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RESEARCH ARTICLE

Entrepreneurial prototyping: the role of purpose, prototype recycling, and skills bricolage

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Abstract This paper explores how entrepreneurs engage in prototyping as part of the venture development process. We conduct a qualitative field study of 156 instances of prototyping across eight venture development processes. From a theoretical perspective, we build on alternative and complementary views of entrepreneurial action and their implicit modes of prototyping, emphasizing experimentation and transformation. Our findings identify three important themes in the prototyping process. These include purposes where the entrepreneurs use prototyping for either flexible experimentation or directed transformation. Further, the entrepreneurs predominantly engage in prototype recycling and skills bricolage when prototyping. Accordingly, the studied entrepreneurs carefully navigate purpose and resource investments in prototyping, making extensive use of their existing resource base of skills and prototypes. After noting the positive aspects of prototyping, we also discuss the potentially destructive outcomes of misapplied prototyping in the form of prototyping myopia and problematic path dependencies of the different ways of prototyping.

Plain English Summary Entrepreneurs rely on prototyping as an important activity to develop their businesses, products, services, and business models, but we know little of how they do so. In this paper, we look at the differences in how entrepreneurs use prototyping. We find that entrepreneurs use them in different ways. They use prototyping for specific narrow purposes and broader generative aims. They also often recycle prototypes and rely on skills that they already possess to undertake prototyping activities. Following our findings entrepreneurs must balance the purposes and resource investments in the form of skills and prototypes when prototyping, and this balancing skill is essential to exploit the potentials of prototyping and avoid misusing it when developing new products, services, and businesses.

Keywords Prototyping · Entrepreneurship · Prototypes · Resources · Hypothesis formulation

JEL classification M13

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1 Introduction

The existence and importance of prototypes and prototyping in entrepreneurial processes have long been acknowledged in entrepreneurship research (see, e.g., Audretsch et al., 2012; Carter et al., 1996; Wessel et al., 2022). Indeed, with the recent emergence of action-oriented theorizing, prototyping and prototypes in the form of design artefacts, a/b tests, landing pages, business model canvases, and similar objects increasingly appear in the accounts of what entrepreneurs do (Clarke, 2011; Jones et al., 2010; Koning et al., 2022; Lamine et al., 2019). This is further accentuated by recent attempts to place design, experimentation, and creation at the heart of entrepreneurship research (Berglund et al., 2020; Bruce & Baxter, 2019; Ding, 2019; Selden & Fletcher, 2019).

Some advances have been made in the study of prototyping in entrepreneurship research, suggesting, for example, that prototypes can help entrepreneurs access resources, by acting as a vehicle for transfer of information (e.g., Audretsch et al., 2012; Wessel et al., 2022). The exploration of the underlying dynamics of how entrepreneurs engage in prototyping activities, however, contain very little explicit empirical work and only limited theoretical development (Berglund & Glaser, 2022; Seyb et al., 2019; Shepherd et al., 2021). Indeed, in the overall study of entrepreneurial processes, prototypes and prototyping have largely been considered secondary topics to other research efforts (Paust et al., 2024).

The limited treatment of prototypes and prototyping represents a missing component in our understanding of entrepreneurial processes (Seyb et al., 2019), as prototyping plays an increasingly prevalent and important role in prescriptive practitioner-oriented frameworks[1] strongly endorsed by the supporting systems of accelerators, educational institutions, and experimental makerspaces (Browder et al., 2017; Cartel et al., 2018; Mansoori & Lackéus, 2020; Nair et al., 2022). A prominent example is the build-measure-learn cycle of lean startup, which is suggested to replace the "old toolkit" of business planning (Eisenmann et al., 2013; Frederiksen & Brem, 2017; Ries, 2011). However, while the use and effect of business planning have been studied extensively (Brinckmann et al., 2010; Honig & Karlsson, 2004; Shane & Delmar, 2004), limited research attention has been granted to these new toolkits and their alleged universal applicability (Berglund et al., 2018; George & Bock, 2011). Even though much inspiration is drawn from the rapid diffusion of design thinking and its focus on iterative prototyping (Beverland et al., 2015; Micheli et al., 2019; Verganti et al., 2021), the varied and essential insights and experiences from design thinking are neither theoretically nor empirically sufficiently explored in the context of entrepreneurship (Klenner et al., 2022; Mansoori & Lackéus, 2020). In particular, we know little about why entrepreneurs prototype, how they do it, and what artefacts are used as prototypes.

In this paper, our research question explores how entrepreneurs use prototyping as they engage in entrepreneurial action. We conceptualize prototyping as the use of representational artefacts to advance entrepreneurial processes (Paust et al., 2024). This view captures the expansive use and conceptualization of prototyping across fields in which anything that serves the purpose of representing an artifact can be considered a prototype (Houde & Hill, 1997; Innella & Rodgers, 2017; Lim et al., 2008; Vestad & Steinert, 2019). The definition is derived primarily from work on prototyping found in the design research field (e.g., Buchenau & Suri, 2000; Camburn et al., 2017; Lim et al., 2008; Yang, 2005), but also aligns well with recent innovation research focusing on artifacts, such as the Business Model Canvas and visual business modelling representations (e.g., Doganova & Eyquem-Renault, 2009; Eppler et al., 2011; Haggège & Vernay, 2019).

Our study uses a qualitative field study of 156 instances of prototyping embedded within new venture development processes. This design allows an in-depth insight into prototyping instances initiated by entrepreneurs involving multiple prototyping activities. Theory on entrepreneurial action serves as an analytical lens to outline a spectrum of analytically distinct ways in which entrepreneurs can use prototyping. Specifically, prototyping activities are analytically focusing on either experimentation as formulation and test of a hypothesis (Camuffo et al., 2019; Felin et al., 2020; Shepherd & Gruber, 2021) or transformation

[1] Such as the works by Mullins and Komisar (Gruber 2010; Mullins and Komisar 2009), Bland and Osterwalder (2020), Thomke (2020), and on the Google sprint model (Knapp et al., 2016).

that facilitates the creative generation of new entrepreneurial artefacts in interaction with stakeholders (Berglund et al., 2020). These two modes outline a conceptual landscape of different uses of prototyping with potentially important differences in the purposes and processes of prototyping activities.

This empirical exploration of how entrepreneurs engage in prototyping, through an analytical lens of entrepreneurial action, offers an important and necessary extension to both dominant prescriptive frameworks and recent conceptual developments in entrepreneurship research towards experimentation, design and creation (Berglund et al., 2020). The main contribution of our paper lies in showing how entrepreneurial prototyping is a varied and heterogeneous activity involving different balances of purpose and effort related to skills and prototypes. Specifically, we find little of the purely hypothesis testing prototyping suggested in the experimental approach to entrepreneurial action. We also find little of the entirely means-driven and open-ended form of prototyping suggested by the transformation perspective of entrepreneurial action. Instead, we find a varied pattern of what we refer to as flexible experimentation and directed transformation, extensive recycling of prototypes, and a predominance of skills bricolage, defined as reliance on skills already mastered by the entrepreneur when prototyping. We also discuss the potentially destructive outcomes of misapplied prototyping, prototyping myopia, and cost-driving risks of certain ways of prototyping.

The paper begins with a theoretical overview of two approaches to entrepreneurial action in recent entrepreneurship research outlining a conceptual landscape of different forms of prototyping for entrepreneurs that we explore empirically. After this, an outline of the research design and methods deployed in our study follows. The findings of the study are reported next, with the first part outlining the findings related to purpose, use of prototypes, and skills used in the prototyping processes and the second part outlining the patterns across the three themes. In the discussion section, we discuss our findings, in particular as they relate to the potentials and challenges of prototyping and the implications for research.

2 Theoretical foundation

Theoretical developments in entrepreneurship research have incorporated an increasing interest in entrepreneurial action (Berglund et al., 2020; Mansoori & Lackéus, 2020; McMullen & Shepherd, 2006; Townsend et al., 2018). This increasing focus comes in multiple forms, including research streams related to effectuation (Berends et al., 2014; Klenner et al., 2022; Sarasvathy, 2001), entrepreneurial experimentation (Andries et al., 2013; Berends et al., 2016; Kerr et al., 2014), and entrepreneurship as design (Berglund et al., 2018; Dimov, 2016; Romme & Reymen, 2018).

