Prototyping-driven Entrepreneurship: Towards a Prototyping Support Tool based on Design Thinking Principles

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The complexities and unique requirements of entrepreneurship and commercialization require novel prototyping approaches that go beyond their traditional application in engineering design. Prototyping, as a key part of Design Thinking, can address these requirements by focusing on creative problem-solving and by supporting entrepreneurs' reasoning. The broader requirements of entrepreneurship are not explicitly addressed in existing prototyping tools and instances of inefficient prototyping are still observed in entrepreneurial settings. This paper presents insights from expert interviews concerning prototyping and entrepreneurship, along with the formulation of the foundations of a novel prototyping support tool, tailored for entrepreneurs. Prototyping's approaches and challenges, user-prototype interactions, and prototypes' role in funding attraction are among the discussed themes.

Keywords: prototyping, design thinking, entrepreneurship, commercialization, prototyping support tool

Introduction

Prototyping is established as an integral aspect of product development and is considered a tool that can foster product innovation. The broader requirements of entrepreneurship have raised the need for novel prototyping approaches that go beyond their traditional usage in engineering design and fall into Design Thinking methodologies, a movement that can facilitate business success by focusing on the human aspect. Moreover, entrepreneurial failure, especially in the case of hardware innovations, can be strongly related to instances of misguided prototyping that are observed. Despite the establishment of prototyping support in previous research, the requirements of entrepreneurship and commercialization have not been explicitly integrated into developed tools.

2

Consequently, this work aims to introduce the foundations of a prototyping support tool tailored to entrepreneurial activities. The application of this tool can be proved beneficial for experienced designers as it can provide the opportunity to follow a structured design and prototyping process during venture development, as well as for entrepreneurs with inferior design skills through informing about the impact of design approaches on product commercialisation. A hypothesis towards the further development of this novel tool is formulated based on literature and interview findings.

Literature Review

Prototyping in Engineering Design

In engineering design, prototypes are defined as approximations of the end product along certain dimensions or features (Ulrich and Eppinger 2012). Designers utilize prototypes as they can reinforce learning and tacit knowledge by answering questions related to functionality and user requirements (Menold, Jablokow, and Simpson 2017; Lauff, Kotys-Schwartz, and Rentschler 2018), by unveiling unpredicted phenomena and design unknowns (Jensen, Elverum, and Steinert 2017) and by identifying key features, validating integration of product parts and sub-systems and refining the overall design (Camburn et al. 2017). They are also used as communicational tools that transfer information within the design team and to external stakeholders for demonstrating ideas, acquiring feedback and avoiding misunderstandings (Deininger et al. 2019).

Entrepreneurship and commercialization

Entrepreneurship is generally defined as the process of planning, launching and managing a new business venture to make a profit (Gaddefors and Anderson 2017). Several types of entrepreneurship are defined such as Traditional Entrepreneurship in SMEs (offering products/services on a small scale), Scalable Technology-based

Entrepreneurship (aimed at global markets), Social Entrepreneurship (offering sustainable solutions to social issues), or Acquisition Entrepreneurship (obtaining existing businesses) (Ballesteros-Ruiz, Cardenas-del Castillo and Corrales-Estrada 2019). This work focuses on the first two types and particularly on innovation-driven hardware technologies, in terms of introducing products onto the market and improving the entrepreneurs' performance. Profit, the ultimate purpose of entrepreneurial activities and critical factor of business success and continuous growth, primarily occurs through the return of investments, which are achieved by selling products (Godin 2006). The process of transforming ideas into viable products and launching them onto the market is known as commercialization. Commercialization is also regarded as a subpart of the broader innovation process, as an initial concept needs to encompass innovative qualities for increasing people's quality of life and tackling a properly defined problem to evolve into a marketable product. Even though technology can enable the realization of a novel idea, its actual success depends on people's decisions and behaviour (Innovate UK 2020). Nevertheless, innovation is an intricate process that involves a high degree of uncertainty, particularly in its early stages of defining the problem area, exploring the solution space and translating user requirements into product features (Link and Lewrick 2014).

