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USING A DESIGN ONTOLOGY TO IDENTIFY THE TERMS THAT REPRESENT THE DESIGN RESULTS ACROSS RESEARCH COMMUNITIES

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ABSTRACT

This paper is contextualized in a research project that aims to create a new paradigm to support the design process, substituting the sequential nature of design process models by a flexible structure. To implement this paradigm, we must identify the final and intermediate results of the design process, such as documents, models, artefacts, among others. However, design research is wide and multidisciplinary, resulting in non-uniformity of the terminology across research communities, what hinders the results identification by means of a literature review. This paper aims to identify the terms employed by different research communities to refer to the intermediate and final results of the design process, structuring synonym terms across research communities and establishing how those terms interrelate in the design ontology. Using literature review, the following terms were analysed: design objects, elements, deliverables, entities, information, components, data, and artefacts. The results provide a holistic view of how the terms are employed throughout research communities, supporting the creation of search strings and pointing out opportunities for improving the design ontology.

Keywords: Design process, Terminology, Ontologies, Product modelling / models, Design ontology

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1   INTRODUCTION

Traditionally, the manufacturing industry employs design process models as a reference to describe or prescribe design based on best practices and methods (Browning *et al.*, 2006). Using a design process model has been proved to be a good practice, differentiating the best companies from the others (Markham and Lee, 2013). However, this good practice still has weaknesses. First, excessive rigidity of process models may hinder innovation and creativity (Browning *et al.*, 2006). For agile development of innovative projects, those process models may even be useless (Conforto and Amaral, 2015). Second, there are two approaches to establish a specific design process for a company: systematizing and modeling how the work is done or adapting design reference models, such as the ones proposed by Pahl *et al.* (2007) and Cooper (2001). On the latter approach, design reference models must be modified, demanding extra effort from the company to adapt them to its context and environment (Costa *et al.*, 2017; Gericke and Blessing, 2011; Hollauer *et al.*, 2017). Third, differently from operational business processes, which are repetitive and highly predictable, the design process is creative, dynamic, and often fuzzy, being characterized by iterations, rework and jumps (Vajna, 2005). The current design process models do not support developers in dealing with those characteristics (Hollauer *et al.*, 2017).

To overcome those problems, Costa *et al.* (2015) state that it is necessary to focus on the flexibility of reference models. However, few studies deal with this need, such as the propositions from Freisleben and Vajna (2002), and Vajna (2005). They propose that it is possible to structure a high variety of specific design process models by combining a limited variety of design process building blocks. In their proposition, those building blocks are based on design activities, and they are used to support companies on modeling, navigating, and optimizing their existent design process. However, we believe that this rationale can also be employed for creating new flexible design process models and supporting the agile paradigm.

This paper is part of a more comprehensive research project, which is based on a rationale similar to the one presented by Freisleben and Vajna (2002), and Vajna (2005), i.e., combining design process building blocks (BBs) to structure process models instead of adapting generic design process models. Differently from the proposals of Freisleben and Vajna (2002), and Vajna (2005), the BBs of this project are structured around the design process results. The goal is to allow companies to structure specific design process models for each type of recurrent project, and, for innovative projects, to support agile development projects. However, the results of design projects have logic dependencies among themselves, i.e., it is not possible to randomly combine the BBs in any order to structure a design process model. The implementation of this paradigm requires a meta-model that states the relationships among the design process results; such as value proposition, concept, architecture, among others. To create the meta-model that may support the implementation of this new paradigm, we must identify the possible results that may derive from the design processes, which include documents, models, among other artifacts. However, this identification was hindered by the non-uniformity of the design terminology. This publication is inserted in the context of this wider project, dealing specifically with this gap.

Design is a vast and interdisciplinary topic, dealing with different perspectives and knowledge areas (Bucciarelli, 1988). Therefore, throughout the years, design research has spread around several research communities (Margolin, 2013). Each community has its terminology, including jargons and specific terms. However, ideally, any theory should be structured around a well-established set of definitions from a unified terminology (Wacker, 2008). A previous effort of unifying the design terminology into a single design ontology based on the general understanding of each term was already performed, establishing, for example, the design ontology (Štorga *et al.*, 2010) based on the Suggested Upper Merged Ontology (Niles and Pease, 2001). This effort did not unify the design terminology - each community still employs the terms that they are used to and this fact will not be easily modified.