Common to these research streams is skepticism towards the past dominance of cognitive and individualized perspectives on entrepreneurship that neglect the dynamics of social interaction and stakeholder mobilization and hold problematic ontological assumptions about opportunities as objective realities to be discovered through cognitive processes (Ramoglou & Tsang, 2016; Venkataraman et al., 2012). Instead, it is argued that entrepreneurial processes are best viewed as dynamic and creative engagements with a series of emergent knowledge problems (Townsend et al., 2018). As theoretical development has increasingly adopted action-oriented perspectives to the engagement with knowledge problems, more emphasis has been placed on what entrepreneurs do and less on what they perceive and see as profitable opportunities (Shepherd, 2015). As a consequence, an increasing interest has been devoted to the people, organizations, resources, and artefacts that entrepreneurs do something with and to (Berglund et al., 2020; Selden & Fletcher, 2015; Thompson & Byrne, 2022). In particular, among the many actions undertaken by entrepreneurs that have been given increasing attention, we find a broad range of what we refer to as prototyping activities (Bruce & Baxter, 2019; Brunswicker et al., 2013; Grimes, 2018; McDonald & Eisenhardt, 2020; Petrakis et al., 2021; Wessel et al., 2022).

2.1 Two approaches to entrepreneurial action

Within this emerging action-oriented theorizing on entrepreneurial processes, two conceptually distinct approaches and processual logics have been proposed. Building on the recent contribution by Berglund and colleagues (2020), we refer to these ideal types as experimentation and transformation. According to Berglund et al. (2020), the two ideal types incorporate two distinct ways of engaging with artifacts

in processes of entrepreneurial opportunity design. Despite considerable overlap in theoretical heritage and commonalities in their critical take on classic opportunity discovery and planning approaches, the experimentation and transformation approaches to entrepreneurial action differ significantly in the underlying logic of how and why entrepreneurs should engage with artifacts (such as prototypes) and entrepreneurial knowledge problems.

In the experimentation approach, entrepreneurial processes are seen as experimental sequences in which knowledge problems are resolved (Camuffo et al., 2019; Kerr et al., 2014). Inspired by the scientific process of hypothesis formulation and testing, the experimentation view considers the entrepreneur as a kind of scientist and theorist who converts conjectures into knowledge through testing and adaptation (Zellweger & Zenger, 2021). Despite taking its current form through engagement with recent practitioner models such as lean startup (Felin et al., 2020), this notion is quite similar to Thomke's (1998, 2001, 2003, 2020) experimental view of innovation processes. It also resembles the analytical notion of convergent thinking within design thinking, focusing on experimentation, iteration, and trial-and-error learning by testing a range of possible options generated through divergent thinking (Beverland et al., 2015; Cross, 2021; Liu et al., 2003; Micheli et al., 2019).

In the experimental view of entrepreneurial action, the entrepreneur is situated in an uncertain decision-making context where knowledge of key elements related to option and outcome sets are unavailable. Through experimentation, the entrepreneur reduces uncertainty as distinct knowledge problems are resolved and option and outcome sets close (Packard et al., 2017). This is structurally similar to the build-measure-learn cycle offered in lean startup, although recent studies emphasize the importance of formulating precise and carefully thought-out conjectures and hypotheses—an element not well-described in prescriptive models (Felin et al., 2020). Like conventional cumulative views of science, the entrepreneur then builds knowledge by discovering new knowledge through experimentation (Camuffo et al., 2019; Menold et al., 2017).

The transformation approach takes an alternative view of entrepreneurial processes (Berglund et al., 2020). It largely builds on the theoretical foundation of Herbert Simon's work on design in which entrepreneurship is seen as a form of opportunity design based on entrepreneurial heuristics (see Dimov, 2016; Romme & Reymen, 2018; Sarasvathy, 2008; Selden & Fletcher, 2015). Here, collective creation is the primary driver of the engagement with entrepreneurial knowledge problems, and knowledge, markets, and business models are more created than discovered (Venkataraman et al., 2012). Sarasvathy's (2001, 2008) theory of effectuation provides a central example of this view of entrepreneurial action. Stakeholder mobilization and collective creativity result in the creation of new entrepreneurial artefacts such as business models, markets, products and services. Rather than discovering and solving distinct knowledge problems, and thereby closing option and outcome sets, the entrepreneurial processes are fundamentally generative and transformative, essentially opening new options and outcomes (Packard et al., 2017; Sarasvathy & Dew, 2005). The practitioner models similar to this view of entrepreneurial action are not found in the lean startup lineage, but rather resemble the analytical notion of divergent thinking within design thinking and its treatment of prototyping to imagine, experience, and explore possible future scenarios as vehicles for ideation and generative processes (Kimbell, 2015; Klenner et al., 2022; Liedtka & Ogilvie, 2011; Micheli et al., 2019; Verganti et al., 2021).

A central concern of the transformation approach is the role of resources or available means (Sarasvathy, 2008). According to effectuation, experienced entrepreneurs most often start from the resources available. From currently controlled resources, a dual process of expanding the resource pool and converging on a design of means-ends relationship drives forward the entrepreneurial effort. Taking a starting point in resources and maintaining this emphasis throughout the entrepreneurial process is meaningful for entrepreneurs, as it keeps cost under control (affordable loss) and represents a superior way of dealing with the fundamental ontological uncertainty that faces entrepreneurs, which calls for exploratory open-ended creation rather than analytically-driven discovery (Martina, 2020). The resources controlled by entrepreneurs thus create important path-dependencies beyond a distinct entrepreneurial action. Underlying this resource-focused perspective of entrepreneurial action further lies an assumption of exaptation (Dew & Sarasvathy, 2016; Dew et al.,

2004). Building on Penrose (1959), Dew, Sarasvathy and others argue that resources are open-ended and allow for creative reinterpretation that puts them to new uses (Dew & Sarasvathy, 2016; Dew et al., 2004). Notably then, prototypes can be considered open-ended resources as well that allow for creative reuse and reinterpretation, while at the same time creating path-dependencies across entrepreneurial actions.

The emphasis on the importance of resources in the transformation ideal type differs from the experimentation type where the focus is on the end rather than the means of the entrepreneurial action, in so far as the purpose of entrepreneurial actions such as prototyping is to resolve a specific knowledge problem by securing accurate and relevant data. In this view, entrepreneurial processes involve artifact creation at multiple levels, including business models, products, and markets (Ding, 2019; Selden & Fletcher, 2015), and the artifacts involved are mutable and plastic (Berglund et al., 2020).

2.2 Experimentation and transformation focused prototyping

The two alternative perspectives of the logic of entrepreneurial action embodied in the approaches of experimentation and transformation hold distinct forms of engagement with artifacts, including prototypes. As such, it is clear from the exposition above that prototyping should be modally different in the two approaches. When experimentation and hypotheses are the focal interest, we would expect prototyping to be associated with a testing mode where prototypes act as a means for information gathering related to well-defined and distinct knowledge problems (Menold et al., 2017). As suggested by Berglund et al. (2020), the prototype is thus best seen as an instrument for discovery (Ammon, 2017). This approach sees prototyping as part of a scientific systematic search process, e.g., for business model, product, or service attributes and product-market fit (Wessel et al., 2022). By formulating and testing hypotheses, entrepreneurs target critical assumptions, which are resolved in a series of distinct prototyping instances. The outcome set of the prototyping is closed and goal-specific, hence mirroring a causal approach that attempts to resolve absolute uncertainty into creative uncertainty by addressing environmental uncertainty (Packard et al., 2017). The use of prototypes to support experimentation is clearly important, and examples of prototypes include a broad array of artifacts, such as a/b tests (Koning et al., 2019), minimum viable products (Frederiksen & Brem, 2017), virtual artifacts (D'Adderio, 2001), 3D printed models (Rayna & Striukova, 2016), science fiction sketches (Johnson, 2011), and pretotypes (Savoia, 2011).

When transformation serves as the focal point, such as in Sarasvathy's transformation logic of action, prototyping is first and foremost a mean for open-ended creation at multiple levels, in which the particular purpose(s) of the prototyping activity emerges within the activity (Ding, 2019; Selden & Fletcher, 2015). Rather than serving as an instrument for discovery, prototypes in this context are design tools that serve to enable creative and collaborative design (Berglund et al., 2020). Prototypes are "mutable boundary objects" (Berglund et al., 2020) or proxy devices that act as windows to an imagined future, referencing not what is, but what could be (Ammon, 2017). The primary differences between experimentation and transformation focus of entrepreneurial prototyping are summarized in Table 1 below.

Notably, in using the two approaches to entrepreneurial action as the theoretical foundation of our study, we treat them as ideal types. This is not to be confused with the notion of taxonomy and its relationship to prototyping, which are neither "ideal" nor "types." Instead, ideal refers to "…the adjectival form of 'idea'—and type refers not to a classificatory kind we meet in the world, but to a 'mental construct" (Baden-Fuller & Morgan, 2010, p. 161). Unlike the notion of taxonomy as being the classes of things observed in the world developed bottom-up from empirical work, a typology contains a whole set of characteristics decided theoretically or conceptually by the researcher, which will rarely be found in fully developed form (Baden-Fuller & Morgan, 2010). Instead, the two approaches and the different foci they incorporate outline a conceptual spectrum in which different ways of prototyping can emerge, with potentially important differences in the mode, purposes, and resource use in prototyping activities. With the ideal types as our theoretical point of departure, we thus explore how entrepreneurs use prototyping as they engage in entrepreneurial action from bottom-up empirical work. Following the theoretical point departure, we further focus on the purposes and resource use of the entrepreneurial prototyping activities.