Prototyping in Design Thinking

Design Thinking (DT) has become prevalent among other problem-solving methodologies such as systemic design or stage-gate models, as it is a process that empowers innovation by focusing on Human-Centred Design (HCD) and facilitates the alignment of desirability, feasibility and viability; crucial factors for innovation success (Brown 2008). It also uses the power of creativity to help innovators gain insights constantly and address arising challenges.
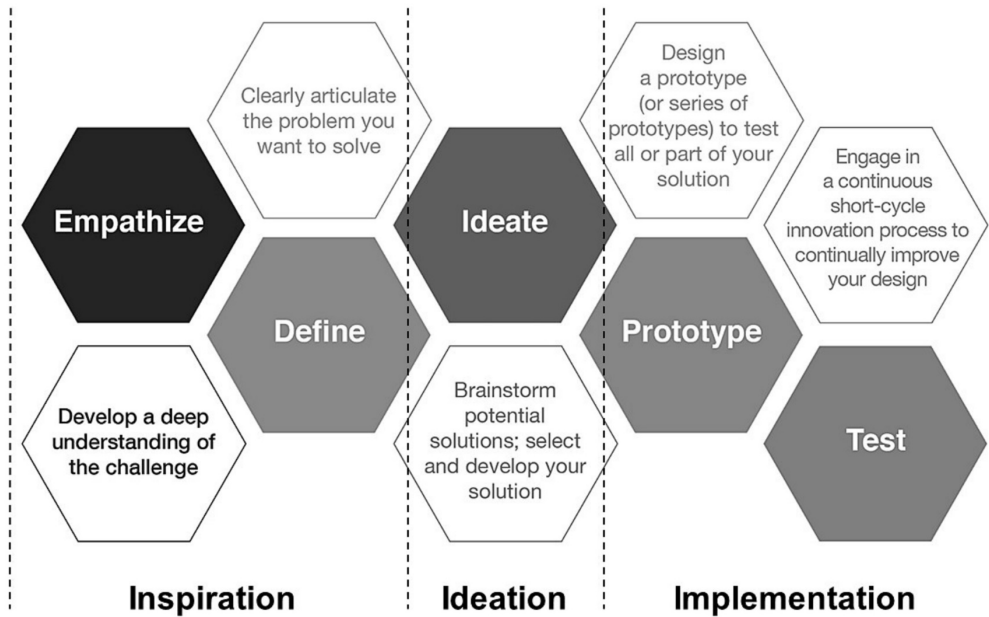
Figure 1. DT process (adapted from CITL 2021)

As Figure 1 shows, the DT process contains the phases of inspiration (empathizing with users for defining the problem or opportunity), ideation (brainstorming possible solutions) and implementation (conceptualization, evaluation and iterative idea refinement). Prototyping's role is vital in this iterative learning approach. As opposed to prototypes being traditionally considered as functionality verification tools, their role in DT falls within exploration and problem-solving phases, with a particular focus in the early stages (Alterum, Welo, and Tronvoll 2016). In this sense, prototypes can enable accurate evaluation and continuous refinement of tangible concepts (Kelley 2010), can stimulate imagination and facilitate idea exploration through divergent approaches (Böhmer et al. 2017) and are considered as 'building to think' tools (Brown 2008). Moreover, DT concentrates on the insights gained through the actual prototyping process, apart from the final prototyping outcome (Camere and Bordegoni 2016).

Prototyping in entrepreneurship

Due to the diverse requirements of entrepreneurship, the application of prototyping in such contexts can differ considerably from its usage in engineering design. The main advantages of prototyping during entrepreneurial activities lie in reducing uncertainties as early as possible (Camburn et al. 2017), cost-efficient testing, and the concept of 'failing early to succeed sooner' (Brown 2009). Although prototyping incurs a certain amount of expenses, the early verification of assumptions can prove time-savings and minimize the risk of requiring higher cost alterations during final development (Punkka 2012). Also, end users' interactions with prototypes result in valuable feedback which facilitates the evaluation of the product's desirability, by testing its purchasability, consumer value and user satisfaction (Menold, Jablokow, and Simpson 2017). Finally, prototyping can assist resource-constrained businesses with either inadequate funding, timescale pressures or insufficient experience (Nelson et al. 2020). In these cases, prototypes can aid in raising funds from investors or crowdfunding campaigns by representing the idea and attracting interest (Gerber and Hui 2013). This is particularly important for new ventures, as they can apply prototypes for demonstrating their progress and acquired knowledge (Mehlenbacher 2017) and therefore being considered as lower-risk investment options.

The issue of misguided prototyping

Even though many domains are showing interest in implementing DT approaches, and despite prototyping being at the core of the DT philosophy, misinterpretations and instances of inefficient prototyping are still observed according to research studies (Christoforakos et al. 2019; Diefenbach et al. 2019; Nelson et al. 2020; Srinivasan et al. 2020). The reasons behind misguided prototyping mainly feedback to the broader requirements of entrepreneurial practice, as opposed to traditional product development

processes, as well as to the complexity of modern, globalized markets and user requests (Hansen et al. 2020). Also, given that several diverse stakeholders are integrated into such processes, ineffective prototyping is often connected to their different perceptions and responsibilities, which in turn affect their productive communication (Diefenbach et al. 2019; Blomkvist and Holmlid 2011). The lack of available funding resources and the limited skillset of innovators in accomplishing design and entrepreneurial tasks are other two significant factors that impede effective prototyping and prevent the execution of specific strategies (Srinivasan et al. 2020; Nelson et al. 2020). However, ineffective prototyping also relates to businesses not realizing the full value of design and not adopting design approaches. Such barriers can be caused by insufficient investment in design, poor management of design processes and lack of strategic design leadership (Innovate UK 2020). Furthermore, it is observed that businesses struggle to view 'design' as something more than a form-fitting or styling process that belongs to the final stages, ending up not incorporating it in their processes and consequently in disregarding prototyping's strategic value (Danish Design Centre 2016).