Therefore, to overcome the obstacle of terminology non-uniformity that was faced during the development of this research project, this paper aims to identify the terms employed by different research communities to refer to the partial and final results of the design process, structuring synonym terms and establishing how those terms interrelate. We reinforce that this paper does not aim to propose a single terminology, but to understand and schematize how each design community employs each term. We also reinforce that, even though design practitioners employ design process models, we aim to understand the terminology employed by design research communities, since the intention is to employ it for literature research purposes.

2   METHODOLOGY

The purpose of this work requires gathering information on how researchers from each community deal with specific terms employed to refer to partial and final results of the design process. The first step required identifying which terms should be included in this analysis. To perform that, a systematic search based on snowballing was performed. This search started with typical classic references from design, such as the works from Pahl *et al.* (2007), and Simon (1969). On the classic references, we have identified which terms were commonly employed for the final and partial results of the design process. Those terms were then employed as keywords for a systematic search in the databases Scopus and Web of Science. The most cited resulting papers were analyzed, identifying other terms that they employed for referring to final and partial results of the design process. Those terms were employed in a new search string, repeating this process iteratively until no new terms were identified. After this iterative search, the terms selected for analysis were: design objects, design elements, deliverables, design entities, design information, design components, design data, and design artifacts.

The second step of this methodology was to establish a comparison structure for the terminology, creating a first overview of the selected terms based on a design ontology. Most design ontologies focus on the design process (Štorga, 2005). However, in this study, it would be necessary to select a domain ontology that focuses on the design process results instead of the process itself. Based on this requirement, the most appropriate ontology for this purpose is the one proposed by Štorga *et al.* (2010), which, in turn, was structured based on the epistemological ontology SUMO (Suggested Upper Merged Ontology) (Niles and Pease, 2001). The SUMO is an ontology created from the merge of "publicly available ontological content into a single, comprehensive, and cohesive structure" (Niles and Pease, 2001). The core structure of the SUMO is extracted from WordNet (Princeton University, 2010), a lexical database for English, which was developed and tested by hundreds of researchers. The structure of Wordnet, in turn, is based on semantic relationships. Three semantic relationships were considered in this analysis: hypernyms, synonyms, and hyponyms, which are explained in Table 1. Those relationships may be direct (one level up in the hierarchy) or inherited (two or more levels up in the hierarchy). We analyzed how the design-related terms were defined in the design ontology and how they interconnected through those relationships. Those results are presented in section 3.1.

Table 1. Semantic relationships employed to structure the comparison basis

Relation	Description	Example
Hypernym	A is a hypernym of B' means 'B is a kind of A.'	Car is a hypernym of cab
Hyponym	A is a hyponym of B' means 'A is a kind of B.'	Cab is a hyponym of car
Synonym	A is a synonym of B' means 'A is equal B.'	Car is a synonym of automobile

The third step of this methodology covers a systematic literature review (Tranfield *et al.*, 2003) to identify how the selected terms are employed in the literature. The string combined those terms in an "OR" logic, accompanied by the term "design" in an "AND" logic, according to the following string:
TITLE-ABS-KEY(("design elements" OR "design objects" OR deliverables OR "design entities" OR "design information" OR "design components" OR "design data" OR "design artifacts" OR "design artefacts") AND design).

Limiting the research to the subject areas of engineering, computer science, decision sciences, social science, multidisciplinary, and business, management, and accounting, it resulted in 17946 papers. Due to the meaningful amount of results, only the 50 most cited papers employing each term were included. For each term, the papers were categorized based on theme similarity, composing what we call in this publication as "research communities". Therefore, communities may have different levels of abstraction when comparing different terms. For some terms, the communities were broader, such as "software design". For other terms, the communities were more specific, such as "object-orientation" and "axiomatic design". After categorization, the set of selected papers was thoroughly read, understanding how each author employed and defined each one of the terms and attempting to identify patterns within and among the research communities. The results obtained are provided in section 3.2.

