984; Beynon-Davies et al., 1999; Blomkvist & Segelström, 2014). For instance, prototyping is often regarded as a distinct phase in technical specializations, while it takes on a more exploratory role extended to the entire process in design. Thus, across domains, the term refers to "a large variety of situations, where they [prototypes] fulfill different roles leading to different outcomes" (BenMahmoud-Jouini & Midler, 2020, p. 1). This is also evident in the different understandings and uses of prototyping related to architecture and design (Beaudouin-Lafon & Mackay, 2003; Berglund & Leifer, 2013; McElroy, 2017), innovation (BenMahmoud-Jouini et al., 2014; BenMahmoud-Jouini & Midler, 2020), engineering (Lauff et al., 2018; Menold et al., 2017), human–computer interaction (Houde & Hill, 1997; Lim et al., 2008), and entrepreneurship (H. Berglund et al., 2020; Dimov, 2016; Haefliger et al., 2010). Consequently, 'prototyping' is oftentimes used without further definition, which suggests that the existence and use of prototyping is (mistakenly) taken for granted as a well-defined empirical phenomenon.

Yet, an analysis of patterns of similarity and difference shows key characteristics for conceptualization. First, a shared convergence of representation as a central feature of prototyping is evident. This was particularly pronounced in papers exploring design and engineering, where several key contributions emphasize that prototypes serve to represent, embody, and instantiate aspects of an emerging solution or idea (Beaudouin-Lafon & Mackay, 2003; Buchenau & Suri, 2000; Camburn et al., 2017; Houde & Hill, 1997; Lim et al., 2008; Menold et al., 2017; Ulrich & Eppinger, 2012). Second, while some refer to prototyping as a specific type of evaluation vehicle for later phases of product development, others extend the notion to the entire development process, where every artifact that performs the role of representation can be regarded as a prototype (Houde & Hill, 1997; Ravn et al., 2016; Ulrich & Eppinger, 2012). In this conceptualization, prototyping is not limited to specific distinct phases and is furthermore iterative in nature. Also, artifacts are prototypes by virtue of their role rather than their characteristics, while they act as both outputs of past efforts and inputs for current and subsequent activities (Coughlan et al., 2007; Rhinow et al., 2012). Third, contemporary research increasingly reflects how prototyping is not narrowed to a product-focused or physical form (Kleinsmann & ten Bhömer, 2020; Yu & Enste, 2019) but includes a broad range of activities and manifestations. Thus, in this conceptualization, prototyping, as an activity, can "concretize and externalize conceptual ideas" (Lim et al., 2008, p. 4), and it does so in ways that can be experienced by others and the self (Brenner & Uebernickel, 2016; Buchenau & Suri, 2000). Fourth, prototyping is inherently incomplete and explicitly forward-looking (Selden & Fletcher, 2019). Hence, purpose is key to driving the intentional generation of manifestations of design ideas in ways that represent aspects of interest to the actor (Coutts et al., 2019; Jangir, 2012; Lim et al., 2008; Ravn et al., 2016).

Following these patterns in the literature, we define prototyping as the *intentional generation and use of representational artifacts that embody critical aspects of ideas to assist in managerial and organizational processes*. This definition resonates strongly with work on the management of design and engineering processes, artifacts such as the Business Model Canvas and visual business modeling representations (Brunswicker et al., 2013; Doganova & Eyquem-Renault, 2009; Haggège & Vernay, 2019; Wrigley et al., 2016), and work on the role of boundary objects and visual representations in organizational communication, innovation, and collaborative development (Comi & Whyte, 2018; Ewenstein & Whyte, 2009; Orlikowski & Scott, 2008). Examples of definitions of prototyping and prototypes are included in Table 1.

4.2. Themes in the literature on prototyping

In addition to the above identification of a similarity in defining prototyping as a representational function, our analysis resulted in seven themes. These themes incorporate distinct but coherent aspects of prototypes and prototyping prevalent across the different streams of literature reviewed. As will be apparent in the description of the themes and the subsequent conceptual overview, they somewhat overlap albeit with different theoretical and empirical foci. Notably, the themes identified are not specifically linked to certain domains, journals, or streams of research in any systematic way. Indeed, our analysis did not indicate any systematic patterns beyond the themes, suggesting that the themes convey fragmented research interests driven by foci related to specific contexts (e.g., design or engineering) or forms of prototyping (e.g., sketches or 3D-printed prototypes) or are from prototypes being used to explore theoretical concepts (e.g., boundary spanning), which furthers the argument for an integrative review. However, together they provide an extensive overview of the rationales, processes, and outcomes of prototyping as described in the reviewed literature. The themes are organized in accordance with the order of the conceptual overview outlined after the presentation of the themes. A summary of the themes can be found below in Table 2.

Reification. A significant theme in the literature on prototyping relates to reification. Here, prototyping serves as a way of making things real and physical in order to enable reflection on the materials at hand and on assumptions and beliefs about products, designs, and concepts (Atilola et al., 2016; Brown, 2009; Comi & Whyte, 2018; Coughlan et al., 2007; García et al., 2017; Junginger, 2007). Researchers draw on insights from cognitive science and point to the reflective human–material interplay between human cognition and physical creation, use, and interpretation of external representations (Ammon, 2017; Barati et al., 2019; Comi & Whyte, 2018; Dew et al., 2015; Lim et al., 2008; Sass & Oxman, 2006; Suwa & Tversky, 2002). It is through physical modeling that ideas take form, and in tinkering with physical creations that new forms beyond the original ideas come into being (Dew et al., 2015; Sass & Oxman, 2006). The literature within this theme focuses on the cognitive process in which prototypes can be valuable supplements and active enablers of cognitive and mental processes and can act as links between hands-on making, mindful thinking, tinkering, and dwelling (Atilola et al., 2016; Boland & Collopy, 2004; Brunswicker et al., 2013; Cross, 2006; Johnson, 2011; Menold et al., 2019; Seidenstricker et al., 2014; Suwa & Tversky, 2002).

In this theme, prototyping becomes a central vehicle for creativity and improvisation through immersion into and drawing upon the material world (Cross, 2006; McElroy, 2017), which enables prototyping actors to let ideas take shape in the process of converting them into something that can be manipulated and experienced in the real world (Boland & Collopy, 2004; Kelley, 2001; Warfel, 2009). The activity of prototyping therefore not only reproduces existing ideas but also represents a developing act in itself (Camere & Bordegoni, 2016). As proposed by Lim et al. (2008), prototyping filters and manifests design ideas so that certain qualities of ideas are moved into the real world (BenMahmoud-Jouini et al., 2014; Demil & Lecocq, 2015; Ewenstein & Whyte, 2009; Miettinen & Virkkunen, 2005).

Thus, prototypes can act as both output and input of creative ideation endeavors, as "it is in the work with models that ideas take shape"

Table 1
Definitions of prototyping (and prototypes) that emphasize the representational aspect (*our emphasis*).

Author(s)	Definition
Beaudouin-Lafon and Mackay (2003, p. 1007)	"concrete *representation* of a part or all of an interactive system. A prototype is a tangible artifact, not an abstract description that requires interpretation"
Buchenau and Suri (2000, p. 1)	"any kind of *representation*, in any medium, that is designed to understand, explore or communicate what it might be like to engage with the product, space or system we are designing"
Camburn et al. (2017, p. 1)	"a pre-production *representation* of some aspect of a concept or final design"
Camere and Bordegoni (2016, p. 156)	"*instantiations* of the design concept as it is in the moment of the design process. It is a moment of reflection in which designers increase their awareness on both design problems and possible solutions"
Couglan et al. (2007, p. 3)	"*representations* of design ideas created before the final artifacts exists […] in our use of the term, and more typically within the design profession, prototypes can be usefully thought of as 'learning tools' and consequently may exist at any level of resolution – from very rough to highly refined – and may be used at any stage in the design process to explore, evolve, and/or communicate ideas"
Christie et al. (2012, p. 1)	"an initial *instantiation* of a concept as part of the product development process"
Houde and Hill (1997, p. 370)	a prototype as "any *representation* of a design idea –regardless of medium"
Innella and Rodgers (2017, p. 1155)	"any kind of *representation* that is created to help designers, users and clients to understand, explore and communicate what qualities a product has, and how a user might engage with it"
Jangir (2012, p. 72)	"a rudimentary sample, model, *exemplar* or archetype built to test so that the design can be changed if necessary, before the product is manufactured commercially or can be said to be a concept or process or to act as a thing to be replicated or learned from"
Jensen et al. (2016, p. 822)	a "prototype designates a *representative* form of an idea"
Lauff et al. (2018, p. 9)	"a physical or digital *embodiment* of critical elements of the intended design, and an iterative tool to enhance communication, enable learning, and inform decision-making at any point in the design process"
Lim et al. (2008, p. 10)	"*representative* and manifested forms of design ideas"
Menold et al. (2019, p. 187)	"any physical pre-production model, regardless of fidelity, that serves as a *representation* of the design or features of the design"
Polydoras et al. (2011, p. 2)	"an artifact *incorporating* characteristics of the new product under development that enables designers to test various aspects of their ideas before committing themselves to the expense and risks of producing commercial quantities"
Ulrich and Eppinger (2012, p. 291)	"an *approximation* of the product along one or more dimensions of interest"
Wang (2002, pp. 232–233)	"a model of a structure or apparatus (or a product) […] Used for testing and evaluating form, design fit, performance, and manufacturability […] Used for study and training"
Warfel (2009, p. 6)	"a *representative* model or simulation of the final system. Unlike requirements documents and wireframes, prototypes go further than show and tell and actually let you experience the design"
Yang (2005, p. 650)	"an early embodiment of a design concept […] by definition, prototypes are not production stage design"
Zupan et al. (2017, p. 174)	"low- or high-fidelity *representations*, regardless of the medium, used to explore or demonstrate some aspect of the future artifact"

(Boland & Collopy, 2004, p. 142), and the building of prototypes "helps to supplement designers' incomplete mental models leading them to better ideas" (Viswanathan et al., 2014, p. 1). Therefore, prototyping becomes a means to the process of thinking itself by enabling actors to engage in unarticulated testing and reflection upon the situation, problem, or solution at hand in a way where *making* becomes a language

Table 2
Overview of themes.

Theme	Description	Exemplary sources
Reification	Focus on the material nature of prototyping in expressing abstract ideas and mental concepts into alternative, tangible, and concrete forms that can be experienced and manipulated in the real world, which can supplement thought and act as active cognitive partners to foster hands-on tinkering, dwelling, and reflection upon materials at hand, features and affordances, and assumptions and beliefs.	Suwa and Tversky (2002), Boland and Collopy (2004), Viswanathan et al. (2014)
Visualization	Focus on the visual nature of prototyping in manifesting information, knowledge, and abstract ideas of the future into externalizations, which can stimulate creative thinking, enhance idea generation, and aid problem-solving as means to overcome limitations on human cognition related to offloading, comparison, and recall.	Comi and Whyte (2018), Ewenstein and Whyte (2009), Eppler and Kernbach (2016)
Boundary spanning	Focus on the social role of prototyping as key to facilitate communication, interaction, and joint problem-solving through the creation and use of prototypes that can trigger discussion and feedback on shared grounds by acting as social actors, integrative devices, or boundary objects supporting boundary spanning and the construction of collaborative space across social or thought worlds.	Carlile (2002), Orlikowski and Scott (2008), Bechky (2003b)
Testing	Focus on the evaluative role of prototyping in gradually and iteratively refining designs through the creation and use of prototypes for early user involvement and as experimental components to test, simulate, or evaluate aspects of solutions, reduce errors and mistakes, validate assumptions and hypothesis, and identify necessary and potential improvements.	Lauff et al. (2018), Thomke (2001), Camuffo et al. (2019)
Exploration	Focus on the generative role of prototyping in exploring situations, scenarios, users, ideas, and problems through the creation and use of prototypes to imagine, generate, and discover new alternatives, options, and understanding, especially in situations where the problems or the requirements of solutions are not fully defined.	Buchenau and Suri (2000), Jarzabkowski and Kaplan (2015), Brunswicker et al. (2013)
Organizational learning	Focus on the learning role of prototyping in fostering collective learning beyond individuals and induce adaptive learning processes as knowledge is continuously embedded into prototypes that can act as vehicles to gain new knowledge about possible problems, process requirements, or solutions and reinforce or validate existing knowledge.	Hargadon and Sutton (1997), Andries et al. (2013), Nicolini et al. (2012)
Process coordination and momentum	Focus on the coordinative role of prototyping in reducing complexity by acting as means to break down larger, complex tasks and to facilitate and mediate coordination and collaboration in order to reduce confusion, enhance integration, link the various stages of developments through prototypes as milestones, and foster emotional benefits related to experiences of momentum, involvement, and beliefs about creative ability.	Kelley (2001), Dow et al. (2012), Gerber and Carroll (2012)

and thinking, discovery, and learning occur through the practice of making (Coughlan et al., 2007; Neeley et al., 2013; Passera et al., 2012; Suwa & Tversky, 2002; Viswanathan et al., 2014; Vyas et al., 2009).

Visualization. A second theme in the literature relates to the visual nature of prototyping in manifesting abstract ideas of the future. This theme points to the epistemic role of visualizing knowledge in artifacts that can be experienced, shared, and discussed (Bechky, 2003a; Comi & Whyte, 2018; Ewenstein & Whyte, 2009), and it draws on cognitive science in underlining how externalization and visual artifacts are key to generating ideas and overcoming limitations on human cognition (Akgün et al., 2006; Jacucci & Wagner, 2007; Sass & Oxman, 2006; Suwa & Tversky, 1997).