Justification of research

Although significant research has been conducted with regards to structuring the prototyping process (Lauff, Menold, and Wood 2019; Menold, Jablokow, and Simpson 2017; Hansen et al. 2020), the developed frameworks and tools do not thoroughly address the unique requirements of commercialization and the particular challenges of entrepreneurs. Therefore, our fundamental goal is the creation of appropriate support that will guide such individuals during prototyping and decision-making activities and will assist them in achieving entrepreneurial success through the adoption of a design-driven and prototyping-driven mindset. In addition, this is an opportunity to evolve previous work (Petrakis, Wodehouse and Hird 2021), which focuses on prototyping's

multiple purposes, by appreciating their importance in entrepreneurial settings. Defining an explicit purpose to be achieved by a prototype can ensure higher quality outcomes and inform decision making (Houde and Hill 1997); still, the task of constituting this purpose requires experience and reflective thinking which comes less naturally to individuals with limited design knowledge (Petrakis, Hird and Wodehouse 2019). In summary, this work has been led by the following research questions:

- What are the advantages and challenges of prototyping in entrepreneurship and commercialization efforts?

- How can prototyping, as a part of DT, assist entrepreneurs in achieving business success, attracting investment and developing a design-driven mindset?

- What are the requirements and the key process steps of an entrepreneurship-focused prototyping support tool and how can it be adopted in practice?

Methodology

Scope of study

To better understand prototyping in entrepreneurial settings, we have engaged with experts to understand how they applied prototypes during these activities and to validate literature findings based on practice. Since these processes do not follow an identical structure and involve organizations and individuals of a diverse nature, our objective was to gain insights from multiple types of stakeholders. In this way, we will be able to appreciate all arising challenges and realize which areas have to be addressed to develop prototyping support. In this work, we will be holistically regarding prototypes as information prompts, regardless of their fidelity, and we will be mainly based on their emergent roles in supporting learning, communication and decision-making (Lauff, Kotys-Schwartz, and Rentschler 2018).

Research design

A qualitative research approach was implemented to facilitate the investigation of the research topic from the participants' point of view and interpretation and allow insight into their experiences and perspectives (Creswell 2013). Semi-structured interviews were applied for the gathering of data, as the structure of this method is known to be specifically designed to promote discussion, which is highly valuable in the case of an exploratory study (Patton 2014). Also, this method allows a significant degree of flexibility to expand on specific areas, if something stimulating or unexpected is mentioned, through additional follow-up questions.

Interview agenda and data collection

An interview agenda was prepared before the initiation of the study and comprised of open-ended questions along with particular themes to be discussed, both developed following the article's research questions and the related literature. The included questions were designed to be as broad as possible to facilitate a wide scope of answers and to allow the extraction of unbiased information from the participants. The themes which guided the interviews along with their descriptions can be seen in Figure 2.

Themes	Description
Prototyping perceptions & approaches	• Interpretations and language terms for specifying prototypes according to function • Explanation of strategies applied and why they are selected • Opinions on the "Purposeful Prototyping" concept and importance of "purpose" factor • Factors affecting selection of prototyping methods
Challenges & barriers with prototyping	• Difficulties in acquiring necessary funding for the completion of prototyping activities • Challenge of properly managing cash flow and project's time schedule • Importance of prior engineering/design/prototyping knowledge, mindset and experience • Identification, understanding and ideal selection of available prototyping technologies and services
Investors' expectations and funding attraction	• How prototypes can show the potential of concepts in front of investment panels and attract interest • Particular usage and importance of physical models as persuasive tools • Importance of prototype usage as a backstage tool demonstrating the overall conducted work • Developing appropriate context around prototypes and considering the different types of audiences
Users' interactions with prototypes	• How prototypes can facilitate user feedback during the project's fuzzy front-end stages • Exploration and appreciation of market landscape and consumers' behaviours through prototyping • How active involvement of end users into design and prototyping processes can benefit the process • Description of different types of users to be included
A novel prototyping support tool	• Overall views on the potential of the research project • Brief discussion of the requirements and factors to be addressed in the developed support • Tool's interface, layout and areas of focus

Figure 2. Interview themes and descriptions (own graphic)

Each interview lasted approximately 60 minutes and was performed either through phone/video calls, or face-to-face meetings. All participants were asked their permission for recording the interviews and the audio files were transcribed. The processing and synthesizing of the results were manually performed, as the pre-defined themes, along with the chosen method of semi-structured interviews, allowed the systematic presentation and analysis of the collected data. For the composition of findings, colour-coding methods were applied for the identification of statements against the specified themes, which were then merged according to similarity. Figure 3 shows that the 15 interviewees occupied a variety of roles and all have either theoretical knowledge or hands-on experience in prototyping during entrepreneurship. To show the different sectors they represent, we categorized them into 4 types of actors existing in a design-driven entrepreneurship scenario: Innovation experts, Entrepreneurs, Design engineers and Design consultants. The diversity of their backgrounds in combination with their shared experience in entrepreneurship allowed us to attain a comprehensive understanding of prototyping usage and consider as many perspectives as possible during the formulation of the new hypothesis.