Finally, the usage of the terms by the distinct research communities was compared to the usage proposed by the design ontology proposed by Štorga *et al.* (2010). This comparison was structured in the table presented in section 3.2.

3   RESULTS

3.1   Design terminology according to the design ontology

This section structures the design terminology covered by this paper with basis on the design ontology (Štorga *et al.*, 2010), complementing it when necessary with the propositions of SUMO (Niles and Pease, 2001) and Wordnet (Princeton University, 2010). Figure 1 illustrates the first three levels of this structure. The figure presents the broader hypernyms to the left and the most detailed hyponyms to the right. First, the term "entity" is the broadest hypernym in SUMO, i.e., it is a term that does not belong to any group of words. Therefore, in the context of design, the term "entity" could be generically used to refer to any of its direct or inherited hyponyms. The term "entity" may regard physical entities or abstract entities – its direct hyponyms. The design ontology subdivides the possible physical entities into two groups (object and process) and the abstract entities in four groups (attribute, proposition, quantity, relation). One highlight is that the term "object" may have another meaning according to Wordnet (Princeton University, 2010), which is "the goal intended to be attained and which is believed to be attainable". This meaning is an inherited hyponym of "abstract entity". Based on this definition, it is possible to infer that the term "object" as a physical entity could be related to any tangible result of the design process, such as a prototype, a tool, or a final product, while the term "object" as an abstract entity could refer to the ultimate intent of design: a product, a service, or an organization. The term "object" as an abstract entity is relevant to the current trends of designing product-service systems, for example, which may employ the term "design object" to refer to tangible and intangible solutions.
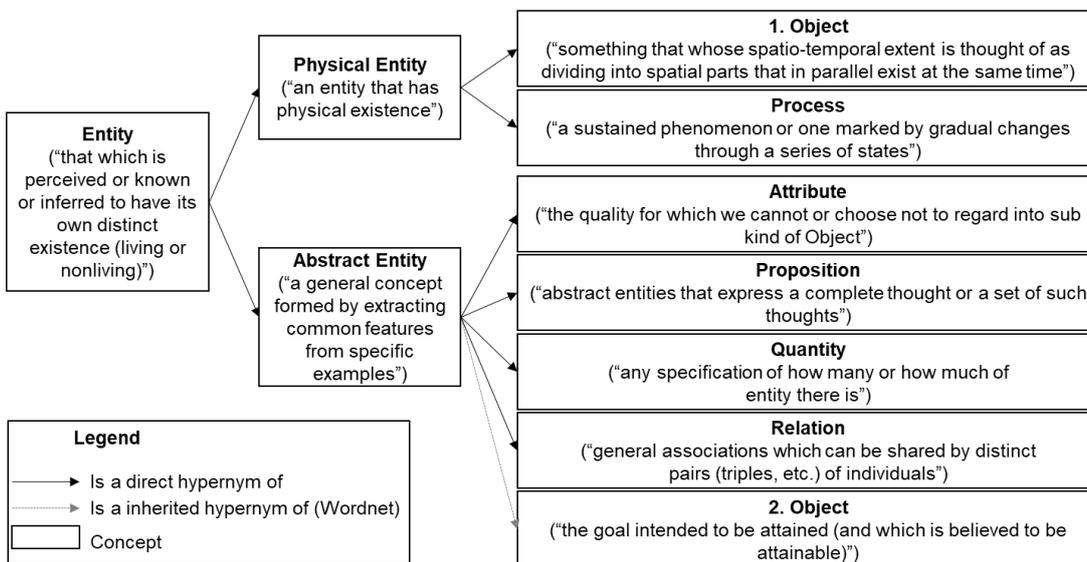

Figure 1. Meaning and semantic relationships of the terms according to the first three levels of the design ontology (Štorga et al., 2010), complemented by the meanings proposed by SUMO (Niles and Pease, 2001) and Wordnet (Princeton University, 2010)