This theme concerns the influence of prototyping as a means to bridging the abstract and the concrete by bringing visuality to abstract ideas and mental concepts (Eppler & Kernbach, 2016; Ewenstein & Whyte, 2009; Meyer et al., 2013; Sass & Oxman, 2006). Particularly, visualization, which Bresciani and Eppler (2015, p. 1) define as the "graphic display of information and knowledge," is a key aspect of many prototypes as external representational artifacts, as also illustrated by the wealth of visual materials used in practice, ranging from process roadmaps to spreadsheets, collage, CAD renderings, storyboards, experience journeys, business concept illustrations, and visual images (Beaudouin-Lafon & Mackay, 2003; Gonçalves et al., 2014; Liedtka, 2015; Whyte et al., 2008), as well as business model canvases, pitch decks, and user journeys (Liedtka & Ogilvie, 2011; Mansoori, 2017; Osterwalder & Pigneur, 2010; Rae, 2007; Seeling, 2015).

The visual nature of such representations helps actors make the abstract and intangible concrete in ways that allow for new mechanisms to come into play (Lim et al., 2008). The presence of representations as visual stimuli is especially useful for problem-solving (Goldschmidt & Smolkov, 2006) and for provoking change, where visual representations serve as "encouragements to behave in new ways and as ongoing prompts or reminders of the new behavior" (Coughlan et al., 2007, p. 130) and help transform abstract imaginings into realizable courses of actions (Comi & Whyte, 2018). Thus, visual representations come to act as thinking tools for individual and collective problem-solving as they embed abstract knowledge and information into concrete and visual formats (Bechky, 2003a; Ewenstein & Whyte, 2009; Jacucci & Wagner, 2007), which fuels imaginativeness and fosters changes in perspectives (Eppler & Platts, 2009; Kier & McMullen, 2018; Schön, 1983). Given the ambiguous, incomplete, and often flexible nature of visualizations, they can further stimulate reflection upon use and experiences that set ideas and mental concepts into motion (BenMahmoud-Jouini & Midler, 2020). Thus, ambiguity in visual representations is not necessarily a constraint but can be a central source of creativity (Atilola et al., 2016), as it provides openness for multiple interpretations (Eppler et al., 2011; Henderson, 1991; Pfister & Eppler, 2012) and allows them to continuously change, evolve, and unfold (Ewenstein & Whyte, 2009).

Here, visualization relates not only to the use of prototypes but also to the very process of externalizing or visualizing, which aids in overcoming human cognitive limitations and fueling imagination. These cognitive benefits are especially prevalent in research on sketching, which is key in design (Cardella et al., 2006; Goldschmidt, 2003; Kier & McMullen, 2018; Schön, 1983; Suwa & Tversky, 1997; 2002). Sketching presents a simple, cost-effective way to overcome fixation and promote idea fluency, described as "generating a wide range of ideas quickly and avoid favoring one single idea" (Ranscombe et al., 2020, p. 367). The act of externalizing the mind's eye can directly influence the actor's ideation as "visual representation and the visual experience as a whole allow new ideas to be created in the mind" (Atilola et al., 2016, p. 113). The process of visualizing evokes reflection upon ways to filter the intangible into visual manifestations (Lim et al., 2008), and these can make actors sensitive to dimensions and features of their own ideas (Goldschmidt & Smolkov, 2006). Through visualization, actors do not merely externalize already existing ideas but "draw sketches to try out ideas, usually vague and uncertain ones" (Suwa & Tversky, 2002, p. 342), which enables discovery and inference from their own visualizations. Visual representations, therefore, not only help an actor overcome cognitive limitations by acting as external memory aids for offloading and better recall but equally perform the role of mediums for reflective interplays between the visual representation and the ideas of the actor (Suwa & Tversky, 1997; 2002).

Boundary spanning. A third theme in the literature is the role of prototyping as boundary spanning. This theme is prevalent in several fields of research, whenever new product development, interorganizational collaboration, technical issues, or design processes are studied. Much inspiration is drawn from science and technology studies and actor–network theory, where material and visual artifacts have been highlighted as important actors in the construction of social structures and outcomes. Hence, prototyping is regarded as a key to creating objects that can facilitate boundary spanning (Carlile, 2002; Orlikowski & Scott, 2008). In the literature on new product development, the focus is also directly on boundary spanning, where prototypes are stressed as boundary objects to link different phases and activities of the development process (Bogers & Horst, 2014; D'Adderio, 2001; Elverum & Welo, 2014), and as tools for joint problem-solving (Bechky, 2003b).

Emphasis in this theme is placed on prototypes as boundary objects or integrative devices that can act as boundary-spanning mechanisms for creating a collaborative space across social worlds or thought worlds for collective knowledge development (BenMahmoud-Jouini et al., 2014; Carlile, 2002; Christiansen & Gasparin, 2017; Eppler et al., 2011; Hargadon & Bechky, 2006; Hargadon & Sutton, 1997; Nicolini et al., 2012; Whyte et al., 2008). Prototypes thus become communication mediums to share information and ideas, while simultaneously enabling feedback and interaction (e.g., Beaudouin-Lafon & Mackay, 2003; Berglund & Leifer, 2013; Deininger et al., 2017; Elverum & Welo, 2014; Houde & Hill, 1997; Rhinow et al., 2012). In this way, prototypes can act as representations of abstract ideas and vehicles of thought among people and thus support conversation by helping those involved share information and ideas (Gengnagel et al., 2016; Gerber & Carroll, 2012; Neeley et al., 2013), explicate assumptions and jointly comprehend abstract ideas (Buchenau & Suri, 2000; Liedtka, 2015; Lim et al., 2008), facilitate communication by helping participants discuss and interact around the focal artifact and experiences (Beaudouin-Lafon & Mackay, 2003; Rhinow et al., 2012), encourage collaboration by creating involvement and engaging people's imagination (Eppler & Platts, 2009; Schrage, 1999), overcome and reduce confusion arising from boundaries and differences in knowledge and language among participants (Carlile, 2002; Innella & Rodgers, 2017; Wouters & Roijmans, 2011), and stimulate cross-functional knowledge flows and integration (Bogers & Horst, 2014; D'Adderio, 2001).

Testing. The fourth and perhaps most common theme in the literature is the notion of testing as discussed in studies on business experiments, experimentation, and hypothesis testing. Here, prototypes are seen as experimental components for gradually refining solutions through testing and evaluation in an iterative process. This allows for progression toward a solution without committing to the risk and cost of producing only make-or-break, complete versions (Brunswicker et al., 2013; Coughlan et al., 2007; Dow et al., 2009; Houde & Hill, 1997; Lim et al., 2008; Ulrich & Eppinger, 2012; Viswanathan & Linsey, 2013; Wensveen & Matthews, 2015). In Camburn et al.'s (2017) survey of literature spanning engineering, management, design science, and architecture, design refinement was found to be "the most commonly cited objective" (p. 3) of prototyping. Here, the purpose of prototyping is often related to helping actors refine technical elements of a product solution (Lauff et al., 2018), as prototyping has traditionally related to the technical aspects of testing in product development and innovation (Otto & Wood, 2001; Seidenstricker et al., 2014; Ulrich & Eppinger, 2012) and been "predominantly focused on technical function and resource management, with a secondary focus on user interactions and prototype development" (Menold et al., 2017, p. 71). Further, prototyping oftentimes relates to material product refinement, which stems from its

origins in technical fields such as mechanical and software engineering (e.g., Alavi, 1984; Bischofberger & Pomberger, 1992; Budde et al., 1984; Gomaa & Scott, 1981; Muñoz & Miller-Jacobs, 1992; Naumann & Jenkins, 1982; Smith, 1985; Wall et al., 1992).

Prototyping enables actors to gradually improve their product and service solutions as a result of testing efforts to systematically gather feedback from early user interaction, which can inform subsequent adjustment of solutions (Beaudouin-Lafon & Mackay, 2003; Camuffo et al., 2019; Christiansen & Gasparin, 2017; Liedtka, 2015; Stoll, 1999; Wang, 2002). How actors use prototypes as testing vehicles differs, however, across technical and design contexts (Wensveen & Matthews, 2015; Yu et al., 2018). In the technical contexts of engineering and product development, prototype testing often mirrors scientific experimentation with higher fidelity prototypes as embodiments of hypotheses for the manipulation of focal variables (Beaudouin-Lafon & Mackay, 2003; Felin et al., 2020; Hartmann et al., 2006). This typically occurs at later stages of development in a sequential, product-centric fashion as part of a relatively linear process, where prototyping represents an experimental approach to testing clear questions, often focused on features and functions (Menold et al., 2017; Ries, 2011; Thomke, 2001; Thomke et al., 1998; Ulrich & Eppinger, 2012; Yu et al., 2018). Recent efforts in technical fields, however, have started to emphasize the potential and use of prototyping in earlier stages of concept development (e.g., Elverum & Welo, 2014; Yu & Enste, 2019).

In design contexts, prototyping is regarded as a means for testing and evaluating ideas as they emerge from imagination (Buchenau & Suri, 2000; Jensen et al., 2017; Lawson, 2006; McElroy, 2017; Rettig, 1994). Here, actors often rely on low-fidelity techniques and materials to try out new things in parallel; hence, the development of prototypes begins in the earliest stages and requires user involvement (BenMahmoud-Jouini et al., 2014; Brenner & Uebernickel, 2016; Brown, 2009; Buxton, 2007; Kelley, 2001; Sheridan et al., 2014). Rather than primarily focus on testing product-centered aspects, design contexts underscore the potential of rapid instantiations to fail inexpensively and facilitate feedback on explicit and latent user needs (Coughlan et al., 2007), investigate the design space through more open-ended questions, and test dimensions of human–solution interactions, such as experiences in action (Camere & Bordegoni, 2016; Wang, 2002; Yu et al., 2018).

Exploration. A fifth element relates to prototyping as an exploration vehicle, meaning the use and creation of prototypes as valuable tools and active means to explore situations, users, and ideas in order to generate new alternatives, options, and understandings for subsequent development activities (Brown, 2009; Brunswicker et al., 2013; Buchenau & Suri, 2000; Camburn et al., 2017; Camere & Bordegoni, 2016; Elverum & Welo, 2016; Jensen et al., 2015, 2017). This theme emphasizes the role of prototypes as generative tools for when the requirements of future products, services, or solutions are yet to be fully defined and for developing understandings of user experiences (Brown, 2009; Buxton, 2007), concept generation (Boer et al., 2013; Buchenau & Suri, 2000; Gonçalves et al., 2014; Kelley, 2001; Kleinsmann & ten Bhömer, 2020), business modeling (Brunswicker et al., 2013; Eppler et al., 2011; McDonald & Eisenhardt, 2020), or strategy development (Djurić, 2015; Eppler & Platts, 2009; Jarzabkowski & Kaplan, 2015).

In this theme, prototyping is used to help surface and imagine new possibilities with available materials or technologies and to enhance understanding of user needs, problems, and desires, as well as potential problems with how users currently understand the prospective solution (Buchenau & Suri, 2000; Jensen et al., 2015; Johnson, 2011). This use of prototyping is closely related to design contexts in which problem and solution spaces are regarded as dynamically intertwined (Lawson, 2006). In particular, design is characterized as a socio-technical process in which "exploration of alternatives within the problem space is at least as important as convergence within a solution space" (Neeley et al., 2013, p. 1). Hence, prototyping is as important in exploring the interrelation between the spaces as it is in merely generating ideas for solutions. To the actor, prototyping can play the role of cost-effective windows to imagined futures (Buchenau & Suri, 2000; Eppler & Platts, 2009; Johnson, 2011; McDonald & Eisenhardt, 2020).

When prototyping, actors do not merely solve problems as they go. Rather, they use prototyping as a key to open new alternatives, stimulate serendipity, and uncover or create new, unknown opportunities (BenMahmoud-Jouini & Midler, 2020; Carfagni et al., 2020; Erichsen et al., 2016; Jensen et al., 2017). Furthermore, prototyping can open up exploratory discussions among actors and users as to how future solutions might work and quickly materialize various ideas, which can help surface unforeseen possibilities by "making familiar things strange, and by making strange things familiar" in concrete ways (Kimbell, 2015, p. 133). Similarly, actors can use 'provotypes' to expose taken-for-granted values and practices (Boer et al., 2013; Danholt, 2005; Kleinsmann & ten Bhömer, 2020; Mogensen, 1992) and can explore possible future scenarios with science fiction prototyping (Johnson, 2011; Poznic et al., 2020; Roberts & Middleton, 2014). While prototypes are heralded as central to answering known unknowns, prototypes are further emphasized as the driving force behind eliciting unknown unknowns, which means questions on "issues and details whose existence and relevance is unknown," for further exploration (Erichsen et al., 2016; Jensen et al., 2017; Lauff et al., 2018; Menold et al., 2019).

