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The evolving role of prototypes in design research: a discussion on terms and meanings.

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Abstract | In this paper, we present the preliminary findings of an ongoing research project addressing the role of advanced prototypes in design research. The project aims at investigating the evolution of the role of the prototype in design research, given the recent advances in prototyping techniques and processes. In the first phase, we collected a diversity of definitions from literature, outlining both traditional and emerging traits of the use of prototypes. We observed that researchers tend to classify prototypes based on a variety of different purposes, which are tightly bound to the type of enquiry being carried out and the specific area of research in which they work. The emergent heterogeneity of terms and meanings shows that the definition of prototype is anything but univocal. This multiplicity of definitions led us to develop an overview of the assortment of terminologies and purposes that researchers use to describe the role(s) of the prototype.

KEYWORDS | PROTOTYPE, RESEARCH ARTIFACT, DESIGN RESEARCH

1. Introduction

1.1 The changing role of prototypes

Design is deeply rooted in the culture of making, being traditionally devoted to transforming ideas into tangible outcomes. This hallmark of design is currently undergoing a radical change due to a twofold countertrend phenomenon. On the one hand, a profound process of dematerialization, which largely affects the world we live in (Moles & Jacobus, 1988). This process entails everyday objects losing their physical attributes and turning into either purely digital artefacts (e.g., bitcoins) or new types of product merging physical and digital features (e.g., smart objects, IoT, etc.). On the other hand, the emerging role of speculation – meant both as a means and as an end of the enquiry – in some areas of design research (e.g., design fiction (Bleecker, 2009; Dunne, 2013)). This shift makes tangible artefacts no longer an imperative stage of the design process, paving the way for a wider notion of both prototype and prototyping.

In other words, designers are still in charge of making things come into being, but regardless of their physicality. In the context of this paradigm shift, prototypes (both tangible and intangible) have come to acquire a crucial role in the process of knowledge production – mainly at the academic level – as they are considered carriers of meaning and, as such, *means* to conduct research. The terms of this new role are reflected in the preliminary findings we report on in this paper. Indeed, the proliferation of new jargons and terminologies in some areas of design research signals the attempt of giving a status to a *changed role* of the prototype.

1.2 “Advanced prototypes”: scope and limitations

As part of an ongoing research project addressing the “role of advanced prototypes in design research”, our findings shed light on the plurality of perspectives regarding the notion of prototype. From this plurality of views, besides the traditional understanding of what a prototype is (i.e., first unit of a product to be mass-produced), new conceptions emerge clearly, emphasising the theoretical and generative contribution that prototypes give to the research process. As an example, in the field of interaction design, prototypes are often employed to test the experience of users systematically, with the aim of producing knowledge to be shared with other researchers. In this field, prototypes are made mixing physical and digital features, sometimes relying on advanced manufacturing processes (e.g., PCB laser-cutting or milling). This peculiarity led us to term these types of prototype “advanced”. Because this way of prototyping, we believe, marks a significant shift in the way present-day design research contributes to the development of products, our project was named after this term. That being said, the true novelty in this field is that prototypes are conceived of as *means of knowledge production*, whether or not they are made by using advanced manufacturing processes. Indeed, this new role is played by other types of

prototype (and prototyping) as well – substantially intangible – which are gaining significance in design research (e.g., storytelling in design fiction – see section 4.1).

1.3 Focusing on the emerging role(s) of prototypes

Based on literature review, we found that prototypes in design research are used nowadays as means to produce knowledge (i.e., theory), throughout the research process. This innovation, we believe, is of great relevance for the understanding of the emerging role(s) of the prototype in design research. Indeed, the new role of prototypes as *means of knowledge production* extends beyond our notion of "advanced prototypes", including intangible artefacts that are often unrelated to manufacturing processes. Therefore, the focus of our project shifted towards the *evolution* of the role of prototypes in design research, which is not limited to those artefacts made by means of advance manufacturing techniques.

This project is funded by the Department of Design of Politecnico di Milano and developed by nine affiliated researchers, working in different areas of design research. The research group brings together a wide spectrum of expertise ranging from product design to interaction design, fashion design and materials in design. In this plurality of specialisations, the joint interest is the design of products and its evolution. Indeed, the proposal at the base of this research project originated from directly observing the emerging role(s) of the prototype in our daily academic work.