#	Participant Title	Short Description	Role Category
1	Knowledge Transfer Manager	Management of design and acceleration of innovation programmes, creation of support tools for generating value from new products	Innovation Expert
2	Knowledge Transfer Manager	Access to funding and finance specialism, supporting SMEs and start-ups in maximising growth, management of innovation support programmes	Innovation Expert
3	Knowledge Transfer Manager	Design and innovation consulting, supporting SMEs and R&D teams by de-risking processes using design thinking and HCD methods	Innovation Expert
4	Design Engineer & Start-up Director	Design engineering background with strong experience in entrepreneurship, design competitions and product commercialization	Entrepreneur
5	Product Designer & Start-up Founder	Product design and engineering background with strong experience in innovation, entrepreneurship and launching products to market	Entrepreneur
6	Mechanical Product Design Engineer	30+ years of experience in design engineering of hi-tech, high volume products and management of product development innovation processes	Design Engineer
7	Design Innovation Consultant	Significant experience in consulting through the combination of creative, technical and user experience expertise, innovative research direction	Innovation Expert
8	Design Managing Director	30+ years of experience in product design & development, consultancy and business management, co-founder/director of design consultancy	Design Engineer
9	NPD Consultancy Founding Director	New product development expertise, focus on taking products to market, owner of research and product development consultancy	Design Consultant
10	Industrial Product Designer & Consultant	Owner of product design and manufacturing company, 16+ years of experience in product design engineering, R&D, production and branding	Design Engineer
11	Senior Design Engineer	Experience in design, customer support, project management and funding applications for manufacturing and research institutes	Design Engineer
12	Design Strategy Manager	Strong experience in connecting academia to industry, translating design methods to viable products, academic and industrial background	Design Consultant
13	Director of Engineering Consultancy	20+ years of experience in mechanical engineering and manufacturing, expertise in offering project management and engineering training	Design Consultant
14	Design Engineer & Start-up Founder	Design engineering background with entrepreneurship experience, published researcher, project engineering for multinational companies	Entrepreneur
15	Start-up Co-Founder	Entrepreneur with background in international management and experience in business acceleration, logistics and IoT solutions	Entrepreneur

Figure 3. Interview participants and role descriptions (own graphic)

Findings and Discussion

This section presents the findings from the conducted expert interviews, based on the aforementioned themes. Initially, participants' prototyping perceptions and approaches are described in terms of language terms, strategies and prototyping formats. The main challenges of entrepreneurial prototyping which are mainly related to funding availability and entrepreneurs' experience are also discussed. Then, the importance of prototyping, both as a direct or indirect tool, in communicating concepts and demonstrating entrepreneurs' product knowledge to potential investors is reviewed. Finally, this section ends with highlighting the advantages of prototype-user interactions in acquiring feedback, familiarising with the market landscape and co-creation.

Prototyping perceptions and approaches

Perceptions and definitions

Although all participants have significant experience in their respective fields, their perceptions of prototyping were diverse. The ones coming from a design or engineering background defined a prototype as 'something to test, replicate and learn from' or 'anything that can verify what you are trying to achieve' and agreed that it can encompass various levels of fidelity. However, since the confusion of inexperienced stakeholders surrounding prototyping terms was acknowledged, innovation experts suggested using simple, yet descriptive, terms such as 'size mock-up' or 'aesthetic model' which align with the prototypes' main function, to manage clients' expectations. On the other hand, a few did not relate the term 'prototype' with digital models or detailed simulations and do not apply it unless they are building pre-production or final stage models.

Strategies and prototyping purpose

All the participants agreed that the execution of prototyping activities should be guided by a structured process; however, while the existence of established prototyping strategies was accredited, the majority does not regularly use a specific prototyping tool. Instead, they all showed a tendency to apply their processes which are influenced either by their experience or the company's internal 'know-how' and to accordingly modify them in agreement with each project's necessities. Moreover, in entrepreneurial settings where resources may be limited, prototyping processes always need to be revised based on the availability of materials, equipment and overall costs.

As far as specific strategies are concerned, participants highlighted the importance of iterative prototyping, supporting that going back and forth through the

design stages can evolve a prototype better. With this, experts referred to prototyping as 'a continuous tool, always in-play', and believed that it should be applied continuously throughout the process instead of constituting a singular design stage. Nevertheless, they indicated that it is crucial to understand when to apply it during the design process, agreeing that prototypes should always be guided by explicit, pre-defined objectives. Experts considered the planning of a prototype's purpose as a process of due diligence, explaining that significant effort should be made for exploring, understanding and establishing the main intent of a prototyping activity to avoid meaningless outcomes. The overall purpose of prototyping should be the mitigation of risk throughout the design process, which can be achieved by a continuous evaluation and validation of the latest design configurations. Prototyping's ability to make considerations tangible results in constructing a feeling of confidence and comfort around the product. Interviewees stated that prototypes are also major elements of the project plan and believed that they can also function as scheduling tools, assisting in the optimization of project planning in terms of time and cost. Particularly in entrepreneurial settings, prototypes should operate as decision-making points or milestones, and thus, define whether the next steps should be followed based on their performance in set objectives.