Organizational learning. A sixth theme relates to prototyping broadly defined as a vehicle for learning at the organizational level (Berglund & Leifer, 2013; Buchenau & Suri, 2000; Camburn et al., 2017; Comi & Whyte, 2018; Coughlan et al., 2007; Jensen et al., 2015; Lauff et al., 2018; Ulrich & Eppinger, 2012; Yang, 2005). This theme sees prototyping as a means of mediating collaborative learning and unlearning among interdependent groups (Akgün et al., 2006; Bogers & Horst, 2014; Brix, 2017; Carlile, 2002, 2004; Hargadon & Sutton, 1997; Knorr Cetina, 1997; Nicolini et al., 2012; Pershina et al., 2019) and of business model innovation, where prototyping is heralded as an organizational learning vehicle for establishing the strategic space and direction of emerging solutions and business models through adaptive learning, trial-and-error experimentation, and exploratory user engagement (Ammon, 2017; Berends et al., 2016; Brunswicker et al., 2013; Felin et al., 2020; Frederiksen & Brem, 2017; Jones et al., 2010; McDonald & Eisenhardt, 2020; Sosna et al., 2010; Wrigley et al., 2016).

Here, prototyping is a useful means to gain valuable insights into the strengths and weaknesses of ideas or solutions and to identify new directions that subsequent prototyping activities might take (BenMahmoud-Jouini et al., 2014; Brown, 2009; Kelley, 2001; McElroy, 2017). Indeed, the very process of prototyping can serve as a vehicle for experimental learning through active reconfiguration or manipulation and immersion in the design space (cf. Berends et al., 2016; Coughlan et al., 2007; Eppler et al., 2011; Gengnagel et al., 2016; Goldsby et al., 2017; Junginger, 2007).

In this theme, prototyping is specifically emphasized as a tangible vehicle for inquiry and learning (Kelley, 2001; Wensveen & Matthews, 2015; Yu & Enste, 2019). Specifically, prototyping is related to the facilitation of trial-and-error learning through quick generation of new knowledge or validation of existing knowledge as a direct result of using prototyping at either early or later stages (Andries et al., 2013; Buchenau & Suri, 2000; Kiriyama & Yamamoto, 1998; Redeker et al., 2015; Ulrich & Eppinger, 2012). As proposed by Yang (2005), prototyping does not simply answer predefined questions but raises new ones, which can reveal current knowledge gaps and elicit unknown unknowns to support subsequent actions and learning efforts (Jensen et al., 2017; Rhinow et al., 2012). Building cheap and quick prototypes, even seemingly stupid or reckless ones, has therefore been stressed by several scholars as positively contributing to organizational learning by reinforcing or challenging existing knowledge and by enabling learning from low-cost failures and unexpected insights (Berglund & Leifer, 2013; Coughlan et al., 2007; Houde & Hill, 1997; Junginger, 2007; Lauff et al., 2018; Lim et al., 2008; Silva et al., 2009; Viswanathan et al., 2014).

Process coordination and momentum. A final theme relates to prototyping as a vehicle to simplify work complexity, link stages of

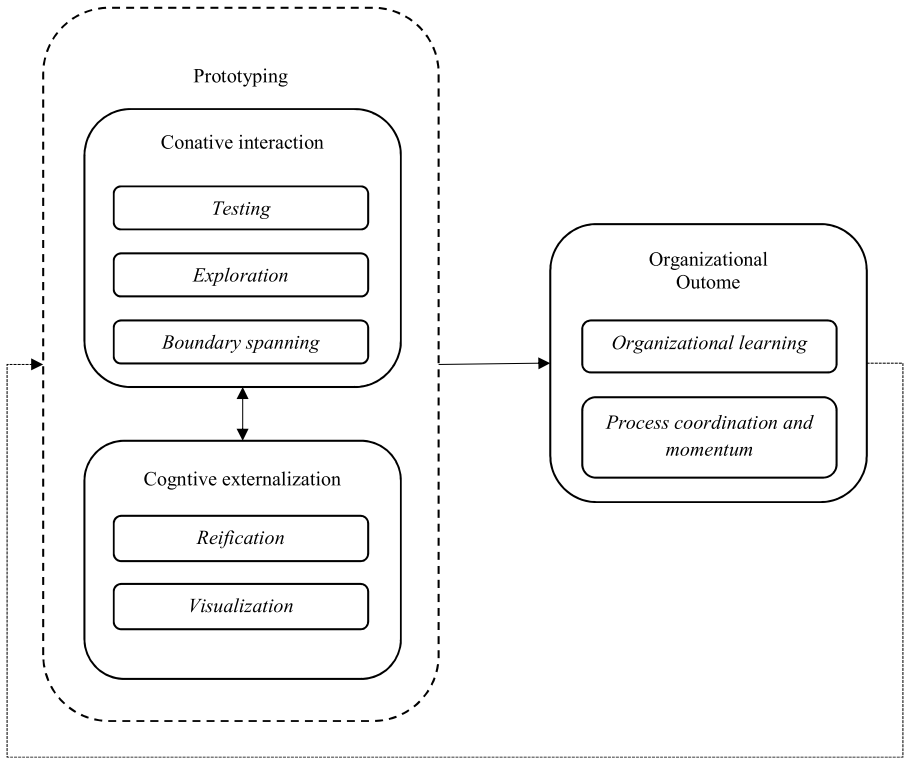

Fig. 2. Conceptual framework.

development, and enhance coordination through facilitation and mediation of relations (Atilola et al., 2016; Carlile, 2002; Hargadon & Sutton, 1997; Hartmann et al., 2006; Rhinow et al., 2012; Ulrich & Eppinger, 2012; Yu et al., 2018). The theme highlights how prototypes are instrumental in simplifying processes through their role as active mediums or passive representations to aid actors in dealing with complexity, such as early-stage fuzziness, and as tools to reduce confusion and conflict in the navigation of social dynamics (Gustavsson & Säfsten, 2017; Henderson, 1995; Jarzabkowski & Kaplan, 2015; Lauff et al., 2018; Stevens, 2014).

In organizational processes, actors often face complex problems requiring the coordination and involvement of various participants. Here, prototyping is heralded as a way to accelerate the process and reduce complexity by enabling actors to break down larger problems and reduce them into minor subcomponents for easier management and thus to achieve incremental progress (Gerber, 2009; Gerber & Carroll, 2012; Kelley, 2001). Prototyping can enable actors to focus on the core of an abstract idea or complex problem, which can facilitate the generation of small wins, which are vital to the psychological experience of everyone involved (Gerber & Carroll, 2012) and their self-efficacy (Dow et al., 2012). Thus, prototyping in this theme is used to enable actors to continuously reframe a situation by targeting minor subcomponents of larger problems in order to either visualize and demonstrate successful achievement (Ulrich & Eppinger, 2012) or reframe failures as opportunities for learning (Gerber & Carroll, 2012). Prototyping thus creates milestones that demonstrate progress and link early stages of inspiration and ideation with later stages of realization (García et al., 2017; Ulrich & Eppinger, 2012; Yu et al., 2018).

Through its technical and social functions, prototyping can encourage and ease interaction (Beaudouin-Lafon & Mackay, 2003; Bechky, 2003a; Berglund & Leifer, 2013; Tory et al., 2008). It can thereby act as tangible means to organize work throughout the innovation process (Hartmann et al., 2006; Yu et al., 2018) and enable peers to "navigate the social dynamics while simultaneously working to develop insights" (Jarzabkowski & Kaplan, 2015, p. 545). Prototypes can act as embodiments of thoughts and ideas and function as communication platforms to establish shared understanding, design language, and syntax (Carlile, 2002; Innella & Rodgers, 2017; Lauff et al., 2018), which aids coordination and the convergence of thinking among participants (Jensen et al., 2016; Rhinow et al., 2012; Wouters & Roijmans, 2011). They can provide an explicit focal point that structures and qualifies feedback, discussion, negotiation, and inputs from everybody involved (Bechky, 2003a; D'Adderio, 2001; Jarzabkowski & Kaplan, 2015). In this regard, prototyping is key to simplifying coordination in meetings and review sessions, for example, where "a good prototype is worth a thousand pictures" (Kelley, 2001, p. 39), and in facilitating knowledge integration among peers based on structured thinking and shared understanding (Berglund & Leifer, 2013; Bogers & Horst, 2014; Carlile, 2002; Junginger, 2007; Rhinow et al., 2012), while supporting the collaborative selection of alternatives and assumptions to emphasize as well as the prioritization of subsequent steps to take (Spee & Jarzabkowski, 2009; Ulrich & Eppinger, 2012). Thus, prototyping is powerful in conflict resolution, as prototypes become participating actors in unstructured creative work (Carlile, 2002; Danholt, 2005; Gustavsson & Säfsten, 2017; Lauff et al., 2020) and thereby serve a political role as "a 'social glue' between individuals and between groups […] not only is a power struggle revealed, but also the interests and actions of the actors involved are made clear as is the process toward the final outcome" (Henderson, 1995, p. 294).

4.3. Toward a conceptual overview of prototyping

Having outlined the most prominent, inductively derived themes as second-order categories in the literature on prototyping, we now organize these themes into aggregate dimensions as we look for similarities and differences among the first-order codes and second-order categories (see Fig. 1). As was the case with our themes, the aggregate dimensions are derived inductively from the data in our literature sample, and they indicate the various activities and processes present in the literature on prototyping in the fields sampled. An overview is provided below in Fig. 2.

The first aggregate dimension, cognitive externalization, captures

the considerable overlap between the visualization and reification themes. Despite their differences in terms of empirical and theoretical foci, they both encapsule the transformation of abstract ideas and mental concepts into tangible, external representations that can be manipulated, experienced, and shared. Visualization provides the visual stimuli necessary for cognitive engagement, while reification offers the material basis for hands-on interaction and reflection and thus functions as a complementary aspect of transforming internal cognitive processes into external representations. Cognitive externalization is key to the 'reflective conversation' between hand and mind, the situated nature of cognition, and abstract ideas and physical environment, as seen for instance in work on reflective practice (cf. Clark & Chalmers, 1998; Schön, 1983; Schön & Wiggins, 1992) and in research underlining the vital interplays between building and thinking in the realization of solutions (Cornelissen, 2013; Cross, 2006; Dew et al., 2015; Simon, 1996). Here, knowledge and ideas are externalized in material or visual form involving creative representational efforts operating in a liminal dimension (Ammon, 2017; Berglund & Leifer, 2013). This is where the representational function of prototyping originates, as the externalization of ideas that were hitherto only internal becomes a performative driver of the process of developing (Berglund & Leifer, 2013; Camere & Bordegoni, 2016; Jensen et al., 2016; Lim et al., 2008). The act of cognitive externalization is performative and generative in that it does not simply represent previously existing concepts but is "part and parcel of the very activity in which conceptualizations and inferences are formed" (Cornelissen, 2013, p. 707), as also demonstrated by insights on visual thinking (Goldschmidt, 1994; Suwa & Tversky, 1997, 2002). Hence, the representation is not passive. It is a dynamic process in which the sketch, drawing, simulation, or physical object made becomes active in the process and "talks back" both during and after its creation (Boland & Collopy, 2004; Henderson, 1995; Rhinow et al., 2012). The concept of cognitive externalization underscores the importance of external representations in the cognitive process and highlights mechanisms such as cognitive offloading, dual-coding, scaffolding, and iterative refinement (Zhang & Wang, 2005).

We suggest that this activity is foundational, as all the themes we identified rely on the primary function of externalizing the mental into representations. It also offers an integrated approach to prototyping, where abstract ideas are continuously transformed and refined through a dynamic interplay of visual and material representations.

The second aggregate dimension, conative interaction, encompasses the themes of testing, exploration, and boundary spanning as it emphasizes the active, intentional dynamic interaction between actors, artifacts, and contexts. Cognitive externalized representations are enrolled in actor–prototype interaction in instances where individuals interact directly with artifacts as well as actor–actor interaction where prototyping acts as a boundary-spanning activity to facilitate communication, interaction, and feedback between "prototypers" and stakeholders such as potential users, suppliers, investors, partners, and so forth. Here, the presence of material or visual artifacts enables and directs the interactions as boundary spanners in ways that would not necessarily be possible without them (Danholt, 2005; Gengnagel et al., 2016; Rhinow et al., 2012). In our data, we found this to be commonly conceptualized as spanning boundaries between multiple actors, stakeholders, systems, etc. involved in design and development processes. The ideas, concepts, products, etc. cognitively externalized can mediate to other actors due to their external and concrete tangible, physical, or visual form, as actors use them in various ways pointing to the social nature of prototyping (Berglund & Leifer, 2013; Crilly, 2010; Yu et al., 2018). Hence, prototyping as boundary spanning enables 'testing' and 'exploration' as distinct activities and functions of prototyping. Here, the interactions take on a role and are embedded within a chain of activities, or what is sometimes referred to as an entrepreneurial or innovative journey, not just defined by cognitive externalization and boundary-spanning interactions but also bound to previous and future activities in the overall process of organizational learning and process momentum and coordination. This aspect of prototyping requires specific attention, as this is where the inner system of the actor interacts with the outer systems of the surroundings, in which the ideas and aspirations of the actor must be realized (Berglund et al., 2018; 2020; Selden & Fletcher, 2019). Notably, in using the term 'conative,' we maintain that prototyping is an intentional and purposeful activity, and interaction is the mechanism through which goals are pursued, whether the focus in on the evaluative or generative role of prototyping.

The third dimension captures the organizational level outcomes of organizational learning and process coordination and momentum, which are both central elements in many of the innovative, entrepreneurial, engineering, and design processes in our review. This perspective emphasizes how prototyping both generates collective knowledge through learning and ensures that knowledge is embedded into processes and applied effectively and thus driving organizations or teams toward shared progress. Then, prototyping is manifested as dynamic outcomes related to the overall process and organization in which it takes place. In this way, prototypes act as milestones or demonstrations of progress as prototyping activities are intertwined with larger organizational dynamics related to existing structures and routines, as well as the changing of these (cf. Carlile, 2002; Coughlan et al., 2007; Henderson, 1995; Seidel & O'Mahony, 2014).