2. Literature review

2.1 Phase 1: "Defining and Understanding"

As a first stage of the project, we collected a wide range of definitions of prototype circulating in different areas of design research.

Analysing the literature, we found that there is no consensus among authors regarding the meaning of the term *prototype*, even when referring to the context of design practice. Some authors use the traditional notion, which understands prototypes as refined artefacts ready for production (Pei, E., Campbell, I. & Evans, M., 2011). Others, in contrast, ascribe a wider role to prototypes, viewed as "design-thinking enablers deeply embedded and immersed in design practice and not just tools for evaluating or proving successes or failures of design outcomes" (Lim, Y., Stolterman, E., & Tenenberg, J., 2008; McElroy, K., 2016).

Despite this lack of consensus, recent studies address specifically the context of design research (mainly academic), where "prototypes are made for operationalization, validation and exploration, and these uses seem to fit in different research approaches. They can be done to test preconceived hypothesis or to reflect on open-ended exploration. Roles prototypes can play in research projects are to confront theories; to confront the world; to evoke discussion and reflection; to changing the world; to test a theory" (Stappers, P. J. ,

2013). This idea of prototypes as means to carry out research extends to areas such as service design and design fiction, where they often consist of intangible artefacts (Kimbell, L., & Bailey, J., 2017; Kymäläinen, T., 2016).

The initial purpose leading the data collection was that of reaching a shared definition of the emerging role of prototypes in design research. Nevertheless, the heterogeneity of definitions that we found in literature led us to rethink the purpose of this stage, directing our efforts towards a mapping of the *diversity* emerged (section 4.2). Giving an account of this diversity, we thought, better responds to the underlying aim of the research project, i.e., *understanding* the emerging role of the prototype in design research.

3. Method

3.1 Selection and review of relevant sources

The term *prototype* is largely used nowadays in several areas of design research to describe unfinished and instrumental artefacts (McElroy, K., 2016; Wakkary, et al., 2015). This connotation revises and overcomes the long-established difference between *model* and *prototype* in the field of industrial design (see section 5.2). Furthermore, the notion of prototype currently used in design research (i.e., academic context) comprises a larger spectrum of categories of artefacts than the traditional one. For this reason, we decided to search for terms such as *model* and *artefact*, which the current notion of prototype seems to have gathered under the same umbrella-term (i.e., *prototype*).

Overall, the role of prototypes, their understanding and the terminology used to differentiate their purposes vary across the wide spectrum of design research, from engineering-based design studies to arts and crafts design research. Therefore, besides the terms *model* and *artefact*, we searched for definitions under the term *demonstrator*, mainly used in engineering-oriented design research.

3.2 Literature review process

Source finding
We started the literature review by collecting relevant sources, using keywords according to terminology (e.g., prototype and design), disciplinary areas (e.g., interaction design, product design, design research, etc.) and research areas (e.g., manufacturing techniques, product development, etc.). We made use of search engines and sharing platforms, such as Google Scholar, ResearchGate, Academia.edu, Mendeley, Online databases (library of Politecnico di Milano, ACM Digital Library).

Collection

We selected and sorted 95 publications among books, journal articles, papers, web articles and definitions from encyclopaedias. Hence, we extracted relevant content, consistently with the key topic of our research. Thereupon, we clustered the excerpts according to terminology, disciplinary area, and role played in the (design) research process. We identified eight clusters: prototype (49 publications); artefact (11 publications); culture and artefact (8 publications); design (encyclopaedia) (5 publications); model (5 publications); fashion (4 publications); product (design) (8 publications) and systems (design) (5 publications).

Document analysis using the Data Grid

We developed a grid to organise and review the excerpts systematically (Tab.1).