According to the design ontology, the object as a physical artifact can be divided into four categories: biological object, material object, content-bearing object, and collection. This division, as well as its subdivisions, is illustrated in Figure 2. Only two of those categories were expanded in this paper since the others are not relevant for this discussion. First of all, the content-bearing object that is relevant to the discussion of this paper is "document". Regarding material objects, one of its direct hyponyms is "artifact", which is defined as "a man-made object taken as a whole" according to Wordnet (Princeton University, 2010). Based on this meaning, in the design context, an artifact could be considered as any physical output created by the design team, such as models, prototypes, among others – provided that they are tangible artifacts. In fact, "model" is an inherited hyponym of "artifact" according to the Wordnet structure (Princeton University, 2010). However, this connection is not contemplated in the design ontology, where the only direct hyponym of "artifact" is the term "product", which can be specified into the term "technical product". Another term that is not contemplated by the design ontology is "deliverable", which is an inherited hyponym of "product" according to Wordnet (Princeton University, 2010). However, Wordnet employs another meaning for "product". Based on SUMO, the term "deliverable" is a synonym of "product", being anything that the development team delivers during

the development process inside the product scope. Finally, the lowest level of the object tree in the "engineering component", which refers to the parts that compose the product.
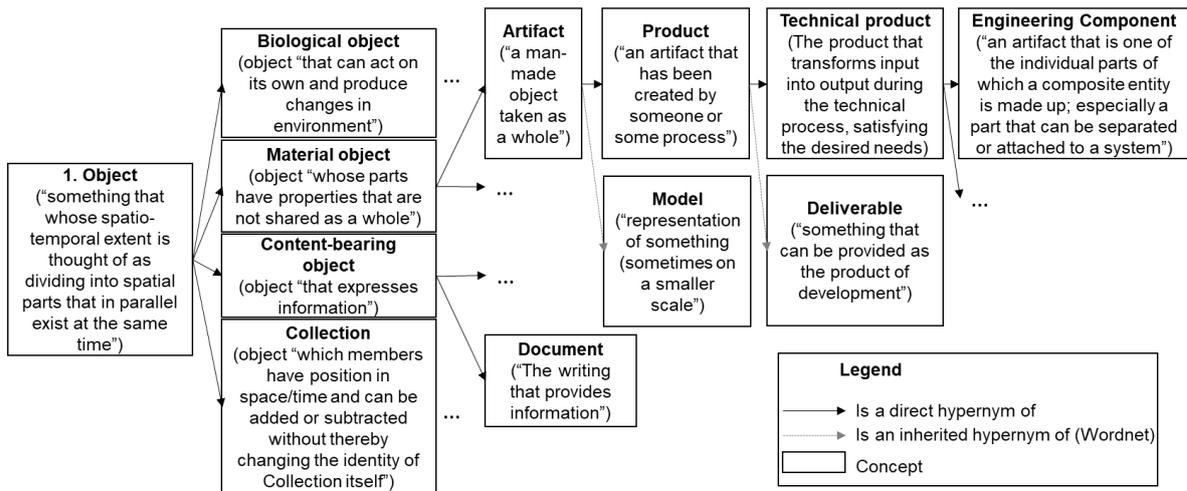

Figure 2. Meaning and semantic relationships of the terms classified as physical objects according to the design ontology (Štorga et al., 2010), complemented by the meanings proposed by SUMO (Niles and Pease, 2001) and Wordnet (Princeton University, 2010)