5. Discussion

The landscape of research on prototyping in management is at first glance made up of a diverse and fragmented display of conceptual vocabularies and disconnected research streams spanning from provotypes used to fuel discussion and reflection on imagined futures to expensive, high-fidelity prototypes used for late-stage demonstrations (cf. Clark & Chalmers, 1998; Schön, 1983; Schön & Wiggins, 1992). Above, we offer a definition and a conceptual framework that organizes this fragmented landscape. We argue that cognitive externalization is foundational for prototyping as a reflective conversation between mind and hand, situated in activities of representation. In the advancement of our understanding of this foundational activity, psychology, behavioral economics, cognitive science, and human–computer interaction can certainly inform further research on mechanisms such as cognitive offloading, dual-coding, scaffolding, and iterative refinement (Zhang & Wang, 2005; Zimmerman et al., 2007). On this foundation of cognitive externalization, two further dimensions suggest how prototyping is undertaken in conative interactions in turn leading to organizational outcomes.

5.1. Toward a research agenda for prototyping

In the following, we will point to some relevant lines of research that grow from the insights generated by the review and that leverage the potential for integration and intensification of research on prototyping in management. First and foremost, the extent of the research reviewed here suggests that prototyping is more than just an empirical phenomenon that can be exhausted through descriptive or prescriptive examination. Nor is it just an empirical artifact that enables the study of other, theoretical phenomena. Much research treats prototyping as an empirical phenomenon secondary to a higher level theoretical construct such as boundary spanning or visualization. While such research, as evidenced in our review, is valuable, we would argue that prototyping is an important managerial phenomenon worthy of theorizing in its own right. The specific mechanism of prototyping as representation through artifacts is a distinct managerial activity – and one that will only become more important with continued advancement in technologies and organizational forms supporting prototyping. A similar point emerges from the valuable research conducted on specific types of prototypes (e.g., provotypes and science fiction prototypes) and prototyping in specific domains (e.g., designers and architects). Here the value of research may be advanced if prototyping is treated as a theoretical concept worth

studying across domains in comparative form to understand even better both the mechanisms of prototyping and the situational contingencies that influence the processes and outcomes of prototyping activities.

To further the theoretical and empirical understanding of prototyping based on our review and overview, specifically, we point to the need for expansive research across the aggregate dimensions (cognitive externalization, conative interaction, and organizational outcome) as well as within the aggregate dimensions (e.g., across themes) of our conceptual overview. Expanding research across themes and dimensions essentially formulate a research agenda on the entire process of making, using, and learning from prototypes, directing future research from prototype attributes (what) to the functions (why) and most importantly the uses (how) of prototyping. While research that focuses on the characteristics, fidelity, affordances, etc. of prototype artifacts is indeed interesting and useful in many respects, it does run the risk of overlooking essential situational and processual aspects or of overestimating the generalizability of findings from specific situations.

5.1.1. *Integrative research potential within aggregate dimensions*

Our integrative literature review offers an initial overview of some of the dynamics across the themes involved in prototyping. However, we suspect that this overview is limited in scope and captures only a part of an ever-evolving landscape. While our integration of multiple domains of research likely enhances our scope compared to past discipline-specific reviews, there are other themes to be uncovered in research within each aggregate dimension. Visualization and reification certainly offer strong insights into the foundational dynamics of cognitive externalization, but other themes may be uncovered in future research, especially as prototyping becomes increasingly digital and increasingly merges with virtual or augmented reality and generative AI techniques. We have already seen how 3D printing techniques, cloud-based software, and new organizational forms (such as accelerators and makerspaces) have changed and 'democratized' prototyping (Browder et al., 2017; Nambisan et al., 2019; Rayna & Striukova, 2016). Similarly, even though our review identifies visualization and reification as separate themes, we know that prototyping often combines elements of materialization and visualization, as many prototypes have both physical and visual properties. Indeed, this will likely be exacerbated with new technologies transcending the boundaries between the digital, visual, tangible, and bodily. The same applies to the use of fiction-based prototyping that may also disclose new mechanisms at work across visualization and reification converging and intersecting in new ways. Hence, future exploratory research is needed to bridge and integrate our understanding of different forms of cognitive externalization within and across visualization and reification – in particular, how new technologies and organizational forms will continue to change prototyping activities and cognitive externalization.

We found a lot of research about the evaluative and generative role of prototyping, and we identified separate themes: testing and exploration. Even though there is a clear analytical distinction between them, research suggests that prototyping activities often incorporate elements of testing as well as exploration (Paust et al., 2024). Hence, we believe that future research will benefit from exploring further how prototypers structure their prototyping activities with generative and imaginative open-ended measures within well-defined outcome measures and how and why they navigate purposeful prototyping of testing and exploration.

Finally, scholars might examine how the process coordination and momentum of prototyping allow organizations to reduce conflict and complexity and to visualize or materialize momentum as well as establish shared understanding that facilitates organizational learning. Also, as prototyping activities unfold in organizations or in teams, they are inevitably tied into inter- and intraorganizational games and struggles. Thus, prototyping creates, coordinates, and frames power struggles in organizations as much as other activities, yet this does not surface very often in the reviewed literature. Exceptions to this include some of the early work on boundary objects as a form of prototyping, especially the literature drawing on STS and actor–network theory (Bechky, 2003a; Groen et al., 2016; Henderson, 1995; Orlikowski & Scott, 2008; Winner, 1980), but it has not been followed up to a degree that matches the likely importance of understanding the political dimensions, roles, and interplays of prototyping and how process coordination and momentum interact with organizational learning.

5.1.2. *Integrative research potential across aggregate dimensions*

In the further advancement of prototyping research in management, we suggest explorative research across the aggregate dimensions. While certainly challenging, understanding the dynamics between cognitive externalization, conative interaction, and organizational outcome and how they interweave is an important step in deepening our understanding of prototyping in management. To achieve this objective, we put forward three central suggestions for future research. The first is to focus efforts on prototyping as opposed to the prototype. As our review shows, the process's situational nature shapes artifacts as prototypes. While prototypes are indeed artifacts of various kinds, and depend on this to serve their representational function, it is the process of prototyping that unfolds that will contribute most significantly to our understanding of the mechanisms (and critical dimensions) of prototyping. As pointed out by Crilly (2010), prototypes perform functions, but people use them; hence, prototypes do not gain their status by virtue of their attribute content but by virtue of their use by creative actors. This is key to future research, as the affordances induced by the attributes and materials of prototypes invite and constrain certain behavior and functions but do not necessarily dictate use given the inherently incomplete nature of prototypes. Their incompleteness means that human imagination and social interactions are crucial to the role of prototyping (Berglund et al., 2020; Norman, 2013). While prototypes are important, they are not only the results of prototyping but part and vehicle of the evolving prototyping process. From this perspective, prototypes are "evolving manifestations […] the result of an intermediate step and the starting point for the next step" (Rhinow et al., 2012, p. 4); hence, they are both output and input in design and development processes, as has been underlined in previous work on the role of representations (Simon, 1996). This is also signified with the feedback loop in Fig. 2. As such, a strong process perspective in the study of prototyping is one way of addressing the need to focus on prototyping as activity rather the prototype artifact (cf. Camburn et al., 2017; Camere & Bordegoni, 2016; Gengnagel et al., 2016; Lim et al., 2008). A strong process perspective has the distinct advantage here in that it incorporates the contingency and change of objects as a central premise in longitudinal studies of organizational processes and allows for the study of multilevel dynamics (Jarzabkowski et al., 2016; Kohtamäki et al., 2022). Focusing on the processual *how* of prototyping also makes better room for alternative forms of prototypes, such as scripted interactions and role plays, visual images, and narratives, that are less obviously artifactual in the literal sense but that have been promoted for the development of service, experience design, and policymaking (Blomkvist & Holmlid, 2011; Blomkvist & Segelström, 2014; Brenner & Uebernickel, 2016; Nielsen et al., 2013; Passera et al., 2012; Sanders & Stappers, 2014; Villa Alvarez et al., 2020), for example.

Second, the situational and domain-specific contingencies of prototyping in management, while being much enlightened by the existing research as reviewed here, represent an important and promising line of inquiry. Domain-specific, organizational, relational, and processual context factors influence how prototyping is engaged as well as why some prototyping activities fail, while others succeed. Understanding how the context of prototyping, from for instance resource-strapped entrepreneurial venturing, high tech corporate R&D, aesthetically sensitive design processes, or scientifically inspired testing of features, influences the dynamics of prototyping will enhance understanding of both underlying mechanisms and foundations as well as essential contingencies. To further this endeavor, different kinds of comparative

Table 3
Future avenues of research and research questions.

Avenues and questions within dimensions	
Background	*Potential research questions*
Further research on the interplay of visualization and reification as foundational dynamics of prototyping may expand understanding of cognitive externalization – especially in light of the rapid emergence of new technologies (such as generative AI) that can bring about transcendence of current boundaries between the digital, visual, tangible, and bodily. Also, new organizational forms such as platforms can radically reshape prototyping as a representational practice.	How are the foundational dynamics of prototyping shaped by new technologies such as generative AI and by new organizational forms? How is the interplay of visualization and reification influenced by new technologies and organizational forms? What new foundational dynamics might emerge from new technologies used for prototyping?
Future research will benefit from exploring further how prototypers structure their prototyping activities with generative and imaginative open-ended measures within well-defined outcome measures, and how and why they navigate purposeful prototyping for testing and exploration.	How do prototypers structure their prototyping activities with generative and imaginative open-ended measures within well-defined outcome measures? How and why do prototypers navigate purposeful prototyping between testing and exploration?
Given that prototyping can generate organizational outcomes (e.g., learning and process coordination and momentum), it may allow organizations to reduce conflict and complexity. Notably, prototyping may also become enmeshed in inter- and intraorganizational games and struggles suggesting the importance of understanding the political dimensions, roles, and interplays of prototyping.	How does prototyping contribute to organizational development and stability – or lack thereof? How are prototyping activities shaped by organizational politics, roles, and dynamics – and vice versa?
Avenues and questions across dimensions	
Background	*Potential overall research questions*
A strong process perspective in the study of prototyping is one way of addressing the need to focus on prototyping as activity rather the prototype artifact, as it incorporates the contingency and change of the objects of study as a central premise in longitudinal studies of organizational processes and allows for the study of multilevel dynamics.	How do prototypes as enacted and dynamic artifacts emerge in processes of prototyping?
Domain-specific, organizational, relational, and processual context factors influence how prototyping is engaged as well as why some prototyping activities fail while others succeed. Understanding how the context of prototyping, in e.g. resource-strapped entrepreneurial venturing, high tech corporate R&D, aesthetically sensitive design processes, or scientifically inspired testing of features, influences the dynamics of prototyping will enhance understanding of underlying mechanism and foundations as well as essential contingencies.	How are prototyping activities shaped by situated and domain-specific factors? What are the important contingencies that influence prototyping outcomes across domains, contexts, and specializations within management? Which mechanisms related to prototyping have general applicability across domains, contexts, and specializations within management?
Dualist ontologies with their sharp distinction between an individualized and mental subjectivity and a given objective external reality may struggle to disclose how the two are closely interwoven in prototyping activities and how the reflexive conversation of prototyping breaks down boundaries between the cognitive, the physical, and the social. New philosophical, ontological, and epistemological perspectives may thus represent an important avenue of research related to prototyping.	How do prototyping activities manifest in different philosophical, ontological, and epistemological perspectives? What new aspects of prototyping can be disclosed through application of an alternative philosophical approach to predominant dualist ontologies?

research designs will benefit the field – whether experimental, qualitative, or quantitative in nature. Such research will also advance the field's ability to provide scientifically based insights on the generalizability and transferability of modes of prototyping across domains – and, importantly, the potential downsides of prototyping (see e.g. Zuzul, 2019; Elsbach & Flynn, 2013). Prototyping comes in many forms and with many purposes not easily reduced to simple recipes for success, as BenMahmoud-Jouini and Midler (2020) and others have reported. Some caution is therefore warranted with regard to the sometimes generic depiction of prototyping in practitioner literature on lean startups or sprints, for example, that originates from specific industries and technology sectors.

The third central suggestion revolves around the need for philosophical grounding of the research in nondualist ontologies. The reason for this is the need to be able to explore the dynamics between the proposed aggregate dimensions in an integrated way. Dualist ontologies, with their sharp distinction between an individualized and mental subjectivity and a given objective external reality, will struggle to disclose how the two are closely interwoven in prototyping activities and how the reflexive conversation of prototyping breaks down boundaries between the cognitive, the physical, and the social (Ammon, 2017). One promising example of how nondualist ontologies can pave new avenues for research is the adoption of Herbert Simon's design perspective in management research (Berglund et al., 2020; Dimov, 2016; Ding, 2019; Selden & Fletcher, 2019; Simon, 1996; Visser, 2006). Here, prototyping can be conceptualized as mediating between inner and outer systems through mediating artifacts, which opens a fresh perspective on how prototyping can enable for example opportunity design, idea and uncertainty management, innovation, and other important managerial objectives (Berglund et al., 2020; Berglund & Glaser, 2022; Petrakis et al., 2021).