With the prototype format, experts believed that the choice between physical or digital should be depending on the intended purpose and process stage. Such decisions are also affected by the designers' skillset and confidence they possess in specific methods, by the access to required technologies and by clients' preferences. While physical models seem to be performing better in terms of communicating ideas and raising the level of discussions during a pitch, digital prototyping's advantages should not be overlooked. Simulating performance can be very cost-effective in cases where final materials and tooling are expensive and time-consuming. Also, digital prototyping

facilitates the quicker generation of multiple versions of the same concept, as they can easily be organized, tracked, compared and iteratively tested.

Challenges of entrepreneurial prototyping

Availability of funding

One of the most important faced challenges is related to the availability of funds, as the cost of prototyping activities actively affects their planning and completion. Participants agreed that insufficient funding usually decreases the quality of the prototyping outcome, which in turn affects the information and feedback derived from the prototype negatively. Also, innovation experts claimed that entrepreneurs' creativity and decision-making may also be constrained, as they do not have the opportunity to build, explore and evaluate multiple concepts in parallel, ending up working solely on their initial idea. Such barriers are more common in the cases of individual entrepreneurs and start-ups as they are not able to absorb equity in return for providing services to their customers, to fund their early-stage prototyping and development activities. Providing that the most effective way to attract investments is showcasing evidence of demand or recurring profitable revenue, it is even more challenging for new ventures who have not launched any products yet. In such cases, the most common way to pursue funding is entering early-stage competitions intending to claim awards that can be used to proceed with prototype development.

Skillset and background

Another challenge is related to entrepreneurs' skillset and technical experience, which is unquestionably most observed when they have little or no prior engineering or design knowledge. Successful entrepreneurs indicated the advantages of coming from design university courses, as they were able to exploit their confidence and learning, and create

multiple prototype types easier and faster, using various techniques and tools. Innovation experts also acknowledged this challenge by referring to cases of design-oriented entrepreneurs using prototypes continuously, as opposed to inexperienced ones who tend to put all effort and resources into final pre-production models. In the case of non-experienced entrepreneurs, the only option is to outsource prototyping work to progress through the stages of the development. Although this solution can increase the quality of the end product, they would need to spend a considerable amount of time and funding for such services.

Selection of prototyping methods

Finally, the last main challenge concerns the identification of available prototyping technologies, understanding what they offer and assessing when they should be used. Inadequate appreciation of prototyping methods can mislead inexperienced entrepreneurs and produce false perceptions such as a prototyping failure being treated as a design failure or a working prototype indicating a ready-to-be-made solution. Moreover, due to the lack of confidence in particular prototyping methods, unsuitable prototyping formats may be selected for the required purpose or stage. From the point of view of design consultants, the main challenge is convincing entrepreneurs to commit to the risk of spending money for prototype development. Due to insufficient experience, some entrepreneurs tend to consider iterative prototyping as a low priority, planning instead to spend all available budget on the final prototype. In addition, they show rigidity with regards to prototyping decisions, as they incorrectly follow certain prototyping methods based on success in different sectors.

Investors' expectations and funding attraction

Various types of funding channels exist for entrepreneurs starting or growing their

businesses. The primary forms of available finance fall into the categories of debt (securing a business/start-up loan or overdraft), equity (return of investments to venture capitalists, angel investors or business accelerators) and grants or awards (provided by government or private bodies and competitions). Our discussions focused on the latter two categories and indicated that the specifications of funding applications, investment pitches and competition calls define the nature of work expected from entrepreneurs, which consequently affects the level of involved prototyping. Such requirements are usually related to the process stage, number and background of stakeholders and degree of user-prototype interaction.

Direct, persuasive tool

All interviewees admitted that prototyping can assist entrepreneurs in communicating their ideas to investors or while pitching for competitive grants. Based on our insights, a presented prototype will facilitate a more accurate evaluation of the presented idea, as investors always need unambiguous information to inform their decisions. Although an accompanying prototype may not be considered as a mandatory requirement, it was articulated that investors want to see one as it would reveal the entrepreneurs' initiative and ability; their ambition to exceed what is expected from them. Prototypes were regarded as excellent 'persuasion tools' due to their ability to communicate functionality and aesthetical features and therefore show the product's maturity and attract interest. They can also assist in justifying the product's impact to a market opportunity, by evidencing how it can surpass existing products and in articulating what differentiates it from competitor proposals. Particular mention was also given to the superiority of physical models, in comparison to verbal descriptions or two-dimensional design representations, due to them being conversational prompts and facilitating engagement over real artefacts. Moreover, prototypes can communicate a product by its

price, as it is usually easier to associate a product's value with a physical model. Experts believed that high-resolution realistic models are more attractive for venture capitalists; however, considering their higher cost, combinations of multiple prototyping formats should complement a funding application.