Table 1 Conceptually derived ideal types of entrepreneurial prototyping

	Experimentation focused prototyping	Transformation focused prototyping
Definition	Prototyping activities that involve the formulation of a hypothesis that is subsequently tested through the use of a prototype The prototyping activity treats the resources needed as secondary and sub-servant to the hypothesis	Prototyping activities that do not take a specific end as given and incorporate open ended and generative engagement often with resources currently controlled by the entrepreneurial venture The purpose or outcome set of the prototyping activity is not necessarily defined in a specific form prior to the activity
Mode of entrepreneurial action	Adopts an experimental approach to the engagement with entrepreneurial knowledge problems Here, the purpose of entrepreneurial action is discovery of new and relevant knowledge Consequently, prototypes are seen as experimental components	Adopts a transformative approach to engagement with entrepreneurial knowledge problems Here, the purpose of the entrepreneurial action is to generate new options and commitments through the transformation of artifacts Consequently, prototypes are seen as mutable and plastic artifacts
Similar practitioner frameworks and their main focus	Lean startup (formulation of hypothesis) (Ries, 2011) Business model experiments (Bland & Osterwalder 2019) Business experiments (Thomke, 2020) Prototyping for X (Menold et al., 2017)	Design thinking (exploration with rapid prototyping) (Liedtka & Ogilvie, 2011) Pretotyping (Savoia, 2011) Science fiction prototyping (Johnson, 2011) Experience prototyping (Buchenau & Suri, 2000) Exploratory prototyping (Kimbell, 2015)

3 Methods

Given the research question and the need for studies of how entrepreneurs adopt the activity of prototyping, an exploratory study with a qualitative design was carried out. In this study, we adopted a multi-level qualitative field study (Creswell & Poth, 2018; Miles et al., 2013). This research design allows for studying the multi-level interaction between specific prototyping activities—of which any entrepreneurial venture is likely to have several—and the overall venture development process. As such, our main analytic focus is the micro-level prototyping instances, which serve as our units of analysis. A secondary and supplementary analytical focus is the venture development processes in which the specific prototyping instances are embedded. This research design has previously been used in the study of entrepreneurial decision-making (Maine et al., 2015; Reymen et al., 2015), entrepreneurial pivots (Grimes, 2018), and prototyping in early-stage innovation in corporations (BenMahmoud-Jouini and Midler, 2020). Having embedded units of analysis in the form of distinct prototyping instances within a venture allows us to see potential relations or path dependencies across a venture's prototyping instances and to interpret the events within the overall development trajectory of the ventures.

The selection of ventures through which we access the prototyping instances was done to secure ventures where prototyping was expected to be used substantially, while at the same time avoiding prototyping behaviors that are either industry specific or the results of external conditions, such as in highly structured accelerator processes, where prototyping is demanded from the entrepreneurs (e.g., Mansoori, 2017). Inspired by Grimes (2018), the ventures were selected in a two-stage process of sampling. First, we undertook purposeful sampling in two regional incubators that together represented a broad range of sectors and industries. Accessing ventures through incubators enables easy identification of new ventures that are active and have opportunities to use various facilities and technologies that support prototyping. A total of five ventures were identified through this stage of sampling.

Subsequently, we supplemented this with convenience sampling of new ventures to ensure that incubator exposure was not a boundary condition for our findings (see Grimes, 2018). Consequently, further three ventures were identified using the network of the first author as well as readings of local media

and press releases from the Danish Entrepreneurship Foundation.

The new ventures were identified using the criteria that they were active in their entrepreneurial processes of developing innovative new products, services, and business models; no more than 5 years has passed since founding; multiple instances of prototyping had taken place; and the founder(s) was willing to participate in multiple interviews and provide images, demonstrations, and other material traces of their prototyping activities. The sampling deliberately sought entrepreneurs who were active in the pursuit of innovative and novel products, services, or business models. Overall, our heterogeneous sample contains new ventures of various types, from a broad range of industries and that are active in different (early) development stages. This supports the external validity of the findings so that these are not selection effects from a particular industry or development phase of the new ventures.

From the ventures selected, we collected data for as many prototyping instances as possible with the condition that sufficient data could be collected on the individual prototyping instance to describe it with sufficient depth to explore our research questions. Specifically, we collected data on the purpose, activities, and artifacts (prototype) of each individual prototyping instance.

Table 2 below outlines the ventures and gives an overview of the data sources used to study the prototyping instances. From the data collection across ventures, a total of 156 instances of prototyping were identified. The complete overview of the prototyping instances is included in Appendix 1.

3.1 Data collection

To explore how entrepreneurs adopt the activity of prototyping, data were collected from multiple sources combining retrospective and real-time sources (Eisenhardt & Graebner, 2007). Interviews, photos, videos, internal venture documents and public archival documents, and media sources were collected to build an in-depth understanding of the prototyping instances and the venture development processes in which they are embedded, as encouraged by Creswell and Poth (2018) among others (see, e.g., Miles et al., 2013).

In treating the entrepreneurs as knowledge agents who are capable of eliciting rationales, experiences and activities (Gioia, 2021), interviews were conducted with entrepreneurial founders and key informants involved in the founding and development of the ventures. In total, 27 interviews were conducted across the eight ventures in interviews lasting approximately 70 min on average. The interviews were conducted between May 2020 and March 2021 and took place in person at the site of the entrepreneurial venture, whenever possible, or were conducted via video or telephone calls. All interviews were recorded and subsequently transcribed verbatim in Danish, the native tongue of the informants.

The interview protocol followed a semi-structured format to provide a flexible structure for multiple interviews across ventures (Brinkmann & Kvale, 2018; Creswell, 2013) and gradually evolved over time as entrepreneurs recounted key events and instances of prototype creation and use. The initial protocol consisted of open-ended questions based on five broad themes with the intention of eliciting narratives and stories of the entrepreneurial journey and its key events and activities, as well as to allow entrepreneurs to describe what was to follow in the immediate future. Our theoretical lens helped inform the broad interview guide while also delimiting the area of research in a way that would enable the interviewer to better grasp possible avenues of interest as they arose in the conversation (Linneberg & Korsgaard, 2019). To set the stage, each interview started with stating the central purpose and interest of this study for the participants (Creswell, 2013), also referred to as a briefing (Brinkmann & Kvale, 2018). Following the briefing, the interview protocol combined broad open-ended questions on the five themes of concept, offering, journey of the venture and the offering, and their use of techniques, models, and tools. As previous researchers have demonstrated that prototypes mean different things to different people (e.g., BenMahmoud-Jouini and Midler 2020; Houde & Hill, 1997), the interviewer deliberately avoided such terms that could require specific knowledge and instead sought to identify the interviewees' own terms and concepts, as advocated by Gioia (2021), Wengraf (2001), and Spradley (1979).

When possible, the interviews were supplemented with additional data in the form of field visits to the facilities of the ventures, public and private visual materials (pictures and videos), audio materials (podcasts and public interviews), as well as archival data from private documents, pitch decks, public industry magazines, and case material from social media

Table 2 Overview of venture characteristics and data sources

Venture	Type	Founded	Focus	Data collection:	Data sources
Alpha	Service	2018*	Development of innovative and sustainable concepts and corporate interior designs	May 2020 to May 2021	Interviews with the founder (5) Archival materials (pictures, documents, posters, project proposals, pitches, presentations, notes, and industry magazines, and media and internet resources) (161)
Beta	Product	2020	Development of innovative and low-cost energy solutions for phone and tablet users	May 2020 to November 2020	Interviews with the founder (3) Archival materials (pictures, documents, sketches, physical mockups, and external media resources) (15)
Gamma	Product	2016	Development of innovative and circular building systems for the construction industry	May 2020 to November 2021	Interviews with the founder (4) and non-participatory observation (1) Archival materials (pictures, 3D images, documents, promotional materials, press releases, videos, podcasts, industry reports, and media and internet resources) (141)
Delta	Product	2019	Development of innovative and sustainable footwear and accessories	September 2020 to July 2021	Interviews with the founder (3) and non-participatory observation (3) Archival materials (pictures, documents, videos, design exhibition press releases, online showcases, and media and internet resources) (135)
Epsilon	Service	2019	Development of an AI powered tool to enhance accessibility of legal insights and advice	October 2020 to March 2021	Interviews with the founder and the head of product (3) Archival materials (pictures, project descriptions, social media posts, user survey, videos, job and internship postings, and media and internet resources) (139)
Zeta	Product	2017	Development of healthcare technology for people with mobility issues	October 2020 to November 2021	Interviews with the founders (4) Archival materials (pictures, videos, sketches, mockups, physical prototypes, pitch decks and promotional materials, press releases, notes, webinar material, podcast, blog posts, and media and internet resources) (389)
Theta	Service	2016	Development of platform to link creative industry and consumers	October 2020 to June 2021	Interviews with the founder (3) Archival materials (pictures, videos, sketches, website screenshots, project descriptions, pitch and promotional materials, notes, blog posts, job and internship postings, and media and internet resources) (118)
Kappa	Product	2017	Development of innovative and green energy solutions based on Internet-of-Things	November 2020 to March 2021	Interviews with the founder and the IT & Communication analyst (2) Archival materials (pictures, videos, pitch and promotional materials, website screenshots, project descriptions, blogposts, and media and internet resources) (217)

*The startup was founded in 2006, but registered under its current name in 2018

platforms where entrepreneurs were active. To reduce interviewee uncertainty, all informants were guaranteed anonymity and confidentiality, hence the renaming of the ventures (see Table 2).