These suggestions are by no means exhaustive, and there is much to be disclosed and uncovered in our understanding of prototyping in management. Our review hopefully provides a first overview that identifies some overall themes and trends in the otherwise fragmented and heterogeneous research landscape. Our suggestions in formulating future directions for research is an attempt at inspiring and setting some direction for a distinct and focused effort to further expand and integrate research at the intersection of prototyping and management (Table 3).

5.1.3. Implications for practice

The review of the literature has not led to direct and unequivocal practical directions for managers looking to prototype. For this, the landscape is too broad, the prototyping approaches too many, and the domains of applications too diverse. Indeed, the strengthening of situated and domain-specific insights into the mechanisms and dynamics of successful prototyping (through e.g. comparative research designs) is a key component of the future research agenda we offer.

However, we believe there may be substantial practical value for managers, entrepreneurs, innovators, facilitators, and educators working with prototypes in reflecting on the definition and dimensions of the review. In particular, practitioners will do well to follow the research literature in seeing prototyping as a purposeful process in which the intentionality built into the process takes precedence over the specific characteristics and attributes of the prototype as a "thing." Making sure that prototypes are enacted in ways that capture the focal critical aspects of the idea will likely be essential for a successful prototyping process. Furthermore, exploring the diversity of purposes, practices, and

outcomes described in the seven themes that summarize the literature reviewed may help prospective prototypers be inspired to explore new approaches to prototyping and enhance the value of prototyping in organizational settings. In particular, it may help inspire critical reflection on and expansion of the somewhat narrow prescriptive models associated with for instance the lean startup and other popular frameworks used by managers, entrepreneurs, innovators, and educators.

6. Conclusion

In this paper, we used an inductive approach to review management research on prototyping, outlining a broad and fragmented landscape. On the basis of the review, we offered a definition of prototyping as the *intentional generation and use of representational artifacts that embody critical aspects of ideas to assist in managerial and organizational processes*. This definition provided a conceptual lens for the inductive, integrative literature review as well as a starting point for further knowledge building by pointing to research avenues and indicating boundary conditions for prototyping research, which are broad enough to accommodate the current and future heterogeneity of prototypes and prototyping. Our integrative review also provided a thematic overview of the central themes and aggregate dimensions in the form of cognitive externalization, conative interaction, and organizational outcomes. These were organized into a conceptual framework from which we derived future avenues and questions for research.

CRediT authorship contribution statement

Steffen Paust: Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Claus Thrane:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Steffen Korsgaard:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jbvd.2025.100026.

Data availability

Data will be made available on request.

References

Akgün, A. E., Lynn, G. S., & Yilmaz, C. (2006). Learning process in new product development teams and effects on product success: A socio-cognitive perspective. *Industrial Marketing Management, 35*(2), 210–224. https://doi.org/10.1016/j.indmarman.2005.02.005

Alavi, M. (1984). An assessment of the prototyping approach to information systems development. *Communications of the ACM, 27*(6), 556–563. https://doi.org/10.1145/358080.358095

Ammon, S. (2017). Why designing is not experimenting: Design methods, epistemic praxis and strategies of knowledge acquisition in architecture. *Philosophy and Technology, 30*(4), 495–520. https://doi.org/10.1007/s13347-017-0256-4

Anderson, C. (2012). *Makers: The new industrial revolution*. Crown Business.

Andries, P., Debackere, K., & Van Looy, B. (2013). Simultaneous experimentation as a learning strategy: Business model development under uncertainty. *Strategic Entrepreneurship Journal, 7*(4), 288–310. https://doi.org/10.1002/sej.1170

Atilola, O., Tomko, M., & Linsey, J. S. (2016). The effects of representation on idea generation and design fixation: A study comparing sketches and function trees. *Design Studies, 42*, 110–136. https://doi.org/10.1016/j.destud.2015.10.005

Auernhammer, J. (2020). Design Research in Innovation Management: A pragmatic and human-centered approach. *R&D Management, 50*(3), 412–428. https://doi.org/10.1111/radm.12409

Auernhammer, J., & Roth, B. (2021). The origin and evolution of Stanford University's design thinking: From product design to design thinking in innovation management. *Journal of Product Innovation Management, 38*(6), 623–644. https://doi.org/10.1111/jpim.12594

Barati, B., Karana, E., & Hekkert, P. (2019). Prototyping materials experience: Towards a shared understanding of underdeveloped smart material composites. *International Journal of Design, 13*(2), 21–38.

Beaudouin-Lafon, M., & Mackay, W. (2003). Prototyping tools and techniques. *The human-computer interaction handbook: Fundamentals, evolving technologies and emerging applications* (2nd ed., pp. 1006–1031). Lawrence Erlbaum Associates. https://doi.org/10.1201/9781420088892

Bechky, B. A. (2003a). Object lessons: Workplace artifacts as representations of occupational jurisdiction. *American Journal of Sociology, 109*(3), 720–752. https://doi.org/10.1086/379527

Bechky, B. A. (2003b). Sharing meaning across occupational communities: The transformation of understanding on a production floor. *Organization Science, 14*(3), 312–330. https://doi.org/10.1287/orsc.14.3.312.15162

BenMahmoud-Jouini, S., & Midler, C. (2020). Unpacking the notion of prototype archetypes in the early phase of an innovation process. *Creativity and Innovation Management, 29*(1), 49–71. https://doi.org/10.1111/caim.12358

BenMahmoud-Jouini, S., Midler, C., Cruz, V., & Gaudron, N. (2014). Creative artefacts: How stimulators, demonstrators and prototypes contribute to the creative processes? *Academy of Management Proceedings, 2014*(1). https://doi.org/10.5465/ambpp.2014.14113abstract

Berends, H., Smits, A., Reymen, I., & Podoynitsyna, K. (2016). Learning while (re) configuring: Business model innovation processes in established firms. *Strategic Organization, 14*(3), 181–219. https://doi.org/10.1177/1476127016632758

Berglund, A., & Leifer, L. (2013). Why we prototype! an international comparison of the linkage between embedded knowledge and objective learning. *Engineering Education, 8*(1), 2–15. https://doi.org/10.11120/ened.2013.00004

Berglund, H., Bousfiha, M., & Mansoori, Y. (2020). Opportunities as artifacts and entrepreneurship as design. *Academy of Management Review, 45*(4), 825–846. https://doi.org/10.5465/amr.2018.0285

Berglund, H., Dimov, D., & Wennberg, K. (2018). Beyond bridging rigor and relevance: The three-body problem in entrepreneurship. *Journal of Business Venturing Insights, 9* (February), 87–91. https://doi.org/10.1016/j.jbvi.2018.02.001

Berglund, H., & Glaser, V. L. (2022). The artifacts of entrepreneurial practice. In N. A. Thompson, O. Byrne, A. Jenkins, & B. T. Teague (Eds.), *Research handbook on entrepreneurship as practice* (pp. 168–186). Edward Elgar Publishing.

Beynon-Davies, P., Tudhope, D., & Mackay, H. (1999). Information systems prototyping in practice. *Journal of Information Technology, 14*(1), 107–120. https://doi.org/10.1080/026839699344782

Bischofberger, W. R., & Pomberger, G. (1992). *Prototyping-oriented software development*. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-84760-8

Bland, D. J., & Osterwalder, A. (2019). *Testing business ideas*. John Wiley and Sons.

Blank, S. (2013). Why the lean start up changes everything. *Harvard Business Review, 91* (5), 64. https://doi.org/10.1109/Agile.2012.18

Blomkvist, J., & Holmlid, S. (2011). Existing prototyping perspectives: Considerations for service design. In *Proceedings of the nordic design research conference* (pp. 1–10).

Blomkvist, J., & Segelström, F. (2014). Benefits of external representations in service design: A distributed cognition perspective. *The Design Journal, 17*(3), 331–346. https://doi.org/10.2752/175630614X13982745782849

Boer, L., Donovan, J., & Buur, J. (2013). Challenging industry conceptions with provotypes. *CoDesign, 9*(2), 73–89. https://doi.org/10.1080/15710882.2013.788193

Bogers, M., & Horst, W. (2014). Collaborative prototyping: Cross-fertilization of knowledge in prototype-driven problem solving. *Journal of Product Innovation Management, 31*(4), 744–764. https://doi.org/10.1111/jpim.12121

Boland, R. J., & Collopy, F. (2004). *Managing as designing*. Stanford Business Books.

Brenner, W., & Uebernickel, F. (2016). *Design thinking for innovation*. Cham, Switzerland: Springer Verlag.

Bresciani, S., & Eppler, M. J. (2015). The pitfalls of visual representations. *Sage Open, 5* (4), 1–14. https://doi.org/10.1177/2158244015611451

Brix, J. (2017). Exploring knowledge creation processes as a source of organizational learning: A longitudinal case study of a public innovation project. *Scandinavian Journal of Management, 33*(2), 113–127. https://doi.org/10.1016/j.scaman.2017.05.001

Brooks, H., & Aitchison, D. (2010). A review of state-of-the-art large-sized foam cutting rapid prototyping and manufacturing technologies. *Rapid Prototyping Journal, 16*(5), 318–327. https://doi.org/10.1108/13552541011065713

Browder, R. E., Aldrich, H., & Bradley, S. W. (2017). Entrepreneurship research, makers, and the Maker movement. *Academy of Management Proceedings, 2017*(1), 14361. https://doi.org/10.5465/AMBPP.2017.14361abstract

Brown, T. (2009). *Change by design: How design thinking transforms organizations and inspires innovation*. Harpercollins Publishers Inc.

Brunswicker, S., Wrigley, C., & Bucolo, S. (2013). Business model experimentation: What is the role of design-led prototyping in developing novel Business models? In M. Curley, & P. Formica (Eds.), *The experimental nature of new venture creation capitalizing on open innovation 2.0* (pp. 139–151). Springer International Publishing Switzerland. https://doi.org/10.1007/978-3-319-00179-1_13.

Buchenau, M., & Suri, J. F. (2000). Experience prototyping. In *Proceedings of the conference on designing interactive systems processes, practices, methods, and techniques - DIS '00* (pp. 424–433). https://doi.org/10.1145/347642.347802

Budde, R., Kuhlenkamp, K., Mathiassen, L., Züllighoven, H., & Züllinghoven, H. (1984). *Approaches to prototyping*. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-69796-8

Buxton, Bill. (2007). *Sketching user experiences*. Morgan Kaufmann.

Callahan, J. L. (2010). Constructing a manuscript: Distinguishing integrative literature reviews and conceptual and theory articles. *Human Resource Development Review, 9*(3), 300–304. https://doi.org/10.1177/1534484310371492

Camburn, B., Dunlap, B. U., Kuhr, R., Viswanathan, V. K., Linsey, J. S., Jensen, D. D., et al. (2013). Methods for prototyping strategies in conceptual phases of design: Framework and experimental assessment. In *, 5. Proceedings of the ASME 2013 international design engineering technical conferences and computers and information in engineering conference* (pp. 1–10). https://doi.org/10.1115/DETC2013-13072

Camburn, B., Viswanathan, V., Linsey, J., Anderson, D., Jensen, D., Crawford, R., et al. (2017). Design prototyping methods: State of the art in strategies, techniques, and guidelines. *Design Science, 3*(13), e13. https://doi.org/10.1017/dsj.2017.10

Camburn, B., & Wood, K. (2018). Principles of maker and DIY fabrication: Enabling design prototypes at low cost. *Design Studies, 58*, 63–88. https://doi.org/10.1016/j.destud.2018.04.002

Camere, S., & Bordegoni, M. (2016). A lens on future products: An expanded notion of prototyping practice. In *, 84. Proceedings of the international design conference, DESIGN, DS* (pp. 155–164).

Camuffo, A., Cordova, A., Gambardella, A., & Spina, C. (2019). A scientific approach to entrepreneurial decision making: Evidence from a randomized control trial. *Management Science*, 1–23. https://doi.org/10.1287/mnsc.2018.3249. *November*.

Cardella, M. E., Atman, C. J., & Adams, R. S. (2006). Mapping between design activities and external representations for engineering student designers. *Design Studies, 27*(1), 5–24. https://doi.org/10.1016/j.destud.2005.05.001

Carfagni, M., Fiorineschi, L., Furferi, R., Governi, L., & Rotini, F. (2020). Usefulness of prototypes in conceptual design: Students' view. *International Journal on Interactive Design and Manufacturing, 14*(4), 1305–1319. https://doi.org/10.1007/s12008-020-00697-2

Carlile, P. R. (2002). A pragmatic view of knowledge and boundaries: Boundary objects in new product development. *Organization Science, 13*(4), 442–455. https://doi.org/10.1287/orsc.13.4.442.2953

Carlile, P. R. (2004). Transferring, translating, and transforming: An integrative framework for managing knowledge across boundaries. *Organization Science, 15*(5), 555–568. https://doi.org/10.1287/orsc.1040.0094

Cartel, M., Boxenbaum, E., & Aggeri, F. (2018). Just for fun! how experimental spaces stimulate innovation in institutionalized fields. *Organization Studies*. https://doi.org/10.1177/0170840617736937

Cecil, J., & Kanchanapiboon, A. (2007). Virtual engineering approaches in product and process design. *International Journal of Advanced Manufacturing Technology, 31*(9–10), 846–856. https://doi.org/10.1007/s00170-005-0267-7

Christiansen, J. K., & Gasparin, M. (2017). How experiments in the fuzzy front end using prototyping generates new options. *CERN IdeaSquare Journal of Experimental Innovation, 1*(1), 35. https://doi.org/10.23726/cij.2017.463

Christie, E., Jensen, D., Buckley, R., Menefee, D., Ziegler, K., Wood, K., et al. (2012). Prototyping strategies: Literature review and identification of critical variables. In *Proceedings of the 2012 ASEE annual conference & exposition proceedings*. https://doi.org/10.18260/1-2-21848, 25.1091.1–25.1091.22.