Indirect, backstage tool

It was argued that investors capitalize on the actual business instead of on innovative products since their main concern is the return of their investments through market opportunities which indicate strong growth potential. Consequently, they tend to look for skilful teams, able to deploy this relevant field knowledge and show a clear way to market. In such cases, entrepreneurs have to shift their focus from the prototyping outcome and instead make prototyping work effectively as a backstage tool; as a means to achieve their main objective of launching their product. As an indirect tool, a prototype can demonstrate the overall conducted effort of progressing from research and ideation stages into multiple rounds of testing iterations and illustrate how risk has been quantified and managed. Even prototyping failures can help investors understand a product's potential compared to a single detailed and matured prototype with no surrounding information outputs. In other words, prototypes can convey confidence to investors by showing how questions have been answered and help them understand what an entrepreneur wants to achieve out of his new business. Thus, 'funding should not be the ultimate purpose', as stated by a design expert who explained that grants will naturally be attained through this comprehensive grasping and communication of learning achieved through prototyping activities. Apart from building the right context around the prototype, carefully considering the types of audiences to whom it is demonstrated is also important, as investors do not share identical technical backgrounds. As a result, it is vital to align the prototype's purpose and features with

the audience's characteristics, through prior research in their expertise and technology understanding.

Users' interaction with prototypes

Feedback and market landscape

End users are regarded as key stakeholders during entrepreneurial activities, and it is vital to verify desirability during the initial stages. User-prototype interaction can strongly contribute to this by empowering feedback and reinforcing the process of translating requirements into design features. Entrepreneurs stated that having available prototypes for users to explore, offers a massive advantage by generating a positive first impression. Providing that having a pipeline of ready-to-buy customers is a vital requirement, user involvement makes them feel more valued and inclined to buy the product. Concerning the market landscape, user-prototype interaction can define a clear way to define target users and show how the product will be aligned with the opportunity. As market validation is considered as a basic design principle, applying prototypes can facilitate the understanding of customers' behaviours, language, problems, and help in picturing the competitive landscape. In the case of non-existing competition, users' interaction with prototypes can elicit new habits or examine how current ones can be displaced. Moreover, user-prototype interactions can define the modifications needed due to diverse cultures, when entrepreneurs are aiming to expand their business into new markets.

Active involvement and co-creation

Interviewees also mentioned the benefits provided by the active involvement of users in prototyping activities. This kind of co-creation can significantly fulfil the HCD aspect of the product, as prompting users to participate in design tasks results in constant

feedback and honest answers to requirement-related questions. Users may happen to use prototypes in different ways than intended or imagined, which can also lead to the elicitation of new, unknown requirements. However, in circumstances where direct involvement is not possible or very costly, innovation experts clarified that it is vital to try and connect the users to the prototyping activities through alternative methods which would still allow fruitful conversations. Design experts also noted the significance of considering all different types of users, as modern products tend to have a long lifecycle. Distinctions should be made between people who purchase and people who engage with the product in various ways, and input should be sought from manufacturers, assembling, shipping and packaging partners and servicing clients.

Formulation of a New Hypothesis for an Entrepreneurship-focused Prototyping Support Tool

Based on the discussed interview insights and literature findings, we have formulated a hypothesis that presents the underlying foundations towards a newly proposed prototyping support tool. This has been achieved through deriving its essential requirements and defining its overall aim. Based on these, we have developed a support process by explaining the rationale for its key steps, as illustrated in Figure 4. Finally, we provide implications on how it can be applied in practice and adopted within entrepreneurial practices.

Tool requirements and areas of focus:

- *Decision-making:* Findings from section 'Strategies and prototyping purpose' confirm that prototyping should not be treated as an isolated activity or an individual design stage; however, explicit purposes and the specific points at which it is applied should be defined. Since these two requirements are clearly

correlated, the support should comprise of a decision-making guide that restrains wrong decisions about what kind of prototyping is applied, at which stage and for which purpose. Moreover, providing that choosing prototyping formats is one of the observed challenges according to 'Selection of prototyping methods', entrepreneurs should also be guided in appreciating the value that different prototyping levels and technologies would offer to their project and whether it is aligned with their intentions.

- *Communication and persuasion:* Based on the acknowledged standing of prototypes as communication and persuasion tools, according to both literature and findings from section 'Investors' expectations and funding attraction', the tool should have the capacity to assist entrepreneurs with articulating their ideas and building the right context around them. In this way, they will be enabled to appropriately complement their investment pitches and help the audience reach a clear understanding of the prototype's intentions.

- *Development of design-driven mindset:* In section 'Indirect, backstage tool' notable acknowledgement was given to prototyping's ability to reveal the actual learning that has been achieved throughout the overall process. Therefore, entrepreneurs should be provided with the opportunity to develop and properly reflect that kind of holistic approach to design and prototyping activities. This can be accomplished by guiding them on how they should conduct research, evaluate ideas, manage resources and consider risks or failures. In this manner, they can demonstrate that key decisions have been reached through tangible understanding and informed outputs instead of personal bias and assumptions, and therefore display the attributes of confidence and business potential sought by investors.