3.2 Data analysis

To explore how and why entrepreneurs use prototyping in their entrepreneurial ventures, we undertook a multi-step analysis process (Grodal et al., 2021; Miles et al., 2013). The analytic process developed from a dynamic process of categorization of our data, as suggested by Grodal et al. (2021), to provide an overview, understanding, and interpretation of our data in light of the research question guiding the study. The steps of the analytic process are outlined in Fig. 1. The first step provides insights into the purposes (why), activities (how), and prototypes (what) of the prototyping activities. With purpose, activities, and prototype as sensitizing concepts (Bowen, 2006), guiding the inductive exploration of the prototyping instances, a first coding overview was generated outlining a long list of purposes, prototypes, and activities adopted by the entrepreneurs. This first step helped unearth a broad variation in the prototyping instances at a descriptive level, yet in itself presented a much too varied and fragmented view to make inferences at a conceptual level. The second step of the process engaged in a merging exercise in which codes at the descriptive level of the first step were combined into broader categories (Grodal et al., 2021; Miles et al., 2013). This move was similar to the operation in grounded theory analysis where first-order codes are merged into categories at a pre-conceptual level of analysis (Gioia et al., 2013; Glaser & Strauss, 1967). This resulted in a shorter list of purposes, prototypes, and activities.

The third step involved interpretation of the patterns of similarities and differences across the categories and the prototyping instances within the context of the venture development processes. This allowed us to provide important interpretations of the prototyping instances and lead to a selection of three themes that provide the focal point of our analysis. The details of this third step were somewhat differentiated and followed the logic of the data and research question rather than the standard templates of, e.g., grounded theory coding. With regard to the central theme of purpose, the third cycle involved a differentiation between purposes into two groups, inspired by the theoretical differentiation between experimentation and transformation (resulting in the flexible experimentation and directed transformation categories). Two further themes were developed from the activities and prototypes in the data, focusing on two observations that came to light as categories were interpreted against the backdrop of the venture development processes: the use of prototypes (in particular recycling of prototypes) and the skill sets used by the entrepreneurs in executing the activities of the prototyping instance (skills bricolage). These themes subsumed a set of categories as summarized and outlined in Table 3 below. The themes and the important variations within them are presented in the findings section in some detail.

In the fourth step of the analytic process, the prototyping instances were recoded using the three themes identifying for each individual prototyping instance the purpose (flexible experimentation or directed transformation), recycling or single use of prototype, and whether the entrepreneur relied on skills bricolage or invested in new skills for the prototyping activity. This coding cycle allowed us to finally identify conceptually relevant patterns of similarity and difference across the prototyping instances that informed us on our research question. Following this, the fifth and final step of the analytic process identified the distribution of combinations of the purposes, recycling or single use of prototypes, and skills bricolage or investment in new skills. An overview of the distribution of the combinations of purposes, recycling of prototypes, and skills usage is included later in Table 4.

4 Findings

4.1 Prototyping purposes: flexible experimentation and directed transformation

The first theme from our analysis is purpose. Overall, the predominant view was of purposeful prototyping, yet the purposes came in different forms. Some were narrowly focused on gathering knowledge on some predefined measure or element, while others were more open-endedly seeking to incite creativity. This suggests that entrepreneurs set purposes that either structure or guide their prototyping, depending on the specific situation in the venture development process.

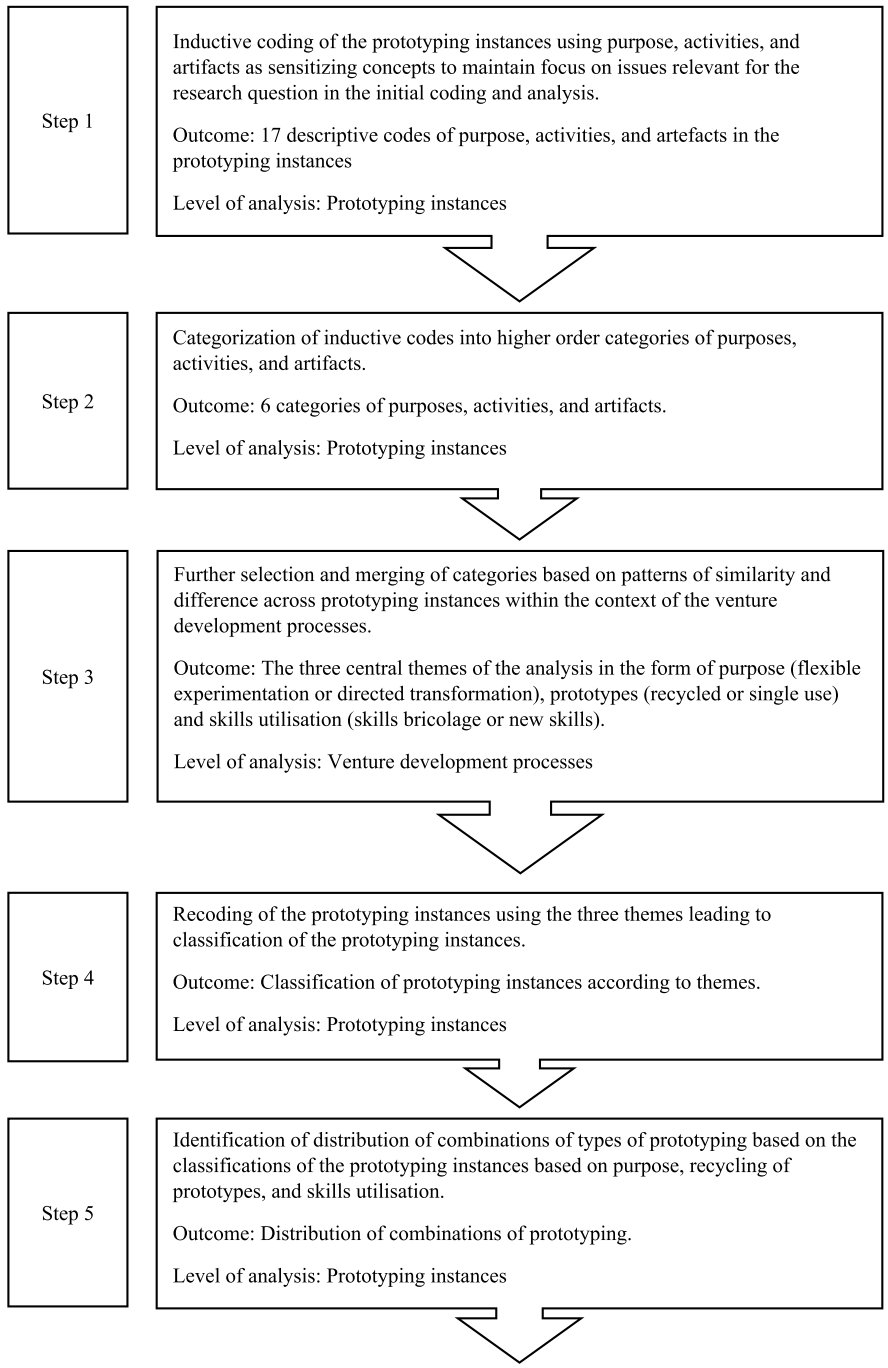

Fig. 1 Analytical process

The landscape of purposeful prototyping that was in our data, in some ways, resembles the theoretical spectrum of experimental and transformation prototyping, but with some important qualifications. Importantly, we did not find many instances of the hypothesis testing suggested by the experimental ideal type approach to entrepreneurial action, nor did we find instances where purposes were left entirely open-ended and flexible as some aspects of the transformative approach

would suggest.[2] Instead, we found prototyping that did incorporate many of the elements of the ideal type of experimentation, but in a way that is more flexible than hypothesis testing. Also, we did find open-ended prototyping without a clearly defined outcome, yet such prototyping was always guided so as to direct the creative and generative responses in a space delineated by the entrepreneur. We thus refer to these empirically defined types as flexible experimentation and directed transformation respectively.