Clark, A., & Chalmers, D. (1998). The extended mind. *Analysis, 58*(1), 7–19.

Cohen, S. L., Bingham, C. B., & Hallen, B. L. (2019). The role of accelerator designs in mitigating bounded rationality in new ventures. *Administrative Science Quarterly, 64*(4), 810–854. https://doi.org/10.1177/0001839218782131

Comi, A., & Whyte, J. (2018). Future making and visual artefacts: An ethnographic study of a design project. *Organization Studies, 39*(8), 1055–1083. https://doi.org/10.1177/0170840617717094

Cornelissen, J. P. (2013). Portrait of an entrepreneur: Vincent van Gogh, Steve Jobs, and the entrepreneurial imagination. *Academy of Management Review, 38*(4), 700–709. https://doi.org/10.5465/amr.2013.0068

Coughlan, P., Suri, J. F., & Canales, K. (2007). Prototypes as (Design) tools for behavioral and organizational change: A design-based approach to help organizations change work behaviors. *Journal of Applied Behavioral Science, 43*(1), 122–134. https://doi.org/10.1177/0021886306297722

Coutts, E. R., Wodehouse, A., & Robertson, J. (2019). A comparison of contemporary prototyping methods. In *, 1. Proceedings of the 22nd international conference on engineering design (ICED19)* (pp. 1313–1322). https://doi.org/10.1017/dsi.2019.137

Crilly, N. (2010). The roles that artefacts play: Technical, social and aesthetic functions. *Design Studies, 31*(4), 311–344. https://doi.org/10.1016/j.destud.2010.04.002

Cronin, M. A., & George, E. (2023). The why and how of the integrative review. *Organizational Research Methods, 26*(1), 168–192.

Cross, N. (2006). *Designerly ways of knowing*. Springer-Verlag. https://doi.org/10.1007/1-84628-301-9

D'Adderio, L. (2001). Crafting the virtual prototype: How firms integrate knowledge and capabilities across organisational boundaries. *Research Policy, 30*(9), 1409–1424. https://doi.org/10.1016/S0048-7333(01)00159-7

Danholt, P. (2005). Prototypes as performative. In *Proceedings of the 4th decennial aarhus conferenc on critical computing - between sense and sensibility* (pp. 1–8). https://doi.org/10.1145/1094562.1094564

Deininger, M., Daly, S. R., Sienko, K. H., & Lee, J. C. (2017). Novice designers' use of prototypes in engineering design. *Design Studies, 51*, 25–65. https://doi.org/10.1016/j.destud.2017.04.002

Demil, B., & Lecocq, X. (2015). Crafting an innovative business model in an established company: The role of artifacts. *Advances in Strategic Management, 33*(December), 31–58. https://doi.org/10.1108/S0742-332220150000033003

Dew, N., Grichnik, D., Mayer-Haug, K., Read, S., & Brinckmann, J. (2015). Situated entrepreneurial cognition. *International Journal of Management Reviews, 17*(2), 143–164. https://doi.org/10.1111/ijmr.12051

Ding, T. (2019). Understanding the design of opportunities: Re-evaluating the agent-opportunity nexus through a design lens. *Journal of Business Venturing Insights, 11*(December), e00108. https://doi.org/10.1016/j.jbvi.2018.e00108

Djurić, D. (2015). *Strategy tools as symbolic objects in managerial language games*. Springer Fachmedien Wiesbaden. https://doi.org/10.1007/978-3-658-09665-6

Doganova, L., & Eyquem-Renault, M. (2009). What do business models do? *Research Policy, 38*(10), 1559–1570. https://doi.org/10.1016/j.respol.2009.08.002

Doke, E. R., & Swanson, N. E. (1995). Decision variables for selecting prototyping in information systems development: A Delphi study of MIS managers. *Information and Management, 29*(4), 173–182. https://doi.org/10.1016/0378-7206(95)00021-N

Dow, S. P., Glassco, A., Kass, J., Schwarz, M., Schwartz, D. L., & Klemmer, S. R. (2012). Parallel prototyping leads to better design results, more divergence, and increased self-efficacy. In H. Plattner, et al. (Eds.), *17(4). Design Thinking Research, Understanding Innovation, Springer-Verlag Berlin Heidelberg 2012* (pp. 127–153). Design Thinking Research: Studying Co-Creation in Practice. doi:10.1007/978-3-642-21643-5_8.

Dow, S. P., Heddleston, K., & Klemmer, S. R. (2009). The efficacy of prototyping under time constraints. In *Proceeding of the 7th ACM conference on creativity and cognition - C&C '09* (p. 165). https://doi.org/10.1145/1640233.1640260

Elsbach, K. D., & Flynn, F. J. (2013). Creative collaboration and the self-concept: A study of toy designers. *Journal of Management Studies, 50*(4), 515–544.

Elsbach, K. D., & van Knippenberg, D. (2020). Creating high-impact literature reviews: An argument for 'integrative reviews. *Journal of Management Studies*, 95616. https://doi.org/10.1111/joms.12581

Elverum, C. W., & Welo, T. (2014). The role of early prototypes in concept development: Insights from the automotive industry. *Procedia CIRP, 21*, 491–496. https://doi.org/10.1016/j.procir.2014.03.127

Elverum, C. W., & Welo, T. (2016). Leveraging prototypes to generate value in the concept-to-production process: A qualitative study of the automotive industry. *International Journal of Production Research, 54*(10), 3006–3018. https://doi.org/10.1080/00207543.2016.1152406

Eppler, M. J., Hoffmann, F., & Bresciani, S. (2011). New business models through collaborative idea generation. *International Journal of Innovation Management, 15*(6), 1323–1341. https://doi.org/10.1142/S1363919611003751

Eppler, M. J., & Kernbach, S. (2016). Dynagrams: Enhancing design thinking through dynamic diagrams. *Design Studies, 47*, 91–117.

Eppler, M. J., & Pfister, R. (2011). Sketching as a tool for knowledge management. In *Proceedings of the 11th international conference on knowledge management and knowledge technologies - i-KNOW '11* (p. 1). https://doi.org/10.1145/2024288.2024301

Eppler, M. J., & Platts, K. W. (2009). Visual strategizing: The systematic use of visualization in the strategic-planning process. *Long Range Planning, 42*(1), 42–74. https://doi.org/10.1016/j.lrp.2008.11.005

Erichsen, J. A. B., Pedersen, A. L., Steinert, M., & Welo, T. (2016). Learning in Product development: Proposed industry experiment using reflective prototyping. *Procedia CIRP, 50*(3), 454–459. https://doi.org/10.1016/j.procir.2016.04.142

Ewenstein, B., & Whyte, J. (2009). Knowledge practices in design: The role of visual representations as "epistemic objects". *Organization Studies, 30*(1), 7–30. https://doi.org/10.1177/0170840608083014

Felin, T., Gambardella, A., Stern, S., & Zenger, T. (2020). Lean startup and the business model: Experimentation revisited. *Long Range Planning, 53*(4), Article 101889. https://doi.org/10.1016/j.lrp.2019.06.002

Frederiksen, D. L., & Brem, A. (2017). How do entrepreneurs think they create value? A scientific reflection of Eric Ries' Lean Startup approach. *International Entrepreneurship and Management Journal, 13*(1), 169–189. https://doi.org/10.1007/s11365-016-0411-x

Freitas, G., Pinho, M. S., Silveira, M. S., & Maurer, F. (2020). A systematic review of rapid prototyping tools for augmented reality. In *Proceedings of the 2020 22nd symposium on virtual and augmented reality, SVR 2020* (pp. 199–209). https://doi.org/10.1109/SVR51698.2020.00041

García, L. M., Deserti, A., & Teixeira, C. (2017). Entrepreneurial design: The role of design as driver of entrepreneurial opportunity generation and assessment. *International Journal of Entrepreneurship and Innovation Management, 21*(1/2), 64–85. https://doi.org/10.1504/IJEIM.2017.081494

Gehman, J., Glaser, V. L., Eisenhardt, K. M., Gioia, D., Langley, A., & Corley, K. G. (2018). Finding theory–Method fit: A comparison of three qualitative approaches to theory building. *Journal of Management Inquiry, 27*(3), 284–300. https://doi.org/10.1177/1056492617706029

Gengnagel, C., Nagy, E., & Stark, R. (2016). *Rethink! prototyping*. Springer International Publishing. https://doi.org/10.1007/978-3-319-24439-6

Gerber, E. (2009). Prototyping: Facing uncertainty through small wins. In *Proceedings of the international conference on engineering design, ICED 09* (pp. 333–342).

Gerber, E., & Carroll, M. (2012). The psychological experience of prototyping. *Design Studies, 33*(1), 64–84. https://doi.org/10.1016/j.destud.2011.06.005

Gioia, D. A., Corley, K. G., & Hamilton, A. L. (2013). Seeking qualitative rigor in inductive research: Notes on the Gioia methodology. *Organizational Research Methods, 16*(1), 15–31. https://doi.org/10.1177/1094428112452151

Glaser, B. G. (1965). The constant Comparative method of qualitative analysis. *Social Problems, 12*(4), 436–445.

Glaser, B. G. (1967). Strauss. In *The Discovery of Grounded Theory*. Chicago: Aldine Publishing Company.

Goldsby, M. G., Kuratko, D. F., Marvel, M. R., & Nelson, T. (2017). Design-centered entrepreneurship: A four stage iterative process for opportunity development.