DATA GRID					
reference	**general definition**	**extensive definition**	**synthesis**	**interesting aspects**	**comment**
publication data	overall description of prototype and its meaning	extended description of prototype and its meaning	sum up of the publication	highlight of the relevant parts of the publication	reader's annotation
"Artifact"					
Design Dictionary: Perspectives on Design Terminology Michael Erlhoff, Tim Marshall (Eds.) Birkhauser, Berlin (2008)	"Quite literally, an artifact is an object that is the product of human skill and ingenuity. The term derives from the Latin ars (art or skill) and factum (made or done), and thus is a pivotal term to describe almost any designed entity." p.27	"All products of design are artifacts of one kind or another, and a common definition of design is the organization of the interface between humans and the "made world," that is, the interaction between people and our artifacts" p.27 "Although usually understood to refer to a material object, artifact can also refer to designed spaces, images, [...].	The term refers to anything is produced by humankind: the "made/designed world". Thus, the notion of artefact is not limited to tangible objects; rather, it includes non-tangible things such as software and environments.	The meaning of the term "artefact" is much wider than that of "prototype", though sometimes they are used interchangeably in some studies.	Artefacts is often another word for prototype; the fact that the term may refer to a diversity of things, much different from each other, raises the problem of the limitedness of the notion of prototype based on materiality. In other words, understandably and rightly enough, the term prototype can be applied to non-tangible things.

Table 1. Data Grid for literature synthesis and analysis – example of the term "artifact" in the Design Dictionary (Erlhoff M. & Marshall T. Eds., 2008).

Organizing literature

The literature review was carried out over a four-month period. During this process, unfitting publications were discarded. On the other hand, new ones were included, relying on the references of those we had already collected. The number of publications collected was considered enough to gain a general understanding of what a prototype is and what roles the latter plays in today's design research.

4. Results

4.1 Preliminary findings

The literature review carried out using the Data Grid (Tab.1) allowed us to gain a first understanding of the evolving role of prototypes in design research. We collected a wide range of definitions that describe what prototypes in research are meant by, under terms such as “demonstrator”, “proof of concept”, “sample” – just to mention a few. Such terms constitute a specialised lexicon used in specific areas of design research. Over the last ten years, a variety of new terms have been introduced, with the aim of defining some emergent types and uses of prototypes. One example is the notion of *counterfactual artefact*, developed by Wakkary et al. (2015), which encompasses critical design, HCI, interaction design and philosophy. Another example is the notion of *diegetic prototypes* by Kirby (2010), who investigates the narrative role of those prototypes that are used to influence cinema audiences. These neologisms signal the need to fill an ontological gap related to prototypes in today’s design research, beyond terminology. In other words, the proliferation of new terms used to describe the role of prototypes testifies a change of perspective in the field of design, where research has expanded its horizons. In particular, various strands of research in design have been turning their attention to theory and social phenomena, besides the development of products. In these strands, prototypes are used as means to conduct research and generate knowledge, which does not pertain to one or more specific products. In fact, the knowledge generated may be used at a later time by other researchers either to develop a product or to investigate relevant theoretical matters further. This understanding of the role of prototypes sets apart from the traditional view spread in industry, showing the occurrence of a shift in the way the very research in design is understood.

4.2 Prototype: from *definition* to *role*

Overall, we observed that the diversity of terms currently circulating are part of a jargon that design researchers use to classify prototypes, according to a variety of purposes deemed as most relevant to their specific research areas. As a result, terms and definitions vary according to the specific research contexts, questions and, sometimes, stages of the process. In this respect, the classifications are often based on the specific *objectives* or *purposes* to which the single prototype aims. Therefore, terminology is tightly bound to both the specific aim and the general purpose (i.e., *role*) that the prototype is expected to help achieve. Such a functionalist approach to taxonomy is widespread among researchers and led us to move our focus from the *definition* to the *role* of prototypes. We therefore reframed the Data Grid, highlighting the diverse *roles* and *aims* ascribed to prototypes (Tab. 2). Moreover, we revised the data collected according to the changes made.

DATA GRID II			
Reference	**Role of the prototype in the interpretation of the author**	**Categorisation criteria:** **Aim** **Discipline** **Terminology** **Context (academia, practice…)** **Fidelity (low, medium, high)**	**Author's specific distinction(s) (to be highlighted)**
publication data in APA style	description of the authors' intepretation of the role of prototype	collection of information based on a set of criteria of categorisation	notes about any author's specific distinctions about the role of prototypes
"Prototype"			
Blackwell, A. H. (2015). Prototype. In UXL Encyclopedia of Science (3rd ed.). UXL.	The role of prototype is to perfect items and processes of a design before implementing them on a large scale.	Aim: Allowing designers to see their design in action; Persuading marketers. Discipline: Design and Engineering. Terminology: Prototype (prototype for testing); Fully working prototype (first type of a series). Context: Industry (R&D); design practice (studio). Fidelity: No reference to the concept of fidelity. However, it is implicit in the definition of prototype (plain one) – "[...] a prototype is not exactly what the final design will contain, but that is close enough to let the designers see if it will work or not." Phase (process): Not specified but implicitly it should be throughout the process.	Prototype vs Fully working prototype (clear distinction).