Applying these categories in our analysis, we found an almost evenly distributed use of flexible experimentation and directed transformation, although the distribution of purposes should be taken with some reservation. In total, 80 of the prototyping instances involved a flexible experimentation, while the remaining 76 involved directed transformation.

In the instances we label as flexible experimentation, the entrepreneurs formulated some—not necessarily explicit—minimum criteria or success measures for the prototyping activity. As a result of the narrow purposes, the prototyping activities that followed tended to mirror a structured process, wherein the prototype acts as an experimental component to gather knowledge on a predefined measure. Yet, the structures were almost always more flexible than suggested in the scientifically inspired hypothesis testing approach (Camuffo et al., 2019; Felin et al., 2020; Gans et al., 2019). As such, success criteria and measures were predefined, but not with specific targets. Furthermore, important elements of interpretation were used to make outcomes operable in the entrepreneurial process. The purposes thus act to structure the activities and inform the creation or use of the prototype. As expected, our findings show that predefined narrow purposes were often associated with instances occurring in later stages of development in which technical evaluation or product-market fit testing were the objectives. This is illustrated by numerous examples, in which the predefined purpose set by the entrepreneur structured the process of creating and using given prototypes. For instance, the entrepreneur of Delta wanted to investigate actual product-market fit among prospective consumers. With a narrow purpose of testing actual purchase interest, he uploaded a picture set to Instagram, and given the predefined objective, the post featured a direct call to action. Similarly, Zeta wanted to examine whether prospective users would pre-order their offering; hence, they formulated a "purchase contract test" that users would be asked to sign. Unsurprisingly, we found numerous examples of purposes related to technical testing of aspects. For instance, the entrepreneur of Gamma wanted to test the product's capacity to withstand weight. To do so, he used the latest prototype as an experimental component and manually placed large dumbbells on top of the prototype until no more weights were available (see exhibit A in appendix 2). Despite not pre-establishing a clear measure for declaring success, the results demonstrated that the prototype could withstand at least more weight than would usually be required in the industry. Likewise, a narrow objective was recounted by Epsilon, where a test was conducted to assess whether users could find the required information on the prototype website. To do so, they invited potential users to a screen sharing session via Zoom, in which users were tasked with finding specific information while they were being observed. Consequently, the establishing of clear predefined purposes helped structure the prototype creation and use for the entrepreneurs.

In those instances where purposes were not predefined and experimentally focused, we found entrepreneurs engaging in activities with open-ended purposes without well-defined end goals. In contrast to experimental purposes that structure the activities, these open-ended purposes instead guided the activities towards creative and generative outcomes. We refer to these as directed transformation as they incorporate the creative and generative element of the theoretical ideal type of transformation, yet, guided by the entrepreneurs in a way that gave direction to or framed the open-ended processes. Our findings suggest that such broad purposes are particularly evident in early phases of development, during which knowledge about problems and possibilities are still somewhat unclear or undefined. For instance, the entrepreneur of Alpha needed to explore ways to create the foyer area of a

[2] The difference between flexible experimentation and directed transformation to some extent resemble the process characteristics of divergent and convergent, as studied in design research – even as we highlight the purpose adopted by the entrepreneur upon developing the prototyping activity, where divergence and convergence first and foremost relate to the process and outcome of design activities (Micheli et al., 2019).

Table 3 Overview of themes, categories, and codes

Aggregate themes	Categories	Descriptions	Codes	Samples of coded data
Purpose	Flexible experimentation	Category applies to instances where entrepreneurs demonstrate closed-ended purposes, rationales, and objectives for prototyping, albeit often with flexible outcome measures	Structuring activities	"For example, one of the acceptance tests we have established was that it should be able to withstand you dropping it. Then, the next step was to figure out how often we expect people to lose it within a three-year period" (Zeta)
			Formulation of specific goals and hypothesis	"We have to follow the entire hypothesis we have about things, and test it all the way through, and then find out whether it worked or not, so that we can adapt, rather than change midway" (Epsilon)
			Evaluation, experimentation, and testing of focal parameters	"Yes, we made it as a test. It's a do-people-actually-want-to-pay experiment […] like really to test what is the desire to actually buy when you put them on the spot" (Zeta)
			Controlling focal parameters of interest	"But I've had it at a technical school, where some carpenter apprentices made a competition out of it. […] Those (building) with my system won with a ridiculous margin" (Gamma)"
	Directed transformation	Category applies to instances where entrepreneurs demonstrate open-ended purposes, rationales, and objectives for prototyping, albeit often with directed outcome measures	Guiding activities with open-ended questions	"The primary focus has been to get open feedback. So, you know, immediate opinions. They get the prototype in their hands, and then we just want to learn something about what they think" (Zeta)
			Analogies and metaphors as open and flexible guides	"It is simply the analogy about what we were developing that changed. So, the story of making a "breakroom" became the story of making a "town square" inside […] That is also because I keep the process open for as long as possible. And also much longer than most people can stand. I don't care because that's what gives the value" (Alpha)
			Constraining the decision space via self-constraining	"You can say that within this box, where I work, I have tried to solve the dogmas that I establish myself. The limitations that I set for myself that these things just have be able to fulfill. It is not finally solved until it fulfills these requirements that I have set for myself or the product" (Gamma)
			Building to think in itself	"(The process) gives me a physical understanding […] I usually say that my hands are much smarter than my brain" (Alpha)

Table 3 (continued)

Aggregate themes	Categories	Descriptions	Codes	Samples of coded data
Prototype	Prototype recycling	Category applies to instances where entrepreneurs use prototypes more than once	Reactivating a prototype in original form for similar or new subsequent purposes or situations	"…And then we brought our air-concept prototype. The prototype we had that used an air pump. To show (them) what we liked and disliked about that solution. Then it was like…we worked from there" (Zeta)
			Reformatting a prototype to new formats for similar or new subsequent purposes or situations	"At the time, we just used a simple picture deck to explain. I do not know whether it was actually made in Photoshop or something, but it was at least some kind of pictures, and not something we could actually click around in, but simply pictures. So, we could show him (potential stakeholder) "around" on the site by saying stuff like "so you have this picture here, and then you click here, which brings you over here" and so forth, and then show him around some of the other pictures in the deck'" (Theta)
	Single-use prototyping	Category applies to instances where entrepreneurs do not use prototypes more than once	Prototypes created for singular instances	"In this case (shows picture of laser cut model, red.) it was okay that it was laser cut model, but I will not do that again. I simply won't because the process of creating cutting files is just absolutely uninteresting to me" (Alpha)
			Limitations of existing prototypes	"I could not really discern from the 3D model which properties of the wood would work. There I had to physically produce it" (Gamma)
Skills use	Skills bricolage	Category applies to instances where entrepreneurs rely on their existing skills and experiences	Ease of relying on existing skills	"That is just my way of working. I 3D model it. If the 3D works, then there is also a good chance that it works. Also, because, based on my education, I can work so quickly in 3D. I just think my time is better spent testing it in 3D rather than testing it all physically" (Gamma)
			Background and competencies	"We then used them (funds raised, red) to get it developed as much as I could do myself given my engineering background and my software background" (Kappa)
	New skills	Category applies to instances where entrepreneurs do not rely on their existing skills and experiences	External and situational requirements	"My new partner […] he simply required me to go in and use something called Mocqup to make the prototype of the new system. So, I just had to get to know that […] starting completely from scratch with all the ideas I had in my head and the simple things I had sketched" (Theta)
			Mismatch between skills and problems	"But all that technical stuff, we had no knowledge about, and we did not know anything about […] it was then more or less their task" (Zeta)
			Unclear requirements and expectations	"We are talking about a platform that was coded from scratch […] it might be a nice MVP, but it always required (the lead developer) to be there all the time. So, it had been built far too technical" (Theta)

Table 4 Distribution of forms of prototyping

	Percentage	# of instances
Directed transformation, recycled prototype, and skills bricolage	31	48
Flexible experimentation, recycled prototype, and skills bricolage	30	47
Flexible experimentation, single-use prototype, and skills bricolage	16	25
Directed transformation, single-use prototype, and skills bricolage	12	18
Flexible experimentation, recycled prototype, and new skills	3	5
Directed transformation, single-use prototype, and new skills	3	5
Directed transformation, recycled prototype, and new skills	3	5
Flexible experimentation, single-use prototype, and new skills	2	3
Total	100	156

large institution as part of a new multi-stakeholder project. Given the early stage of development in the project, she chose to fuel the creative process by working with broader analogies, as recounted by Alpha who stated that "it is simply the analogy about what we were developing that changed. So, the story of making a "breakroom" became the story of making a "town square" inside […] That is also because I keep the process open for as long as possible. Much longer than most people can stand. I don't care because that's what gives the value." Thus, using the analogy of "breakroom" as a trigger that provided some emotion and feeling, she constrained the search process and maintained a direction that everyone involved could interact around while at the same time allowing for the purpose to evolve from "breakroom" to "campfire site" to "town square." Another interesting example of directed transformation prototyping relates to the use of self-constraining to provide direction in the face of ambiguity. For instance, Zeta decided to establish a purpose based on design criteria in which they self-constrained by refraining from developing software offerings, which helped provoke reflection and consideration of other areas more related to their available skills. Consequently, despite their open-ended nature, the purposes of designing around analogies or self-constraints guided the entrepreneurs forward without predefined end goals, as also explicated by Gamma, who clarified that "You can say that within this box, where I work, I have tried to solve the dogmas that I establish myself. The limitations that I set for myself that these things just have be able to fulfill. It is not finally solved until it fulfills these requirements that I have set for myself or the product."