- *Modularity:* In section 'Prototyping perceptions and approaches' it is observed that participants tend to not regularly apply established prototyping tools. Due to the differences across entrepreneurial journeys, we can assert that while a structured prototyping process offers a solid foundation, to begin with, each project's critical factors and risks need to be explicitly considered for the appropriate integration of them into the tool. Therefore, it should be able to ensure a process that is modified according to unique circumstances and unforeseen changes. Also, engagement with the tool should not be time-consuming and the incorporated guidelines should be easily followed without disrupting progression through stages.

- *Language:* Given the existing ambiguity discussed in section 'Perceptions and definitions', the tool should aim to establish a common prototyping language. As many different individuals are involved in entrepreneurial activities, ensuring understandable linguistic terms for each prototype according to its purpose or design stage would enable effective communication, promote constructive discussions and support audiences who are unfamiliar with design terms.

- *Assessment of prototyping outcomes:* Given prototypes' importance as key project milestones according to section 'Strategies and prototyping purpose', the support should consider how the success of prototyping outcomes will be assessed. Since it is unfeasible to reach perfection with prototyping, it is vital to define specific goals to be achieved and assess prototypes based on pre-established factors at key decision-making points. The performance of prototypes against these factors and the evaluation of the acquired information will consequently reveal if the entrepreneur should progress onto the next steps or, instead, revisit previous tasks.

- *Human-centred design:* Since commercialization is a procedure including individuals with diverse roles, responsibilities or influence, the human factor should be at the core of the support. As previously mentioned in sections 'Investors' expectations and funding attraction' and 'Users' interactions with prototypes', people's engagement with prototypes is a crucial factor affecting business success. Moreover, the characteristics of the targeted audience should strongly define the prototype's features and the chosen format. Consequently, it is vital to elicit every stakeholder's requirements and to consider how people assess feasibility, desirability and viability, the prerequisites of innovation success.

Overall aim and steps of support process:

In general, the tool should assist with minimizing risks and decision-making during entrepreneurial efforts, with the further aim of achieving commercialization. This is based on literature findings indicating that profit through market launch is the ultimate goal of entrepreneurial success and a precondition for continuous growth. Section 'Challenges of entrepreneurial prototyping' shows that risk predominantly arises from inadequate resources or lack of experience and inclusive design understanding. Since commercialization has been defined as 'the capability of a market actor to gain other market actors' acceptance of its value proposition' (Sløk-Madsen, Ritter, and Sornn-Friese 2017), the tool will also be exploiting prototyping's capabilities to help entrepreneurs in demonstrating the competence needed for the persuasion of investors and consumers. In detail, this can be achieved by following a structured process, the 4 key steps presented below:
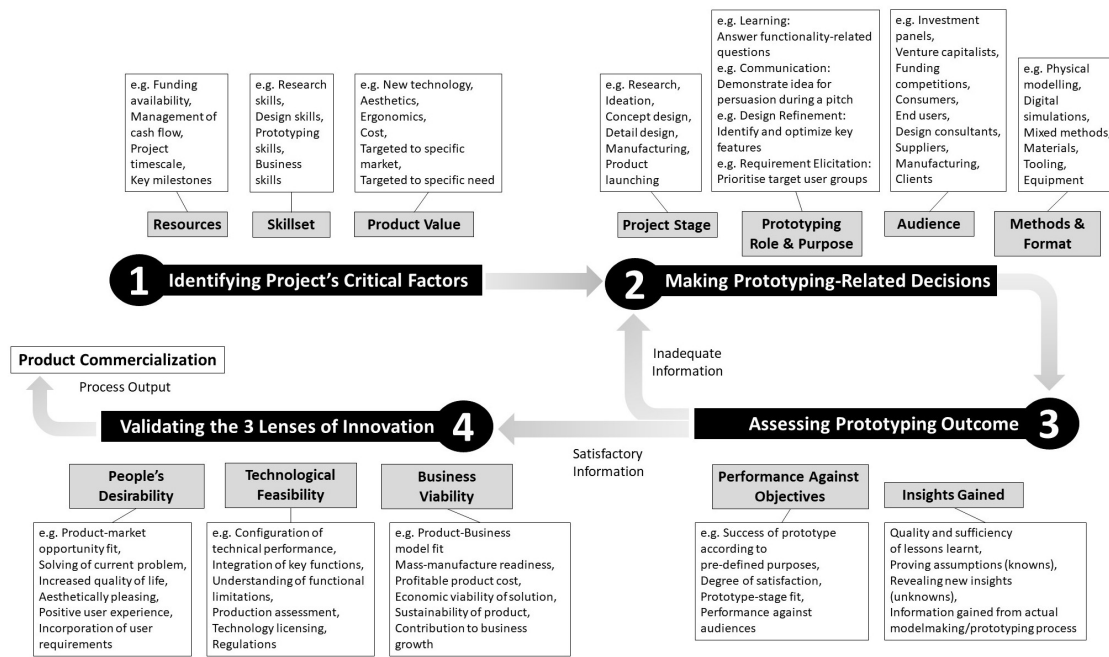
Figure 4. Key steps of the entrepreneurship-focused prototyping tool (own graphic)

(1) In Step 1., entrepreneurs should identify the project's critical factors to integrate them into the process and manage them systematically. These are related to the available resources, their skills and experience, as well as, recognizing which particular aspect of the product is its actual value. These factors will accordingly inform the prototyping activities needed.