Figure 3 decomposes the hyponyms of the "proposition" and "relation" categories, limited to the terms that are relevant for this discussion. The explanation of this figure starts by decomposing the "proposition" category, followed by the "relation" category. One of the direct hyponyms of the proposition is the term "element", which may be a constitutional part of anything. On the same category, two direct hyponyms of "proposition" are the terms "fact", which is a direct hypernym of "data", and "information". One highlight is given to the difference between data and information. Lexically, both terms are synonyms according to Wordnet (Princeton University, 2010). However, the design ontology designates both terms as different categories.
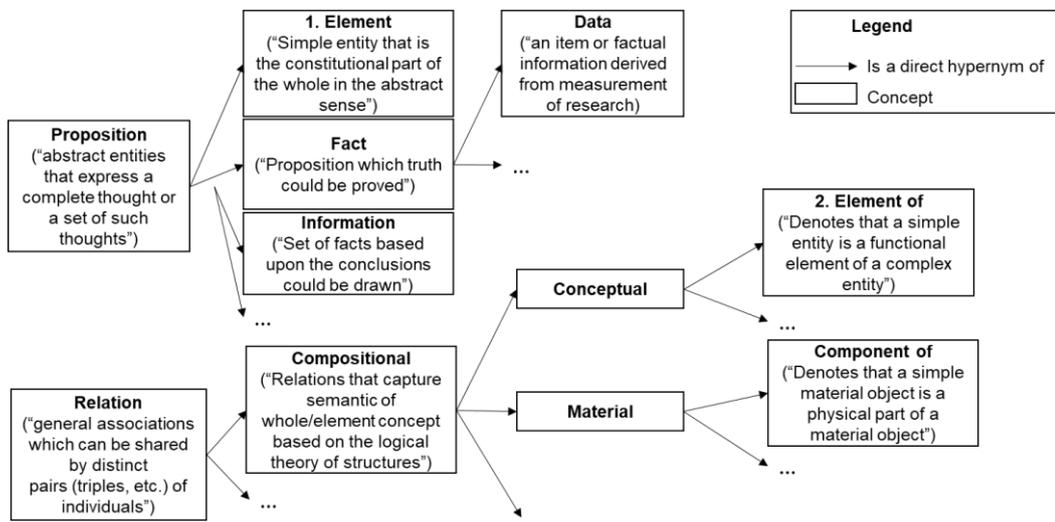

Figure 3. Meaning and semantic relationships of the terms classified as proposition and relation according to the design ontology (Štorga et al., 2010) and meanings proposed by SUMO (Niles and Pease, 2001) and Wordnet (Princeton University, 2010)

Regarding the "relation" category, Figure 3 only expands compositional relationships. Those relations can be conceptual or material, among others. The term "element" appears in the ontology for a second time. In this meaning, it refers to a relationship of a simple entity as part of a complex entity. The term "component" is also a relation here, denoting that "a simple material object is a physical part of a material object" (Štorga *et al*., 2010).

An overview of the terms that were presented in this section, as well as their relationships, is illustrated in Figure 4.
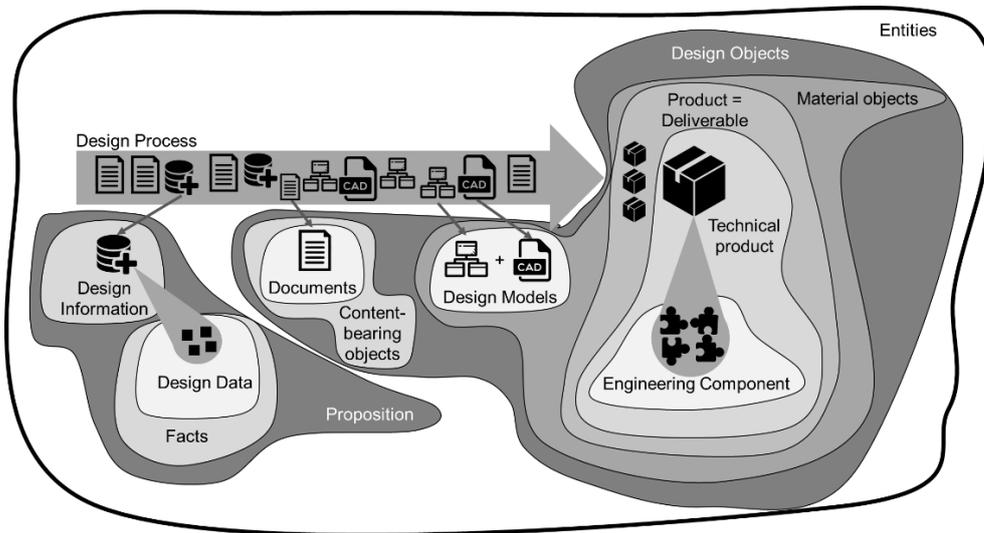
Figure 4. Representation of the structure of partial and final results of the design process

3.2 Literature analysis of the design terminology

Even though many publications may interchangeably use those terms, each one is more frequently employed with specific meanings by distinct research communities. This section provides a perspective of how those terms are used in the literature, which is summarized in Table 2.