In another similar instance, Zeta wanted to explore existing solutions on the market. After borrowing a range of existing solutions, the entrepreneurs allocated an entire month to using only these solutions in their daily lives. Despite the open-ended purpose of this simple exercise, the entrepreneurs discovered vital limitations in existing products related to mono-use and cleaning problems, which had significant influence on the subsequent development. At Beta, the founder took a combination of existing products and a simple wood block with him on a night out. Although representing a simple exploration, this activity provided valuable insights into possible limitations of existing products and fostered ideas for imagined contexts of use for the solution under development. Interestingly, some examples also demonstrate that entrepreneurs sometimes see the hands-on prototyping process as a purpose in itself, as reflected by several entrepreneurs, such as Alpha describing how "for me, the process is important because it is in and through the process that I gain bodily insights and conceptualize […] I usually say that my hands are much smarter than my brain." An illustrative example occurred in Delta, when the entrepreneur wanted to explore possible uses open-endedly with surplus materials available from previous activities. Consequently, the entrepreneur deliberately improvised, using a combination of inspirational pictures and simple hand-drawn sketches, which eventually resulted in the design of a leather case for sunglasses.

4.2 Prototype: recycling or single use

A second theme in our analysis relates to the use of artifacts—prototypes—in the prototyping process. In

the prototyping instances, we saw an extensive recycling of prototypes. Indeed, in 106 of our prototyping instances, we could see that the prototype was also used in other instances. While this specific number must be taken cautiously, it denotes a strong pattern of entrepreneurs using the same prototype multiple times for different purposes after serving its initial purpose. Thus, prototypes are often enacted in various prototyping instances, which contrasts with the creation of prototypes for single purposes. While prototypes may initially be built for single or specific purposes, their subsequent presence enables their reuse for alternative purposes; hence, the set of prototypes already produced constitutes an essential element in the resource stockpile for later prototyping. Specifically, our findings illustrate how prototypes are used for a series of partly unrelated purposes, such as testing specific aspects of a proposed solution and later using the same prototype as an active medium for demonstration. Thus, the same prototype is reused for multiple purposes, and the same purpose is targeted with multiple prototypes.

Our findings show that prototypes are reused through reactivation or reformatting, which can occur through simultaneous or sequential reuse. First, prototypes can be reactivated, which refers to instances where a prototype is reused in its original form for subsequent situations. This is illustrated across a range of prototyping instances by the entrepreneurs. For instance, a physical low-fidelity concept prototype was built by Zeta for early-stage interaction to demonstrate the value of the proposed solution for prospective users. Yet, the same prototype was subsequently reactivated as a vehicle for resource mobilization as part of a submission for fund-seeking, and even later as a communication tool for stakeholder mobilization, as Zeta sought partners for the technical development of the solution. As recounted by Zeta, "…and then we brought our air-concept prototype. The prototype we had (already) that used an air pump. To show (them) what we liked and disliked about that solution. Then it was like… we worked from there." Rather than demonstrating value in this instance, the early concept prototype served as a tool to communicate necessary and unnecessary dimensions for subsequent technical development. Similarly, the entrepreneur of Gamma built a full-scale building using multiple physical full-scale building block prototypes to examine the feasibility of the solution in the real world, but the same prototype building was later reactivated to demonstrate the solution to prospective stakeholders (see exhibit B).

Second, prototypes can be reformatted, which refers to instances in which a prototype is reused in new formats for subsequent situations. This type of reusing is particularly evident for physical and tangible prototypes, as they allow for reformation into two-dimensional formats, which can be beneficial in situations where three-dimensional models are not advantageous. For instance, the entrepreneurs of Theta started building a rough digital prototype, which served as a technical testing component for the development of specific features. Yet, given the technical and incomplete nature of the prototype, the need to interact with prospective stakeholders required reformatting the prototype to gather feedback (see exhibit C). By taking screenshots of the rough platform, the prototype was re-formatted into a picture deck, which could then be used by the entrepreneurs as an interactive presentation tool for interacting with users to gather feedback that could advance the technical development of the underlying digital prototype. In this way, the prototype was reformatted for two simultaneous purposes, both internally and externally. Similarly, Zeta had developed 3D-printed full-scale prototypes as part of the technical product development, and these prototypes were reformatted into professional pictures which were then used for subsequent pitching situations and to test actual buying intentions through a pre-sale campaign on social media (see exhibit D). In this regard, the prototypes were subsequently reformatted into 2D formats that enabled reuse in situations that would otherwise be challenging or even impossible using the original and underlying prototype.

On the one hand, recycling prototypes carries an obvious cost and effort-reducing function for the entrepreneurs. Making or building new prototypes invariably carries some cost in time and money. The general resource-constrained nature of new ventures makes this cost reduction a useful cost-cutting mechanism for many of the entrepreneurs. On the other hand, single-use prototypes can be important and necessary investments for entrepreneurs, when "make or break" aspects related to the venture are in question. Given the resource-constrained situation of the entrepreneurs of our sample and entrepreneurship generally, there is a risk that developing single-use

prototypes may be inefficient, especially in earlier phases of the entrepreneurial processes when uncertainties about both outcomes and options remain high.

4.3 Skills: skills bricolage or new skills

The third theme relates to the skills deployed by the entrepreneurs to execute the prototyping activities. Across the prototyping instances in our study, the strongest trend we see is the use of skills already mastered by entrepreneurs when undertaking the prototyping activities. As such, they often rely on methods and techniques they are skilled in and, therefore, find to be simple and comfortable to employ. Building on existing work on resources in entrepreneurship (Baker & Nelson, 2005), we refer to this as skills bricolage, i.e., relying on skills already mastered when engaging in entrepreneurial prototyping. This is illustrated by the variety of prototypes created, which reflects the different backgrounds, skills, and preferences of the entrepreneurs creating the prototypes. In total, 130 of the prototyping instances involved skills bricolage.

For instance, while Beta, Gamma, and Kappa operate in seemingly different industries and strive to develop different offerings, they initiated their prototyping efforts using similar technical tools and techniques to model advanced early-stage 3D visualizations or to create functional prototypes, as the entrepreneurs had similar skills from their educational backgrounds. In contrast, the limited technology-specific skills of Alpha, Delta, and Zeta were reflected in the vast number of rapid prototypes created using simple available materials, such as cardboard and paper, which enable quick simulation without technical competencies.

Notably, as the founder of Gamma sought to create technical simulations to examine specific aspects, the entrepreneur encountered challenges in simulating using standardized software, as the emerging solution was still handmade, hence non-standardized and unavailable for simulation using the software. In response, the entrepreneur turned to simultaneous prototyping using physical scale models in wood to overcome the limitations of the digital technique. Similarly, the founder of Alpha engaged in a large project involving multiple stakeholders, and the collaboration was centered around an emerging, digital 3D model. However, the technical requirements of the prototype made it challenging for the entrepreneur to engage with the model; hence, she turned to a technique that she was comfortable using and created a physical, cardboard scale model, which then became the prototype in focus in subsequent cross-disciplinary development meetings.

Skills bricolage allowed the entrepreneurs to simplify their prototyping efforts. This means that the prototypes as artifacts that need to be produced are made more easily, at lower cost, and more quickly than if the entrepreneurs had to develop or in-source skill sets that they did not possess. Particularly, as explicated by Gamma, who reflected on the ease of relying on preferred techniques, as "that is just my way of working. I 3D model it. If the 3D works, then there is also a good chance that it works. Also, because, based on my education, I can work so quickly in 3D. I just think my time is better spent testing it in 3D rather than testing it all physically." This aligns well with the existing research on bricolage in entrepreneurship, where bricolage is brought forward as an enabler of entrepreneurial action (Baker & Nelson, 2005).