Journal of Small Business and Entrepreneurship, 29(6), 477–490. https://doi.org/10.1080/08276331.2017.1377396
Goldschmidt, G. (1994). On visual design thinking: The vis kids of architecture. *Design Studies, 15*(2), 158–174. https://doi.org/10.1016/0142-694X(94)90022-1
Goldschmidt, G. (2003). The backtalk of self-generated sketches. *Design Issues, 19*(1), 72–88.
Goldschmidt, G., & Smolkov, M. (2006). Variances in the impact of visual stimuli on design problem solving performance. *Design Studies, 27*(5), 549–569. https://doi.org/10.1016/j.destud.2006.01.002
Gomaa, H., & Scott, D. B. H. (1981). Prototyping as a tool in the specification of user requirements. In *Proceedings of the 5th international conference on software engineering ICSE '81* (pp. 333–342).
Gonçalves, M., Cardoso, C., & Badke-Schaub, P. (2014). What inspires designers? Preferences on inspirational approaches during idea generation. *Design Studies, 35*(1), 29–53. https://doi.org/10.1016/j.destud.2013.09.001
Groen, C., McNair, L. D., & Paretti, M. C. (2016). Prototypes and the politics of the artefact: Visual explorations of design interactions in teaching spaces. *CoDesign, 12*(1–2), 39–54. https://doi.org/10.1080/15710882.2015.1110178
Günzel-Jensen, F., Korsgaard, S., & Müller, S. (2014). A note of caution on systematic literature reviews in entrepreneurship research. In *Proceedings of the 59th international council for small business world conference*.
Gustavsson, M., & Säfsten, K. (2017). The learning potential of boundary crossing in the context of product introduction. *Vocations and Learning, 10*(2), 235–252. https://doi.org/10.1007/s12186-016-9171-6
Haefliger, S., Jäger, P., & Von Krogh, G. (2010). Under the radar: Industry entry by user entrepreneurs. *Research Policy, 39*(9), 1198–1213. https://doi.org/10.1016/j.respol.2010.07.001
Haggège, M., & Vernay, A. L. (2019). Story-making as a method for business modelling. *Business Process Management Journal, 26*(1), 59–79. https://doi.org/10.1108/BPMJ-12-2017-0363
Hampel, C., Perkmann, M., & Phillips, N. (2020). Beyond the lean start-up: Experimentation in corporate entrepreneurship and innovation. *Innovation, 22*(1), 1–11. https://doi.org/10.1080/14479338.2019.1632713
Hargadon, A. B., & Bechky, B. A. (2006). When collections of creatives become creative collectives: A field study of problem solving at work. *Organization Science, 17*(4), 484–500. https://doi.org/10.1287/orsc.1060.0200
Hargadon, A. B., & Sutton, R. I. (1997). Technology brokering and innovation in a product development firm. *Administrative Science Quarterly, 42*(4), 716. https://doi.org/10.2307/2393655
Hartmann, B., Klemmer, S. R., Bernstein, M., Abdulla, L., Burr, B., Robinson-Mosher, A., et al. (2006). Reflective physical prototyping through integrated design, test, and analysis. In *Proceedings of the 19th annual ACM symposium on user interface software and technology - UIST '06* (pp. 299–308). https://doi.org/10.1145/1166253.1166300
Henderson, K. (1991). Flexible sketches and inflexible data bases: Visual communication, conscription devices, and boundary objects in design engineering. *Science, Technology, & Human Values, 16*(4), 448–473.
Henderson, K. (1995). The political career of a prototype: Visual representation in design engineering. *Social Problems, 42*(2), 274–299. https://doi.org/10.2307/3096905
Houde, S., & Hill, C. (1997). What do prototypes prototype? In M. Helander, T. K. Landauer, & P. Prabhu (Eds.), *Handbook of human-computer interaction* (2nd ed., pp. 367–381). Elsevier Science. https://doi.org/10.1016/B978-044481862-1/50082-0.
Innella, G., & Rodgers, P. A. (2017). Making sense: Harnessing communication through prototyping. *The Design Journal, 20*(sup1), S1154–S1166. https://doi.org/10.1080/14606925.2017.1353058
Jacucci, G., & Wagner, I. (2007). Performative roles of materiality for collective creativity. In *Proceedings of the 6th ACM SIGCHI conference on creativity & cognition - C&C '07* (p. 73). https://doi.org/10.1145/1254960.1254971
Jangir, S. K. (2012). Evolution and melioration of software management processes. *International Journal of Software Engineering & Applications, 3*(1), 61–83. https://doi.org/10.5121/ijsea.2012.3106
Jarzabkowski, P., & Kaplan, S. (2015). Strategy tools-in-use: A framework for understanding "technologies of rationality" in practice. *Strategic Management Journal, 36*(4), 537–558. https://doi.org/10.1002/smj.2270
Jarzabkowski, P., L, J., & Spee, P. (2016). Taking a strong process approach to analyzing qualitative process data. *The sage handbook of process organization studies* (pp. 237–251). Sage Publications Ltd. https://doi.org/10.4135/9781473957954.n15. Issue.
Jarzabkowski, P., Spee, A. P., & Smets, M. (2013). Material artifacts: Practices for doing strategy with 'stuff.'. *European Management Journal, 31*(1), 41–54. https://doi.org/10.1016/j.emj.2012.09.001
Jensen, L. S., Özkil, A. G., & Mortensen, N. H. (2016). Prototypes in engineering design: Definitions and strategies. In *, 84. Proceedings of the international design conference, DESIGN, DS* (pp. 821–830).
Jensen, M. B., Balters, S., & Steinert, M. (2015). Measuring prototypes-a standardized quantitative description of prototypes and their outcome for data collection and analysis. In *, 2. Proceedings of the international conference on engineering design (ICED15)* (pp. 295–308).
Jensen, M. B., Elverum, C. W., & Steinert, M. (2017). Eliciting unknown unknowns with prototypes: Introducing prototrials and prototrial-driven cultures. *Design Studies, 49*, 1–31. https://doi.org/10.1016/j.destud.2016.12.002
Johnson, B. D. (2011). *Science fiction prototyping: Designing the future with science fiction*. Morgan and Claypool Publishers. https://doi.org/10.2200/S00336ED1V01Y201102CSL003
Jones, O., Macpherson, A., & Thorpe, R. (2010). Learning in owner-managed small firms: Mediating artefacts and strategic space. *Entrepreneurship and Regional Development, 22*(7), 649–673. https://doi.org/10.1080/08985620903171368
Junginger, S. (2007). Learning to design: Giving purpose to heart, hand and mind. *Journal of Business Strategy, 28*(4), 59–65. https://doi.org/10.1108/02756660710760953
Kelley, T. (2001). Prototyping is the shorthand of innovation. *Design Management Journal (Former Series), 12*(3), 35–42. https://doi.org/10.1111/j.1948-7169.2001.tb00551.x
Kier, A. S., & McMullen, J. S. (2018). Entrepreneurial imaginativeness in new venture ideation. *Academy of Management Journal, 61*(6), 2265–2295. https://doi.org/10.5465/amj.2017.0395
Kimbell, L. (2015). *Service innovation handbook*. BIS Publishers.
Kiriyama, T., & Yamamoto, T. (1998). Strategic knowledge acquisition: A case study of learning through prototyping. *Knowledge-Based Systems, 11*(7–8), 399–404. https://doi.org/10.1016/S0950-7051(98)00086-0
Kleinsmann, M., & ten Bhömer, M. (2020). The (New) roles of prototypes during the co-development of digital product service systems. *International Journal of Design, 14*(1), 65–79.
Knapp, J., Zeratsky, J., & Kowitz, B. (2016). *Sprint: How to solve big problems and test new ideas in just five days*. Simon and Schuster.
Knorr Cetina, K. (1997). Sociality with objects. *Theory, Culture & Society, 14*(4), 1–30. https://doi.org/10.1177/026327697014004001
Kohtamäki, M., Whittington, R., Vaara, E., & Rabetino, R. (2022). Making connections: Harnessing the diversity of strategy-as-practice research. *International Journal of Management Reviews, 24*(2), 210–232. https://doi.org/10.1111/ijmr.12274
Kondaveeti, H. K., Kumaravelu, N. K., Vanambathina, S. D., Mathe, S. E., & Vappangi, S. (2021). A systematic literature review on prototyping with Arduino: Applications, challenges, advantages, and limitations. *Computer Science Review, 40*, Article 100364. https://doi.org/10.1016/j.cosrev.2021.100364
Koning, R., Hasan, S., & Chatterji, A. (2022). Experimentation and start-up performance: Evidence from A/B testing. *Management Science, 68*(9), 6434–6453. https://doi.org/10.1287/mnsc.2021.4209
Lauff, C. A., Knight, D., Kotys-Schwartz, D., & Rentschler, M. E. (2020). The role of prototypes in communication between stakeholders. *Design Studies, 66*, 1–34. https://doi.org/10.1016/j.destud.2019.11.007
Lauff, C. A., Kotys-Schwartz, D., & Rentschler, M. E. (2018). What is a prototype? What are the roles of prototypes in companies? *Journal of Mechanical Design, 140*(6), Article 061102. https://doi.org/10.1115/1.4039340
Lawson, B. (2006). *How designers think: The design process demystified* (4th ed.). Elsevier Ltd.
Liao, Y., Liao, K., & Hutchinson, R. (2010). A conceptual framework for prototyping outsourcing in new product development: A knowledge-based view. *Journal of Manufacturing Technology Management, 21*(1), 122–138. https://doi.org/10.1108/17410381011011515
Liedtka, J. (2015). Perspective: Linking design thinking with innovation outcomes through cognitive bias reduction. *Journal of Product Innovation Management, 32*(6), 925–938. https://doi.org/10.1111/jpim.12163
Liedtka, J., & Ogilvie, T. (2011). *Designing for growth: A design thinking tool kit for managers*. Columbia University Press.
Lim, Y. K., Stolterman, E., & Tenenberg, J. (2008). The anatomy of prototypes. *ACM Transactions on Computer-Human Interaction, 15*(2), 1–27. https://doi.org/10.1145/1375761.1375762
Macpherson, A., & Jones, O. (2010). Editorial: Strategies for the development of International Journal of Management Reviews. *International Journal of Management Reviews, 12*(2), 107–113. https://doi.org/10.1111/j.1468-2370.2010.00282.x
Mansoori, Y. (2017). Enacting the lean startup methodology. *International Journal of Entrepreneurial Behavior & Research, 23*(5), 812–838. https://doi.org/10.1108/IJEBR-06-2016-0195
Mansoori, Y., & Lackéus, M. (2019). Comparing effectuation to discovery-driven planning, prescriptive entrepreneurship, business planning, lean startup, and design thinking. *Small Business Economics*. https://doi.org/10.1007/s11187-019-00153-w
McDonald, R. M., & Eisenhardt, K. M. (2020). Parallel play: Startups, nascent markets, and effective business-model design. *Administrative Science Quarterly, 65*(2), 483–523. https://doi.org/10.1177/0001839219852349
McElroy, K. (2017). *Prototyping for designers: Developing the best digital & physical products*. O'Reilly Media.
Menold, J., Jablokow, K., & Simpson, T. (2017). Prototype for X (PFX): A holistic framework for structuring prototyping methods to support engineering design. *Design Studies, 50*, 70–112. https://doi.org/10.1016/j.destud.2017.03.001
Menold, J., Simpson, T. W., & Jablokow, K. (2019). The prototype for X framework: Exploring the effects of a structured prototyping framework on functional prototypes. *Research in Engineering Design, 30*(2), 187–201. https://doi.org/10.1007/s00163-018-0289-4
Meyer, R. E., Höllerer, M. A., Jancsary, D., & van Leeuwen, T. (2013). The visual dimension in organizing, organization, and organization research: Core ideas, current developments, and promising avenues. *The Academy of Management Annals, 7*(1), 489–555. https://doi.org/10.1080/19416520.2013.781867
Miettinen, R., & Virkkunen, J. (2005). Epistemic objects, artefacts and organizational change. *Organization, 12*(3), 437–456. https://doi.org/10.1177/1350508405051279
Miles, M. B., Huberman, A. M., & Saldana, J. (2013). *Qualitative data analysis: A methods sourcebook* (3rd ed.). Sage Publications.
Mogensen, P. H. (1992). Towards a prototyping approach in systems development. *Scandinavian Journal of Information Systems, 4*, 31–53. https://doi.org/10.7146/dpb.v21i412.6725
Mueller, S., Volery, T., & von Siemens, B. (2012). What do entrepreneurs actually do? An observational study of entrepreneurs' everyday behavior in the start-up and growth