Table 2. Data Grid II (revised version) for literature synthesis and analysis – example of the term "prototype" from Encyclopaedia of Science (Blackwell, A. H., 2015).

The new grid for analysing the literature allowed us to identify two main roles that prototypes have in design research. These roles differ substantially from each other. One, more traditional, consists of giving researchers the chance of gaining useful insights about the prototype itself, as part of the product development process. The other, unusual compared to the long-established role in industrial design, consists of enabling researchers to gain knowledge regarding phenomena that lie outside of the domain of design. In the latter case, prototypes work as instances, embodying ideas and theoretical concepts. In this regard, they can be used to generate new hypotheses, answering research questions, and envisioning new design propositions. This is the major innovation, we observed, regarding the *role* played by prototypes in current design research.

Regarding the specific aims of prototypes, we collected over 140 statements. After a process of review, we made a list of 34 primary aims and clustered them into 9 categories: *Develop*, *Assess*, *Communicate*, *Represent*, *Comprehend*, *Research*, *Explore*, *Provoke* and *Envision* (Fig.1). These clusters well represent the range of purposes for which prototypes are made in design research.

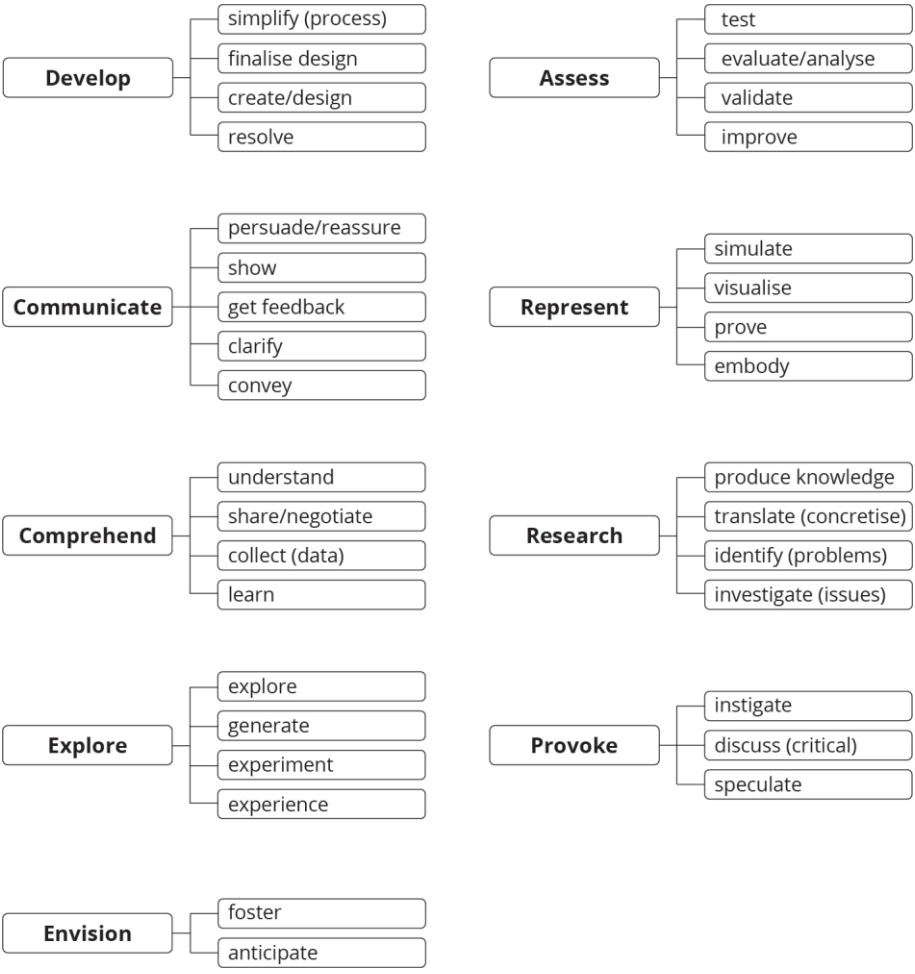

Figure 1. Aims of prototypes: categories and sub-categories

Later, we used this outline as a starting point to proceed with the next stages of our research. In this article, however, we focus on the insights gained by analysing the terminology and the definitions of prototypes currently spread in various areas of design research.