Furthermore, it became clear in many of the instances that relying on their skills made the entrepreneurs feel more comfortable and secure when undertaking prototyping activities, thus limiting the mental strain that these activities placed on them. Again, this focus on resources in the initiation and design of the prototyping activities carries a cost and effort-reducing function for the resource-constrained entrepreneurs.

The findings also illustrate some instances of entrepreneurs investing in new skills. In one example of this, the entrepreneur of Alpha needed a visually pleasing model to persuade key stakeholders responsible for making final acceptance decisions. As the entrepreneur did not possess the technical skills required to create such an instantiation, she ordered a high-fidelity, laser-cut scale model, which succeeded in gaining approval. Similarly, Theta needed to demonstrate the requirements for a digital platform to a programmer abroad. Lacking the technical skills to code a simple mock-up that the programmer abroad could use, the entrepreneur invested time learning to use the online tool Mocqup (see exhibit E). As reflected by Theta, "my new partner […] he simply required me to go in and use something called Mocqup to make the prototype of the new system. So, I just had to get to know that […] starting completely

from scratch with all the ideas I had in my head and the simple things I had sketched." Notably, the entrepreneur restricted focus to the specific functionalities of Mocqup that related to wire-framing.

In a few instances, divergence from the common pattern of skills bricolage had seemingly problematic effects. For instance, at an early stage in Theta, the entrepreneurs sought to develop an early functional prototype of a digital platform. However, rather than relying on simple techniques and tools, the team invested considerable time in coding the platform in PHP, despite possessing little experience with such coding. As a result, the early-stage prototype became overly complex, fostered considerable confusion, and eventually put too much stress and pressure on the entrepreneur in charge of the development, while the other team members still had no knowledge of the particular techniques. These frustrations were voiced by the lead founder in Theta, who explicated that "we are talking about a platform that was coded from scratch […] it might be a nice MVP, but it always required (the lead developer) to be there all the time. So, it had been built far too technical."

4.4 Navigating purpose and effort in entrepreneurial prototyping

Having outlined the three themes that emerged from our analysis and the variation in purposes, recycling or single use of prototypes, and skills use, we can now explore the patterns across the themes. Combining the variations across the themes, we can see that there is an empirically and theoretically interesting distribution of forms of prototyping with regard to the themes of our analysis. Specifically, the distribution of the forms of prototyping is not even, and four combinations occur much more frequently than others. The distribution is outlined in Table 4 which shows that two combinations occur in a total of just above 60% of the instances in our data. These combinations include recycled prototypes and skills bricolage and either flexible experimentation or directed transformation in terms of purposes. Further, another two combinations cover 28% of the instances. These combinations include single-use prototypes, reliance on skills bricolage, and either flexible experimentation or directed transformation. This distribution is empirically important in that it indicates strong patterns of reasoning and priorities on the part of the entrepreneurs. Firstly, it indicates that entrepreneurs find prototyping to be a relevant activity for both experimental and transformational purposes—so that prototyping is used by entrepreneurs to both open and close option sets in their entrepreneurial venture development process. Closing option sets using prototyping is thus clearly considered a worthwhile activity (Packard et al., 2017). Also, seeking to open option sets through open-ended and generative prototyping is undertaken to a significant extent by the entrepreneurs. Notably, the co-existence of experimental and transformative purposes in prototyping activities of entrepreneurs is not a surprising finding. The need to balance divergent and convergent elements and that prototypes can be used for both is well documented in the contexts of design and engineering (Goldschmidt, 2016; Micheli et al., 2019).

Perhaps more surprising is the seemingly very strong focus on existing and currently available resources in the form of already developed prototypes and skills bricolage on the part of the entrepreneurs. This is evident in the predominance of recycled prototypes and in particular the use of skills bricolage in the most common forms of prototyping in our sample of instances. It is also indicated in the very low occurrence of the experimentally oriented, single-use prototype embodying new skills that could be expected if entrepreneurs were to follow closely the scientifically inspired experimentation approach where the knowledge problem defines the prototyping activity such as in the lean startup approach (Camuffo et al., 2019; Felin et al., 2020; Ries, 2011, 2017).

Overall, the distribution suggests that the entrepreneurs encounter a nexus of purpose and effort when prototyping. There is, therefore, probably no single form of prototyping that fits all situations in the venture development process. When undertaking prototyping activities, entrepreneurs do—and probably should—develop prototyping activities that make the most of the resources available to them while achieving as many of the purposes that they want to address as possible. As such, e.g., instances, where entrepreneurs invest heavily in developing prototypes as vehicles for ideation, generative inquiry, and forward-looking discussions, are unsurprisingly rare in our data rather than narrow tests or evaluations of specific features (BenMahmoud-Jouini and Midler 2020; Lim et al., 2008; Yu et al., 2018). Conversely, flexibly experimental prototyping with a

narrow focus with a high reliance on resources held conceptually offers a particularly valuable possibility in the entrepreneurial process, if realizable, as is also stated in the resource-oriented prototyping principle by Lim et al. (2008). Experimentally focused prototyping can often involve elaborate and high-fidelity prototypes as well as carrying costs, but our findings show that this is not always the case when entrepreneurs manage to skillfully filter the focal parameters, using available resources. If such prototypes can be produced from available resources, which manifest as the available set of already developed prototypes and skills to develop and use prototypes, this represents an effective cost-reducing element that can help the entrepreneur move the venture forward. Notably, however, it could be imagined that other resources, such as network contacts and access to potential user or customer groups, would be relevant to include in this discussion.

5 Discussion

5.1 Implications for research: linking purpose and effort in prototyping

By exploring the extensive use of prototyping in our study, our findings extend both prescriptive work promoting the use of prototyping to advance entrepreneurial processes (Berglund et al., 2018; Felin et al., 2020; Frederiksen & Brem, 2017) and the empirical research that finds prototyping to be an important activity for entrepreneurs (Audretsch et al., 2012; Nelson et al., 2020; Wessel et al., 2022). What is most notable in our study, however, is the variation and heterogeneity in the prototyping activities undertaken. Instead of a clear direction in terms of hypotheses-driven experimentation or open-ended and resource-driven transformation, we found hybrid activities in which purposes and reliance on resources currently controlled interweave in analytically distinct ways. While this in no way disclaims the suggestions made by scholars promoting a scientific or experimental approach to entrepreneurial action, both in terms of empirical prevalence and efficacy in the entrepreneurial process, it does indicate some noteworthy issues. First, it suggests that the formulation of hypotheses is but one among many forms of purposes of entrepreneurial prototyping, and second that it may be empirically and conceptually useful to consider experimental prototyping with vocabularies other than the scientific one. While experimental purposes with well-defined outcome measures can be beneficial to constrain the search processes, as seen in systematic search and lean startup (Fiet, 2007; Fiet & Patel, 2008; Goldsby et al., 2014; Ries, 2011), at the same time, the entrepreneurs often found it challenging to prioritize goals and relevant information prior to acting, as also reflected by goal ambiguity and isotropy in the entrepreneurship literature (Sarasvathy & Dew, 2005).

Similarly, we found few instances of entirely open-ended and resource-driven transformative prototyping, which suggests that entrepreneurs most often seek to deliberately structure their prototyping activities with well-defined outcome measures or guiding the activities by broader purposes such as self-constraining criteria to constrain the design space. While research on effectuation suggests that entrepreneurs should act with available means (Sarasvathy, 2001, 2008), most of the entrepreneurs in our sample are nascent entrepreneurs with somewhat limited prior experience, skills, and resources available. This can explain why entrepreneurs in our findings almost always establish some form of purpose before engaging in prototyping to reduce the possible waste of valuable time and resources. Pure transformation becomes inoperable for resource constrained entrepreneurs. Most often, the few instances of purely resource-driven prototyping emerge when the entrepreneurs have difficulties in establishing clear purposes and prioritizing their immediate needs, whereby they turn to prototyping in an attempt to find a way forward.

Understanding entrepreneurial prototyping, in our view, thus requires a fuller understanding of these differentiated patterns and a discussion of their implications. The characteristics and distribution of forms of prototyping from purpose, recycling of resources, and skills bricolage represent an empirically grounded initial sketch for this.