Table 2. Summary of the terms meaning according to the literature review

Term	Community	Meaning
Design entity	Object-orientation	Synonym for classes
	Computer-Aided Design (CAD)	3D graphical objects, including product, assembly, part, component, or feature. Partially equivalent to "Design models" in the SUMO
	Function-Behavior-Structure (FBS)	Components of design artifacts
Design information	Knowledge management	Equivalent to "information" in the SUMO
	Software development	Actions, decisions, and modifications during software design
Design data	Knowledge management	Equivalent to "data" in the SUMO
	Overall usage	Synonym of "information" in the SUMO
Design object	Computer-Aided Design (CAD)	Synonym of "product" in the SUMO
	Feature-based design	Synonym of "product" in the SUMO
	Systems Engineering	Synonym of "element" in the SUMO, but regarding only the system's architecture
	Object-orientation	Identifiable conceptual entity
	Axiomatic design	Synonym of "object" as an abstract entity, following Wordnet.
Design elements	Overall usage	Dimensions (perspectives) that a solution may have, such as provider, customer, offering.
	Overall usage	Synonym of "Engineering components" in the SUMO
	Overall usage	Synonym of "Design information" in the SUMO
Design components	Overall usage	Equivalent to "Engineering components" in the SUMO
Design artifacts	Overall usage	Equivalent to the combination of "design models", "documents" and "product" in the SUMO
Deliverables	Overall usage	Equivalent to the combination of "design models", "documents" and "product" in the SUMO

The first term to be analyzed is "design entity". Probably due to its generic nature, as explained in the last section, this term is rarely employed with specific meanings in the literature. Few documents in the Scopus database employ this term in the title, abstract or keywords when compared with the other selected terms. However, a few patterns can be observed. The usage of "design entity" is well-structured in the community of software design regarding object-orientation. In this community, "entity" is often employed as a synonym for classes (Ekanayake and Kodituwakku, 2015; Marinescu, 2011). Consequently, other papers from different product design communities also employ this term with this meaning when dealing with object-orientation (Dinar et al., 2011). The CAD community, on the other hand, employs the term to refer to 3D graphical objects, including product, assembly, part, component, or feature (Jones, 2004; Krishnamurthy and Law, 1997). A pattern was also observed on papers that employ the Function-Behaviour-Structure (FBS) ontology, referring to "design entities" as the basic components of a design artifact (Jin and Benami, 2010; Kannengiesser and Gero, 2015). No other patterns were observed, even though the term "entity" was also used by punctual papers to refer to other meanings such as the product composition or the companies that perform design.

The second analysis regards the term "design information", which will be accompanied by the discussion regarding the term "design data". The terms information and data are formally differentiated in the knowledge management theory, following what is proposed in the design ontology. In this theory, data is a set of isolated facts with no associated meaning, while information is a set of facts with aggregated meaning due to relational connections (Tuomi, 1999). However, in a vast majority of times, the design literature employs the term design information as an interchangeable synonym of design data (Kim et al., 2006; Zhai et al., 2009). Despite this contradiction, the term design information is well structured. All analyzed publications that cited this term applied it with the same meaning: as a collection of facts regarding the solution that is being developed and its environment/context. This information commonly refers to the content of the design object models, such as value, cost, geometry, feasibility, budget, solution characteristics, among others (Haley et al., 2008; Komoto and Tomiyama, 2012). The only community that makes different usage of this term is the software development community, which usually employs the term design information to refer to actions, decisions, and changes that were performed during the development process (Ding et al., 2002; Reussner et al., 2003).

Regarding the term "design object," five main design research communities make extensive use of this term, employing different meanings: CAD, feature-based design, systems engineering, object-orientation, and axiomatic design. In the CAD and feature-based design research communities, the term design object mainly refers to the final result of the design process ("product" from SUMO) or by the designer's image of the product (Rosenman and Gero, 1996; Yang and Zhang, 2006). Salomons et al. (1993) explicitly criticize designers that refer to components and parts instead of the final assembly as design objects, stating that "the design object or model is the result of the design process". However, this usage is considered possible according to the design ontology, and it is not rare to find this term being employed for this purpose in those communities. In the systems engineering perspective, the meaning of "design object" stands for "a result of an architecture decision to satisfy the motivational reasons," being considered as "architecture elements classified by the data, application or technology viewpoints" (Tang et al., 2007). When dealing with object orientation, the design object is an identifiable conceptual entity with "features that span a local state space" and "operations that can change the status of the system locally", being commonly associated to hierarchical interrelationships (Gorti et al., 1998; Liang and O'Grady, 1998). Finally, in the axiomatic design community, some authors employ the term "design object" similarly to the CAD research community, however stating that they may be tangible or intangible artifacts, such as products, services, or even organizations (Harutunian et al., 1996). Additionally, some authors consider everything that appears in the design process as a design object (Zeng, 2002).