5. Discussion

5.1 The role of prototypes through terminology

Our shift of focus from *definitions* to *roles* of prototypes allowed us to pinpoint a major change of perspective in the field of design research, which has expanded its scope of interests, including theory and social phenomena related to material culture. In particular, our preliminary results show that prototypes have acquired the role of means for the production of theoretical knowledge, which complements the traditional role of testing aesthetic and technical aspects of the to-be-product. Moreover, drawing on literature, we were able to develop an overview of 34 primary aims for which prototypes are used, both in practice and research, defining 9 main categories.

It must be clarified, however, that the emerging role of prototypes – i.e., its evolution – in design research is tightly bound to the terminology used to describe them. That is to say, terminology defines the role of prototypes, highlighting the nuances related to their specific purposes. Indeed, through their discourses – i.e., fine-tuning terms and ascribing new meanings – the actors of research have constructed, conceptually, a new role to be played by prototypes, so influencing the practical dimension of the very research.

The classification of aims that we developed (fig.1) well shows the importance of terminology in the emergence of a new role of prototypes. Take, e.g., the two categories *Develop* and *Research*. It is clear that the aims that these categories gather refer to quite different paradigms, hinting at two distinct roles. Interestingly, other categories – such as *Comprehend* and *Represent* – gather aims that refer to both roles, traditional and emerging, reinforcing the idea that such roles often coexist in design research.

What is relevant about these examples is that the terms that we used to define the sub-categories (i.e., aims) are faithful to the claims made by various authors active in the field. That is why the lexicon used in design research to describe and frame prototypes is relevant to an enquiry into their emerging role in the field (see next sections).

5.2 Semantic overlaps

By mapping the definitions of prototype, we collected over 80 terms and related meanings. In this respect, we noticed that in some cases different meanings are ascribed to the same term (e.g., the term “prototype” is used to address both the provisional draft object that represents the concept of a product and a detailed object that represents the final product before production). In some other cases, the same meaning is described with different terms (e.g., the provisional draft object that represents the concept of a product in an early stage of development might be termed “model”, “mock-up”, “sketch”, “prototype” or otherwise). Therefore, the literature is riddled with semantic overlaps, which show a lack of a shared understanding among researchers of what a prototype is meant by.