(2) In Step 2., they will be able to make prototyping-related decisions according to the factors identified in Step 1., e.g. choosing at which stages prototyping will be applied and establishing clear purposes and objectives of prototyping activities. The factors of timing, purpose and audience at which prototypes are demonstrated in correlation with the availability of resources and the required skill set will consequently prescribe the prototyping format and technologies to be pursued.

(3) In Step 3., entrepreneurs will have to assess the performance of the produced prototyping outcomes against their pre-defined objectives from Step 2 and evaluate the quality and sufficiency of the acquired insights. In case of prototypes not offering satisfactory information, prototyping decisions and execution should be reconsidered through revisiting Step 2.

(4) Finally, in Step 4., the entrepreneurs will be able to utilize the lessons learnt through prototyping to validate their product against the 3 lenses of innovation (Brown 2008). Confirmation and alignment of people's desirability, technological feasibility and business viability based on prototyping outcomes will ensure the product's launch and, as a result, entrepreneurial success.

Scope of applicability

We hypothesize that this tool has great potential within new ventures since the lack of DT mindset and misguided prototyping are commonly detected issues. Providing that there is some overlap between the effectual reasoning used by expert entrepreneurs and the logic of experienced designers (Møller Nielsen, Wikström, and Tollestrup 2013) this support format can facilitate entrepreneurs to develop a wide-ranging design mentality that will reflect the structured thinking and rationale behind their decisions.

Entrepreneurs can apply this tool to plan their overall process based on prototyping and assess the impact of their activities. Through identifying project aims and critical factors, the tool will provide digestible information and bespoke guidelines which will inform decisions of technical or business nature. It can also be utilized by business incubators/accelerators, investment programmes and award competitions provided that it is aligned with their requirements and policies. These bodies and their mentors can use this tool to complement their support and resource-distribution

methods. Moreover, it can be used to enhance the collaboration between entrepreneurial networks and in co-working incubator spaces.

Although this tool is being developed with a focus on entrepreneurial efforts in innovative hardware technologies, it still has the potential of application in other design fields. In design of Product-Service-Systems (PSS), prototypes are similarly integral through their role in understanding and integrating users' needs into the process (Ilg, Wuttke and Siefert 2018). Due to the tool's systematic process and common aspects found in PSS (e.g. stakeholders' profiling, resource-allocation, and risk-assessment modes) it can be aligned with or incorporated into established PSS tools, such as Actor-Network, User Experience Map or Business Model Canvas, and consequently support multiple prototyping formats, for instance, roleplay, scenarios and service mock-ups.

Reaching a generic model solution is a considerable question due to the diverse characteristics of different design fields. Nevertheless, a universal problem-solving process can be followed across all of them, as the applied input factors do not change the overall value of the output produced for learning purposes; which in this case are prototypes as in their general definition 'primitive forms of an idea'.

Conclusion, Limitations of Study and Future Work

This works aims to present the underlying principles of a novel prototyping support tool and is mainly justified from identified instances of inefficient prototyping and the lack of available entrepreneurship-focused prototyping support. The importance of Design Thinking approaches and prototyping's offerings in entrepreneurship are among the key themes discussed in our review of the literature. Expert interviews have also revealed the potential of prototyping in attracting investment interest and acquiring funding, the significance of prototype-user interactions, as well as the key challenges of entrepreneurial prototyping which are mainly related to inadequate resources and design

skills. The above findings are synthesized for the formulation of a new hypothesis towards a novel prototyping support tool, which is comprised of the tool's main aim and requirements, its key process steps, and implications for its adoption in entrepreneurial practice.

Although the conducted interviews provided a meaningful understanding in relation to prototyping usage in entrepreneurial settings, we agree that further engagement with a larger sample of participants, through surveys or workshops, would result in broader insights and would open up new conversations about entrepreneurial prototyping beyond product development, such as prototyping a start-up or PSS prototyping.

Future work includes the completion of the tool's development and the investigation of its impact on design-driven entrepreneurship through the evaluation of its applicability and efficiency based on supplementary empirical studies. Its user interface will be thoroughly examined to ensure an undisruptive and unambiguous type of support. Finally, entrepreneurs' engagement with the tool through focus groups and adoption in projects will offer valuable feedback towards its continuous refinement and validation against the derived requirements.

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List of Figures

Figure 1. DT process (adapted from CITL 2021)

Figure 2. Interview themes and description (own graphic)

Figure 3. Interview participants and role descriptions (own graphic)

Figure 4. Key steps of the entrepreneurship-focused prototyping tool (own graphic)