The fourth analysis of this section regards the terms "design elements" and "design components." The term component is very structured in the literature, being mainly used to refer to parts that constitute a final solution (Sauthoff et al., 2016; Sim and Duffy, 2003). On the other hand, the term "design elements" is unstructured and varied. Some authors employ this term to refer to the solution dimensions (such as offering, provider, and customer) (Ritola and Coatanéa, 2013); to engineering components, possibly extending it to other dimensions, such as aesthetics, function, and ergonomics (Noble and Kumar, 2008; Rosenman and Gero, 1996); or as a synonym for information (design ontology), citing that some of the design elements may be needs, requirements, product functions, service processes, and stakeholders networks (Kimita and Shimomura, 2012; Shimomura et al., 2015).

Regarding the term "design artefacts", it is commonly used to refer to what we understand as a combination of design models and documents (design ontology) (Goknil *et al.*, 2011; Wittern *et al.*, 2012). The essence of the term "artifact" in the design theory is to describe "something that is artificial, or constructed by humans, as opposed to something that occurs naturally" (Gregor and Jones, 2007), i.e., any model, solution, or physical object created by a human is an artifact.

Finally, the term "deliverables", defined by Browning *et al.* (2006) as the set of "inputs, outputs, results, work products, services, information, outcomes, artifacts, items", is very uniform in the literature, being always employed with this same meaning. This term has an activity-related perspective, i.e., they are "the connectors on a flowchart that represent any information, data, result, material, etc. produced or required by an activity" (Browning *et al.*, 2006). Usually, this term is mostly employed by the project management community (Cleland-Huang *et al.*, 2012; Monteiro *et al.*, 2014), by other communities employing concepts of project management (Issa and AlAli, 2011), and by the engineering education community (Pears and Daniels, 2010).

4 CONCLUSION

This paper has analyzed the terminology employed by the many research communities to represent the partial and final results of a design process. This analysis was based on the design ontology and the terminology's usage in the literature. An overview of the terminology and its relationships with research communities is also presented. The obtained results provide a holistic view of how each term is employed by researchers throughout research communities. The main contribution of this paper for practice and academy regards the more comprehensive project in which this publication is included. This terminology will allow us to identify the possible partial and final results of design processes, which, as explained in the introduction, will be inputs for the meta-model that supports structuring the building blocks for the new paradigm that may substitute the concept of reference design models.

Even though this paper is included in this context, we also visualize other contributions from this publication for the academy. It may support researchers who are aiming at gathering contributions from other research communities to structure search strings. Moreover, it may also support researchers on employing the most appropriate terminology for their target readers. The results also point out opportunities for complementing the design ontology with the terms that required complementation from SUMO and Wordnet. Furthermore, the terms from the design ontology that are incompatible with the overall usage in the literature also have improvement opportunities.

Adopting a common terminology would be the ideal scenario to proceed to the integration of the multiple research communities. Adequate definitions and terminologies are one of the pillar properties of a good theory (Wacker, 2008). This scenario, however, is not realistic. Each research community is already used with their daily terminology. Therefore, we reinforce here the need for efforts towards unifying the design terminology across disciplines, identifying approaches that may allow this unification.

A limitation of this publication is to approach a limited number of papers, gathering only the most cited ones, to make this research manageable. However, this decision was based on the hypothesis that, if a paper is well cited, it probably supported the research community on structuring its terminology and is well accepted by the researchers of that research community as a knowledge reference. Therefore, the concepts presented by this paper would reflect the behaviors of that given research community.

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