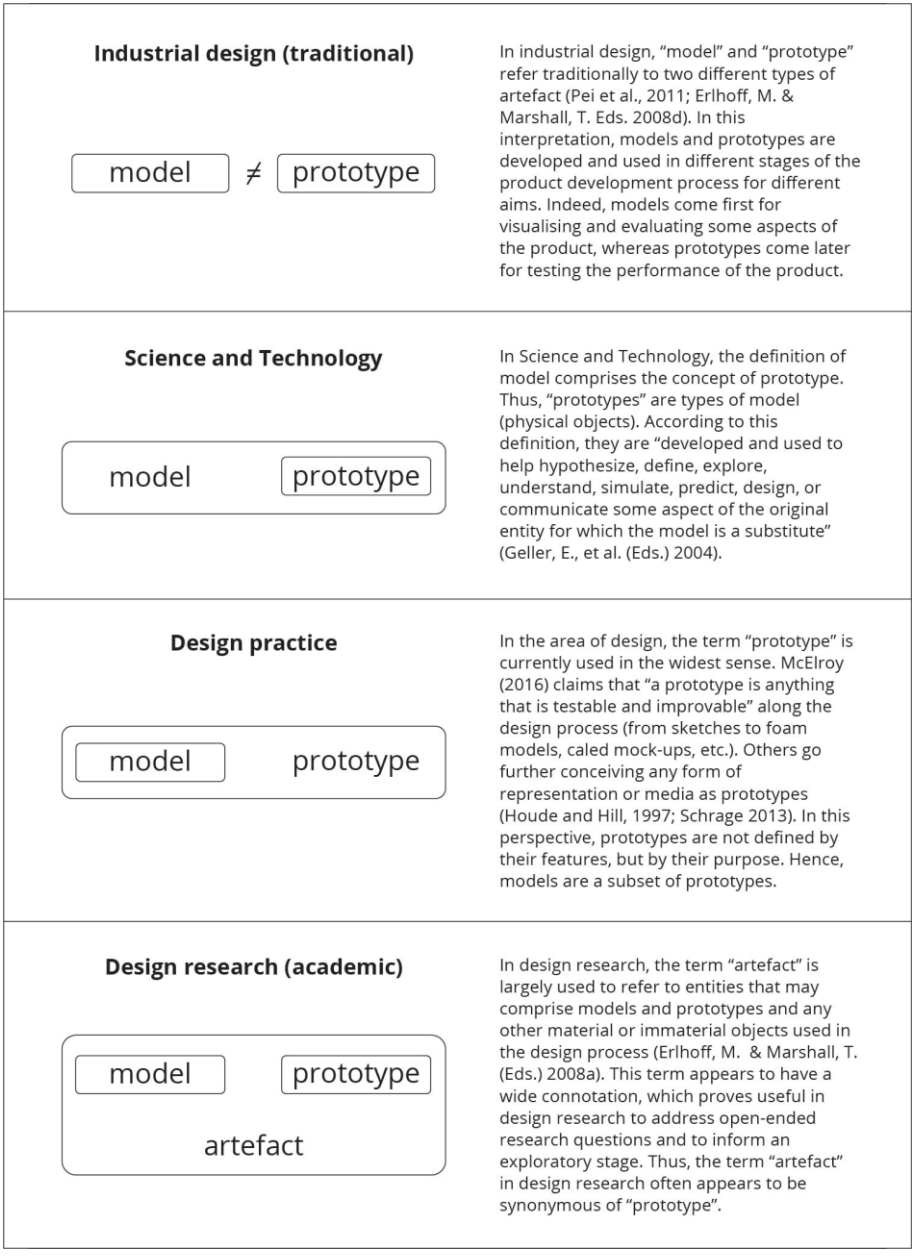

Figure 2. Interpretations of three widely used terms (i.e., artefact, model, prototype) in different areas of design research.

To bring some clarity, we give an overview of the way three widely used terms (i.e., *artefact, model, prototype*) are interpreted in different areas of design research (Fig.2). In addition, we elaborate upon a further term coming from the field of engineering (i.e., *demonstrator*), also adopted in some areas of design research (see section 5.3). Finally, we discuss the interpretation of the term prototype in the field of design research (see section 5.5) and in fields other than design (see section 5.4).

5.3 “Demonstrator” in Engineering

In the process of selecting relevant publications, we extended our scope of enquiry to engineering-oriented areas of design research. In these areas, we found that the term “demonstrator” is often used as a synonym of prototype. Moultrie (2015) points out that “[usually] demonstrators are viewed as technological prototypes which are close to market”. In this respect, Moultry proposes a new conception, arguing that “by considering the broader development space, it is possible to explore the potential for other types of demonstrators”. This point of view assimilates the term “demonstrators” to many of the interpretations of the term “prototypes" used in design research.

5.4 “Prototype” in disciplinary areas other than design

It is worth noticing that the term “prototype” can refer to a diversity of artefacts, depending on the specific disciplinary area. This semantic dissimilarity may lead to misunderstanding, especially in the context of multidisciplinary teamwork, where designers collaborate with researchers coming from different fields. Therefore, as Hallgrimsson puts it:

> “Product designers have to work with professionals from other disciplines where the term prototype could be used to describe many things that are not three-dimensional. Software designers use the term prototype in the context of code. Electronics engineers speak about prototyping printed circuit boards. […] It is worthwhile becoming more aware of these semantic differences since product design has become inherently interdisciplinary.” (Hallgrimsson, B., 2012).

5.5 “Prototype” in Design research

In the field of design research, as in that of design practice, prototypes are understood generally as means to represent ideas, namely, give an intelligible form to undetermined and abstract concepts pertaining to design solutions. In other words, prototypes are deemed as practical instruments to advance the design process, moving from the typical vagueness that characterises the concept phase to the clarity that implementation and experimentation usually require.

This general conception is common to all views on the role of prototypes that dot the diverse landscape of design research. Whether practice-oriented research (e.g., R&D context) or academic research, prototypes in the field of design serve the fundamental need to make magmatic and conceptually embryonic ideas manifest through fathomable forms of representation. Unlike in the professional world, however, in design research, the guiding

principle is that of gaining and/or producing knowledge, often regardless and outside of market requirements. That is to say, the kind of ideas and concepts that research prototypes embody are part of a process of knowledge production, which is not directly related to manufacturing and marketability.