Our findings thus indicate two important dimensions for research on prototyping and entrepreneurial processes: navigating purposes of prototyping as flexible experimentation or directed transformation and navigating resource use of prototypes and skills. The first of these dimensions has been extensively discussed in design thinking, in which prototypes

and prototyping have been intensely scrutinized (Camburn et al., 2015; Lauff et al., 2018). It is thus well established in this literature that an innovative or creative process involves phases of broad generative exploration and narrow experimentation and that different forms of prototyping activities enable these phases (BenMahmoud-Jouini and Midler 2020; Brenner & Uebernickel, 2016; Brunswicker et al., 2013). This mirrors recent developments in the entrepreneurship community, where the entrepreneurial process is increasingly conceptualized as a design and problem-solving process, wherein different stages of development can benefit from both explorative and evaluative techniques (Ding, 2019), and in which material instantiations such as prototypes can be utilized in numerous ways to overcome challenges (Berglund & Glaser, 2022).

What is less discussed in design thinking and other research fields such as engineering and innovation, where prototyping is also studied, is the link between prototyping and effort or resource use. Indeed, scholars are increasingly emphasizing the need for simplicity in prototyping, which indicates the use of simple, basic, or available resources (Buchenau & Suri, 2000; Dow et al., 2009; Lim et al., 2008; Menold et al., 2017; Viswanathan & Linsey, 2013; Yang, 2005), and, as pointed out by Tiong et al. (2019), successful prototyping does not only provide the output wanted but does so in a way that balances effort with the importance of the output (see Yang, 2005 for a similar point). Considering prototyping in the context of entrepreneurship, however, brings resources to the fore (Bruce & Baxter, 2019; Noyes, 2018), partly because entrepreneurs are generally considered to be resource challenged (Leyden & Link, 2015)—a characteristic certainly shared by the entrepreneurs studied here—and partly because the creative reinterpretation of resources is a key source of entrepreneurial success, as evidenced in the research on entrepreneurial effectuation, bricolage, and exaptation (e.g., Baker & Nelson, 2005; Dew et al., 2004; Sarasvathy, 2008).

5.2 Implications for practice: prototyping myopia and path-dependence

In addition to the above, and of particular importance for entrepreneurs, our findings also point to the potential risks and challenges involved in entrepreneurial prototyping. While overall prototyping often benefitted the entrepreneurs in their efforts, there were instances of prototyping that did not seem to advance the overall venture development process, indicating risks involved in prototyping if entrepreneurs engage in too much prototyping or misapply prototyping as a vehicle for development in the venture development process. Notably, any risks that emerge from too little prototyping were not available for study in our data with its focus on prototyping instances that have actually taken place.

Regarding prototyping that involve investments in new prototypes and/or new skills, it is likely that it may in some instances prove to be destructive to the entrepreneurial process if misapplied. By going beyond resources currently controlled, entrepreneurs become involved in potentially very costly engagements with knowledge problems or challenges that are not essential to the entrepreneurial process at any given time. This was clear in the case of Delta, in which open ended prototyping with new materials and skills did very little to advance the entrepreneur's understanding of what products he might actually sell in substantial quantities or the business model that would allow him to do so. As such, the prototyping—as an entrepreneurial activity—was destructive, as energy and resources were spent with no entrepreneurially relevant benefit. Indeed, an illusion of progress was created and sustained through prototyping, as explicated by Delta, who reflected that "I end up becoming distracted by all the new things that I continuously identify as fascinating or problematic, and then they come to occupy my attention rather than the things that matter. Then I make 'endless experiments'. I oftentimes become caught by the creative process. Maybe I am dissatisfied by something, and then that becomes my focus, rather than progressing on something." For Delta, the prototyping was perhaps meaningful as a design activity exploring the design space, but in terms of advancing the entrepreneurial venture, it was in fact destructive. The same was evident in the early stages of Theta when too much time and effort were invested in over-designing a complex, digital prototype, which came at the expense of immense stress and frustration, and eventually led to the prototype being cancelled altogether. As recounted by the principal founder at Theta, their prototype "was like building on a house that did not have mortar between

the bricks […] it was becoming way too demanding, and (the lead developer) ended up sitting with way too many responsibilities […] so we had a guy sitting there, working 18 h a day, and eventually he just completely crashed from stress."

Prototyping involving new investments in prototypes or skills may thus represent a costly option that should be reserved for make or break decisions or knowledge problems at stages of the entrepreneurial process where the option and outcome spaces have become somewhat restricted (Packard et al., 2017). By explicating the link between purpose and resources involved in entrepreneurial prototyping, we suggest that some caution be exercised towards the scientific approach to entrepreneurship, when following this method involves the creation of prototypes that require investment of new resources. The ability to assess when to use and when not to use this type of prototyping thus constitutes an important element in the overall frugal and restrictive investment of resources that most entrepreneurs need to exercise.

Prototyping that relies on available resources in the form of prototypes or skills represent another set of risks and challenges if misapplied. While reliance on resources currently controlled in the shape of already created prototypes or skills enables extensive use of prototyping, as in the rapid prototyping of design thinking (Brenner & Uebernickel, 2016; Klenner et al., 2022; Nielsen et al., 2017), there is a risk that this creates a kind of prototyping myopia. This myopia entails a focus on decisions and knowledge problems that can be addressed with the existing resources yet does not necessarily involve the essential make or break decisions that require new investments. If some critical reflection on whether to explore all that can be explored is not exercised, a false sense of progress may be induced through the use of prototyping—the perception of being very busy prototyping and making progress, yet not engaging with the knowledge problems that are actually important for the development of the entrepreneurial venture. Notably, while experimentally focused prototyping with available resources conceptually offers an attractive possibility for potentially resolving important knowledge problems with limited costs, the risk of prototyping myopia remains. If the narrow purposes explored are of limited real importance to the development of the entrepreneurial ventures, the perception of being hard at work prototyping will still not result in real gains for the venture. As such, the skills and prototypes possessed and already developed by entrepreneurs may lead to an unfortunate path dependency that drives the entrepreneurs to solve primarily those knowledge problems that can be solved using the available skills and prototypes, rather than solving the knowledge problems that are most essential for the development of the venture. Indeed, one concern might be that the positive narrative of prototyping in the practitioner field would strengthen this potentially problematic path dependency. A related concern is equally expressed in some parts of the design thinking literature on the importance of designer's ability to, e.g., visualize as a specific practice to guide an emerging and more open-ended inquiry (Micheli et al., 2019; Verganti, 2017). As provocatively stated by Verganti (2017, p. 101), the "apostles of design thinking […] have done everything they could to say that symbols are irrelevant: you can build whatever goofy prototype you want to build; the aesthetic dimensions of the prototype do not matter." This is to remind us that prototyping is intimately related to prototyping practices and the entrepreneur's ability to visualize, materialize, and so forth.

The above outline of potentials and challenges of entrepreneurial prototyping leads to two central implications for practice. First, a thorough reflection on the risks associated with misapplied prototyping is called for, a reflection that we do not necessarily see unfolded in the practitioner literature. Specifically, the risks of destructive, cost-intensive, and myopic prototyping warrant caution against the strong generalized claim about the potential of prototyping that we see, for example, in lean startup, design thinking, and other practitioner frameworks (Felin et al., 2020; Mansoori & Lackéus, 2020).

Second, the ability to be selective about the use of prototyping by navigating the intersection between purpose and resource investments in prototyping emerges as an important entrepreneurial skill. Unfolding the potential of prototyping thus requires entrepreneurs to skillfully and perhaps serendipitously navigate these two dimensions in a process by which what is needed and conducive changes (Petrakis et al., 2021). Prototyping needs to be tailored to the specific challenges that the entrepreneurial venture faces at any given time as a function of the knowledge problems faced and resources controlled (Lim et al., 2008; Tiong et al., 2019).

5.3 Limitations

Our study outlines several important strands of knowledge related to entrepreneurial prototyping but does have limitations. Owing to the inductive and qualitative nature of the study, the claims put forth represent propositional knowledge that can be analytically, but not statistically extended. Further, the study relies on the experiences and reflections of the entrepreneurs, making it difficult to make objective statements on the success or otherwise of the ventures and the instances of prototyping. While we consider this an important element of understanding how prototyping manifests in entrepreneurial processes, it does make objective and overall assessments of the merit of different ways of prototyping a speculative matter in this paper. Further research would benefit from different research designs if more objective evaluations are to be made.

6 Conclusion

In this paper, we contribute to the understanding of how entrepreneurs prototype, why they do it, and what artifacts are used as prototypes. Specifically, we show that the entrepreneurs use prototyping for flexible experimental as well as directed transformative purposes. We also show that the entrepreneurs make extensive use of prototyping recycling and skills bricolage, overall showing that they carefully navigate the balance between purposes and effort in the prototyping processes. Having identified the dynamics of purpose, recycling of prototypes, and skill bricolage, we further discuss the implications of the findings by suggesting potential challenges of misapplied prototyping in the form of myopia and unfortunate path-dependencies in the context of entrepreneurial prototyping.

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