stages. *Entrepreneurship: Theory and Practice, 36*(5), 995–1017. https://doi.org/10.1111/j.1540-6520.2012.00538.x
Muñoz, R., & Miller-Jacobs, H. H. (1992). In search of the ideal prototype. In *Proceedings of the SIGCHI conference on human factors in computing systems - CHI '92* (pp. 577–579). https://doi.org/10.1145/142750.150712
Murray, F., & Tripsas, M. (2004). The exploratory processes of entrepreneurial firms: The role of purposeful experimentation. *Business Strategy over the Industry Lifecycle, 21*, 45–75. https://doi.org/10.1016/S0742-3322(04)21002-6
Nambisan, S., Wright, M., & Feldman, M. (2019). The digital transformation of innovation and entrepreneurship: Progress, challenges and key themes. *Research Policy, 48*(8), Article 103773. https://doi.org/10.1016/j.respol.2019.03.018
Naumann, J. D., & Jenkins, A. M. (1982). Prototyping: The new paradigm for systems development. *MIS Quarterly: Management Information Systems, 6*(3), 29–44. https://doi.org/10.2307/248654
Neeley, W. L., Lim, K., Zhu, A., & Yang, M. C. (2013). Building fast to think faster: Exploiting rapid prototyping to accelerate ideation during early stage design. In *, 5. Proceedings of the volume 5: 25th international conference on design theory and methodology; ASME 2013 power transmission and gearing conference*. https://doi.org/10.1115/DETC2013-12635
Nicolini, D., Mengis, J., & Swan, J. (2012). Understanding the role of objects in cross-disciplinary collaboration. *Organization Science, 23*(3), 612–629. https://doi.org/10.1287/orsc.1110.0664
Nielsen, S. L., Heidemann Lassen, A., Nielsen, L. M., & Mikkelsen, M. (2013). Opportunity design: Understanding entrepreneurial opportunities through design thinking. *International Entrepreneurship and Management Journal*.
Norman, D. A. (2013). *The design of everyday things: Revised and expanded edition*. Basic Books.
Orlikowski, W. J., & Scott, S. V. (2008). 10 Sociomateriality: Challenging the separation of technology, work and organization. *The Academy of Management Annals, 2*(1), 433–474. https://doi.org/10.1080/19416520802211644
Osterwalder, A., & Pigneur, Y. (2010). *Business model generation: A handbook for visionaries, game changers, and challengers* (1st ed.). John Wiley and Sons.
Otto, K., & Wood, K. (2001). *Product design: Techniques in reverse engineering and new product design*. Prentice-Hall.
Passera, S., Kaerkkaeinen, H., & Maila, R. (2012). When, how, why prototyping? A practical framework for service development. In *Proceedings of the ISPIM conference* (pp. 1–16).
Paust, S., Korsgaard, S., & Thrane, C. (2024). Entrepreneurial prototyping: the role of purpose, prototype recycling, and skills bricolage. *Small Business Economics*, 1–25.
Pershina, R., Soppe, B., & Thune, T. M. (2019). Bridging analog and digital expertise: Cross-domain collaboration and boundary-spanning tools in the creation of digital innovation. *Research Policy, 48*(9), Article 103819. https://doi.org/10.1016/j.respol.2019.103819
Petrakis, K., Wodehouse, A., & Hird, A. (2021). Prototyping-driven entrepreneurship: Towards a Prototyping support tool based on design thinking principles. *The Design Journal, 24*(5), 761–781. https://doi.org/10.1080/14606925.2021.1957531
Pfister, R. A., & Eppler, M. J. (2012). The benefits of sketching for knowledge management. *Journal of Knowledge Management, 16*(2), 372–382. https://doi.org/10.1108/13673271211218924
Polydoras, S., Sfantsikopoulos, M., & Provatidis, C. (2011). Rational embracing of modern prototyping capable design technologies into the tools pool of product design teams. *ISRN Mechanical Engineering, 2011*, 1–12. https://doi.org/10.5402/2011/739892
Post, C., Sarala, R., Gatrell, C., & Prescott, J. E. (2020). Advancing theory with review articles. *Journal of Management Studies, 57*(2), 351–376. https://doi.org/10.1111/joms.12549
Poznic, M., Stacey, M., Hillerbrand, R., & Eckert, C. (2020). Designing as playing games of make-believe. *Design Science, 6*, e10. https://doi.org/10.1017/dsj.2020.8
Rae, D. (2007). *Entrepreneurship: From opportunity to action*. Palgrave Macmillan.
Ranscombe, C., Bissett-Johnson, K., Mathias, D., Eisenbart, B., & Hicks, B. (2020). Designing with LEGO: Exploring low fidelity visualization as a trigger for student behavior change toward idea fluency. *International Journal of Technology and Design Education, 30*(2), 367–388. https://doi.org/10.1007/s10798-019-09502-y
Rauch, A. (2020). Opportunities and threats in reviewing entrepreneurship theory and practice. *Entrepreneurship Theory and Practice, 44*(5), 847–860. https://doi.org/10.1177/1042258719879635
Ravn, P. M., Gudlaugsson, T. V., & Mortensen, N. H. (2016). A multi-layered approach to product architecture modeling: Applied to technology prototypes. *Concurrent Engineering, 24*(1), 3–16. https://doi.org/10.1177/1063293X15590843
Rayna, T., & Striukova, L. (2016). From rapid prototyping to home fabrication: How 3D printing is changing business model innovation. *Technological Forecasting and Social Change, 102*, 214–224. https://doi.org/10.1016/j.techfore.2015.07.023
Rayna, T., & Striukova, L. (2021). Assessing the effect of 3D printing technologies on entrepreneurship: An exploratory study. *Technological Forecasting and Social Change, 164*(December 2020), Article 120483. https://doi.org/10.1016/j.techfore.2020.120483
Redeker, F., Schepurek, S., Golovatchev, J., & Schön, A. (2015). Early prototyping for organisational learning in uncertain environments. In *Proceedings of the ISPIM conference* (pp. 1–26) (The International Society for Professional Innovation Management)*June*.
Rettig, M. (1994). Prototyping for tiny fingers. *Communications of the ACM, 37*(4), 21–27. https://doi.org/10.1145/175276.175288
Rhinow, H., Köppen, E., & Meinel, C. (2012). Design prototypes as boundary objects in innovation processes. In *Proceedings of the 2012 international conference on design research society (DRS 2012)* (pp. 1–10). July.
Ries, E. (2011). *The lean startup: How constant innovation creates radially successful companies*. Portfolio Penguin.
Roberts, J. P., & Middleton, A. (2014). Evolving products: From human design to self-organisation via Science Fiction prototyping. *Technological Forecasting and Social Change, 84*, 15–28. https://doi.org/10.1016/j.techfore.2013.09.003
Saari, M., bin Baharudin, A. M., & Hyrynsalmi, S. (2017). Survey of prototyping solutions utilizing Raspberry Pi. In *Proceedings of the 40th international convention on information and communication technology, electronics and microelectronics (MIPRO)* (pp. 991–994). https://doi.org/10.23919/MIPRO.2017.7973568
Saldana, J. (2015). *The coding manual for qualitative researchers* (3rd ed.). SAGE Publications Ltd.
Sanders, E. B. N., & Stappers, P. J. (2014). Probes, toolkits and prototypes: Three approaches to making in codesigning. *CoDesign, 10*(1), 5–14. https://doi.org/10.1080/15710882.2014.888183
Sass, L., & Oxman, R. (2006). Materializing design: The implications of rapid prototyping in digital design. *Design Studies, 27*(3), 325–355. https://doi.org/10.1016/j.destud.2005.11.009
Savoia, A. (2011). Pretotype it (2nd ed.).
Schön, D. A. (1983). *The reflective practitioner: How professionals think in action*. Basic Books.
Schön, D. A., & Wiggins, G. (1992). Kinds of seeing in designing. *Creativity and Innovation Management, 1*(2), 68–74. https://doi.org/10.1111/j.1467-8691.1992.tb00031.x
Schrage, M. (1999). *Serious play: How the world's best companies simulate to innovate*. Harvard Business Review Press.
Seeling, T. (2015). *Insight out: Get ideas out of your head and into the world*. Harper Collins.
Seidel, V. P., & O'Mahony, S. (2014). Managing the repertoire: Stories, metaphors, prototypes, and concept coherence in product innovation. *Organization Science, 25*(3), 691–712. https://doi.org/10.1287/orsc.2013.0879
Seidenstricker, S., Scheuerle, S., & Linder, C. (2014). Business model prototyping – Using the morphological analysis to develop new Business models. *Procedia - Social and Behavioral Sciences, 148*, 102–109. https://doi.org/10.1016/j.sbspro.2014.07.023
Selden, P. D., & Fletcher, D. E. (2019). The tacit knowledge of entrepreneurial design: Interrelating theory, practice and prescription in entrepreneurship research. *Journal of Business Venturing Insights, 11*, e00122. https://doi.org/10.1016/j.jbvi.2019.e00122. October 2018.
Sheridan, K. K., Halverson, E. R., Litts, B., Brahms, L., Jacobs-Priebe, L., & Owens, T. (2014). Learning in the making: A comparative case study of three makerspaces. *Harvard Educational Review, 84*(4), 505–531. https://doi.org/10.17763/haer.84.4.brr34733723j648u
Silva, A., Henriques, E., & Carvalho, A. (2009). Creativity enhancement in a product development course through entrepreneurship learning and intellectual property awareness. *European Journal of Engineering Education, 34*(1), 63–75. https://doi.org/10.1080/03043790802710201
Simon, H. A. (1996). *The sciences of the artificial* (3rd ed.). The MIT Press.
Smith, P. M. (1985). A prototyping case study. *Journal of Information Systems Management, 2*(3), 20–25. https://doi.org/10.1080/07399018508967765
Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research, 104*(July), 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039
Sosna, M., Trevinyo-Rodríguez, R. N., & Velamuri, S. R. (2010). Business model innovation through trial-and-error learning: The naturhouse case. *Long Range Planning, 43*(2–3), 383–407. https://doi.org/10.1016/j.lrp.2010.02.003
Spee, A. P., & Jarzabkowski, P. (2009). Strategy tools as boundary objects. *Strategic Organization, 7*(2), 223–232. https://doi.org/10.1177/1476127009102674
Stein Dani, V., Dal Sasso Freitas, C. M., & Thom, L. H. (2019). Ten years of visualization of business process models: A systematic literature review. *Computer Standards and Interfaces, 66*(April), Article 103347. https://doi.org/10.1016/j.csi.2019.04.006
Stevens, E. (2014). Fuzzy front-end learning strategies: Exploration of a high-tech company. *Technovation, 34*(8), 431–440. https://doi.org/10.1016/j.technovation.2013.12.006
Stoll, H. W. (1999). *Product design methods and practices*. CRC Press.
Suwa, M., & Tversky, B. (1997). What do architects and students perceive in their design sketches? A protocol analysis. *Design Studies, 18*(4), 385–403.
Suwa, M., & Tversky, B. (2002). External representations contribute to the dynamic construction of ideas. In *Proceedings of the second international conference on diagrammatic representation and inference (DIAGRAMS '02), LNAI 2317* (pp. 341–343).
Thomke, S. H. (2001). Enlightened Experimentation: The new imperative for innovation. *Harvard Business Review, 79*(2), 66–75.
Thomke, S. H. (2020). *Experimentation works: The surprising power of business experiments*. Harvard Business Review Press.
Thomke, S. H., & Bell, D. E. (2001). Sequential testing in product development. *Management Science, 47*(2), 308–323.
Thomke, S. H., & Manzi, J. (2014). The discipline of business experimentation. *Harvard Business Review, 92*(12).
Thomke, S. H., von Hippel, E., & Franke, R. (1998). Modes of experimentation: An innovation process—And competitive—Variable. *Research Policy, 27*(3), 315–332. https://doi.org/10.1016/S0048-7333(98)00041-9
Toward a design science of entrepreneurship. / Dimov, Dimo. Models of Start-Up Thinking and Action: Theoretical, Empirical and Pedagogical Approaches. ed. / J. A. Katz; A. C. Corbett. Bingley, U. K.: Emerald Group Publishing Ltd., 2016. p. 1-31 (Advances in Entrepreneurship, Firm Emergence and Growth; Vol. 18).
Torraco, R. J. (2005). Writing integrative literature reviews: Guidelines and examples. *Human Resource Development Review, 4*(3), 356–367. https://doi.org/10.1177/1534484305278283

Torraco, R. J. (2016). Writing integrative literature reviews: Using the past and present to explore the future. *Human Resource Development Review, 15*(4), 404–428. https://doi.org/10.1177/1534484316671606

Tory, M., Staub-French, S., Po, B. A., & Wu, F. (2008). Physical and digital artifact-mediated coordination in building design. *Computer Supported Cooperative Work, 17*(4), 311–351. https://doi.org/10.1007/s10606-008-9077-4

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *British Journal of Management, 14*(3), 207–222. https://doi.org/10.1111/1467-8551.00375

Ulrich, K. T., & Eppinger, S. D. (2012). *Product design and development* (5th ed.). McGraw-Hill Higher Education.

Villa Alvarez, D., Auricchio, V., and Mortati, M. (2020) Design prototyping for policymaking, in Boess, S., Cheung, M. and Cain, R. (eds.), Synergy - DRS International Conference 2020, 11-14 August, Held online. https://doi.org/10.21606/drs.2020.271.

Visser, W. (2006). Designing as construction of representations: A dynamic viewpoint in cognitive design research. *Human–Computer Interaction, 21*(1), 103–152. https://doi.org/10.1207/s15327051hci2101_4

Viswanathan, V., Atilola, O., Goodman, J., & Linsey, J. (2014). Prototyping: A key skill for innovation and life-long learning. In *Proceedings of the 2014 IEEE frontiers in education conference (FIE)* (pp. 1–8). https://doi.org/10.1109/FIE.2014.7044423, 2015-FebruFebruary.

Viswanathan, V., & Linsey, J. (2013). Examining design fixation in engineering idea generation: The role of example modality. *International Journal of Design Creativity and Innovation, 1*(2), 109–129. https://doi.org/10.1080/21650349.2013.774689

Vyas, D., Heylen, D., Nijholt, A., & van der Veer, G (2009). Experiential role of artefacts in cooperative design. In *Proceedings of the fourth international conference on communities and technologies - C&T '09* (p. 105). https://doi.org/10.1145/1556460.1556477

Wall, M. B., Ulrich, K. T., & Flowers, W. C. (1992). Evaluating prototyping technologies for product design. *Research in Engineering Design, 3*(3), 163–177. https://doi.org/10.1007/BF01580518

Wang, G. G. (2002). Definition and review of virtual prototyping. *Journal of Computing and Information Science in Engineering, 2*(3), 232–236. https://doi.org/10.1115/1.1526508

Warfel, T. Z. (2009). *Prototyping: A practitioner's guide*. Rosenfeld Media.

Wensveen, S., & Matthews, B. (2015). Prototypes and prototyping in design research. In P. A. Rodgers, & J. Yee (Eds.), *The routledge companion to design research* (pp. 262–276). Routledge.

Wessel, M., Thies, F., & Benlian, A. (2022). The role of prototype fidelity in technology crowdfunding. *Journal of Business Venturing, 37*(4), Article 106220. https://doi.org/10.1016/j.jbusvent.2022.106220

Whittemore, R., & Knafl, K. (2005). The integrative review: Updated methodology. *Journal of Advanced Nursing, 52*(5), 546–553. https://doi.org/10.1111/j.1365-2648.2005.03621.x

Whyte, J., Ewenstein, B., Hales, M., & Tidd, J. (2008). Visualizing knowledge in project-based work. *Long Range Planning, 41*(1), 74–92. https://doi.org/10.1016/j.lrp.2007.10.006

Winner, L. (1980). Do artifacts have politics? *Modern Technology: Problem or Opportunity?, 109*(1), 121–136.

Wouters, M., & Roijmans, D. (2011). Using prototypes to induce experimentation and knowledge integration in the development of enabling accounting information*. *Contemporary Accounting Research, 28*(2), 708–736. https://doi.org/10.1111/j.1911-3846.2010.01055.x

Wrigley, C., Bucolo, S., & Straker, K. (2016). Designing new business models: Blue sky thinking and testing. *Journal of Business Strategy, 37*(5), 22–31. https://doi.org/10.1108/JBS-04-2015-0041

Yan, X., & Gu, P. (1996). A review of rapid prototyping technologies and systems. *CAD Computer Aided Design, 28*(4), 307–318. https://doi.org/10.1016/0010-4485(95)00035-6

Yang, M. C. (2005). A study of prototypes, design activity, and design outcome. *Design Studies, 26*(6), 649–669. https://doi.org/10.1016/j.destud.2005.04.005

Yu, F., & Enste, B. (2019). Smart prototyping. In J. Chen, A. Brem, E. Viardot, & P. K. Wong (Eds.), *The routledge companion to innovation management: The strategic perspective of innovation* (pp. 237–267). Routledge. https://doi.org/10.4324/9781315276670.

Yu, F., Pasinelli, M., & Brem, A. (2018). Prototyping in theory and in practice: A study of the similarities and differences between engineers and designers. *Creativity and Innovation Management, 27*(2), 121–132. https://doi.org/10.1111/caim.12242

Zhang, J., & Wang, H. (2005). The effect of external representations on numeric tasks. *The Quarterly Journal of Experimental Psychology Section A, 58*(5), 817–838.

Zimmerman, J., Forlizzi, J., & Evenson, S. (2007). Research through design as a method for interaction design research in HCI. In *Proceedings of the SIGCHI conference on human factors in computing systems* (pp. 493–502).

Zuzul, T. W. (2019). Matter battles": Cognitive representations, boundary objects, and the failure of collaboration in two smart cities. *Academy of Management Journal, 62*(3), 739–764.

Zupan, B., Stritar, R., & Slavec Gomezel, A. (2017). Unlocking latent creativity with rapid prototyping. *Traditiones, 46*(1–2), 171. https://doi.org/10.3986/Traditio2017460204