Although in all areas of design research prototypes are used to produce knowledge, their (claimed) role differs widely depending on both the scope of research and the approach adopted, leading to a diversity of terms and definitions. Notably, Wensveen & Matthews (2015) identify four main roles, highlighting different ways in which prototypes and prototyping contribute to generating design-relevant knowledge. Prototypes can be used either to "test specific hypotheses" (*experimental components*) or to conduct "open-ended explorations" (*means of inquiry*) or to embody/show concepts and arguments (*research archetypes*) (p.272). Moreover, the very process of prototyping can be "a means of enquiry, akin to a research method" (p.269). Each role is bound to a specific methodological approach that proves consistent with the kind of knowledge sought, and yet a single research project may include all of them, relying on several prototypes having different purposes throughout the process (p.271). Thus, not only is the role of prototypes in design research multifarious, but also its variations can be combined in the same project, if needed.

As Wensveen & Matthews (2015) clarify, besides contributing to the discussion on the use of prototypes in design research, their categorisation aims to show that the approach commonly referred to as *Research-through-Design* (RtD) brings together "a multitude of legitimate intersections between design research and practice" (p.263). In other words, making prototypes, as a distinct practice of design put to the service of research, can contribute to producing knowledge relevant for design in many different ways. This open-minded view, which embraces the heterogeneity that characterises the field of design research, leaves room for new conceptions of prototype and prototyping in emerging areas such as that of design for social innovation (e.g., Kimbell & Bailey, 2017; Blomkvist, 2014). In this regard, the attempt of settling an inclusive epistemology for design research, beyond typologies and segmentations around the definition of RtD, is openly expressed by several researchers who proposed the term *Constructive Design Research* (CDR) (Wensveen & Matthews 2015; Krogh et al., 2015).

Notwithstanding someone's attempts of agreeing upon an inclusive epistemology, researchers active in different areas of design tend to emphasise their peculiar way of doing research, coining terms that aim to distinguish their conception from that of others. This need to stand out is also reflected in the understanding of the role of prototypes. To give an example, while Wensveen & Matthews (2015) discuss prototypes and prototyping, Frens & Hengeveld (2013), who share a similar background, prefer to use the term *making* (instead of *prototyping*). Krogh et al. (2015), who present a typology of methods used to produce knowledge in RtD, on the other hand, emphasise the activity of *sketching* (p.5). These few examples show how even strands of research that share the same methodology attribute

different roles to prototypes and prototyping in design research. Interestingly, they claim differences of substance by emphasising semantic nuances and using distinct lexicons.

All things considered, the plurality of views on the role(s) that prototypes and prototyping play in design research – included their terminological inventory – are held together by the common aim of producing knowledge relevant for the design field, besides developing products for the market. This common trait, we believe, is what can be generally viewed as the emerging role of prototypes and prototyping in design research, without detracting from the significance that the diversity of views on such role (i.e., its nuances) offers.

6. Conclusions

In today's design research, a variety of terms are used to describe tangible and intangible artefacts playing the *role* of prototypes. The reason behind this diversity is that the notion of prototype is highly context and purpose dependent, i.e., varies depending on both the specific disciplinary area in which is developed and its use in the research process as it is performed in that very area. Our preliminary findings show that prototypes are best defined by both their general purpose (role) and their specific aims. Furthermore, we found that the role of prototypes in design research has evolved from a traditional conception (i.e., the first unit of a product series to be manufactured) to a new and wider notion, which views them as means to investigate phenomena outside of the domain of design. This evolution reflects a widespread and influential perspective into vogue in various areas of design research today. According to this view, prototypes are no longer aimed exclusively at developing products, also serving the process of knowledge production in the context of academic research.

The contribution of this paper is threefold. First, we provide a classification of prototypes by aims (fig.1), based on the claims made by various authors active in the field of design, both research and practice. Second, we discuss the emerging role of prototypes in current design research, highlighting a change of paradigm regarding the way research is conducted. This change follows an expansion of the scope of investigation, which includes theory and social phenomena. Third, we show that the emergence of a new role of the prototype in design research depends largely on the definitions and discourses that are developed over this topic. In such discourses, terminology plays an important role, influencing the very practice of research.

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