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Requirements for design reuse in open-source hardware: a state of the art

A. Ezoji, J.F. Boujut*, R. Pinquié

Univ. Grenoble Alpes, CNRS, Grenoble INP, G-SCOP, 38000 Grenoble, France

* Corresponding author. Tel.: +33-476-5747-06. *E-mail address:* jean-francois.boujut@grenoble-inp.fr

Abstract

Making a hardware open-source consists of making accessible the documentation of the system so that everyone can use this design for its own purpose. It is an increasing phenomenon that goes hand in hand with the developments of the makers movements and the underpinning societal changes that are at stake today. However, poorly structured communities are sometimes struggling with problems inherent to the reuse of exiting designs. Besides, the exponential number of web-sites and platforms hosting open-source projects makes it almost impossible to properly find similar products or designs to get inspiration from. Design reuse has been an important practice in industry since decades. This paper looks for exiting design reuse research work and makes an attempt to elicit the main characteristics of design reuse identified in the literature. From this, we discuss the conditions of the application of design reuse for open-source hardware products. We conclude that a goal-oriented approach based on the basic principles of open-source hardware (right to study, modify, make, distribute) can be used to structure the approach towards a documentation that allows capture of design rational, documented product models and guidelines for documentation practices.

Keywords: Open-source hardware design; open design; design reuse; design documentation

1. Introduction

Open-Source Hardware (OSH) is hardware whose design is made publicly available so that anyone can freely study, modify, make and distribute it as defined by the Open-Source Hardware Association [1] (OSHWA, 2020). This definition breaks an important number of usual rules applied in industry today, especially the privacy ones. This phenomenon emerged with the expansion of digital manufacturing and the makers movement. Today it is becoming even more popular because it is seen as compatible with other important phenomena such as re localization of the production or circular economy [2] and citizen participation [3]. However, despite some famous success stories including Rep-Rap, Local Motors or Arduino, open-source hardware remains still little developed and far to reach the same level of impact as open-source software has. One of the reasons of this is that this model is often seen as not compatible with traditional industrial practices and therefore it is disregarded by industry. Mostly the main problems encountered are, accessibility of the information, privacy issues and business models. The OPEN!NEXT project [4], funded by the EU aims at developing tools and methods to foster company-community collaboration. As part of this research project, this paper addresses the first issue related to the accessibility of the information.

2. Objectives

In this paper we claim that design reuse is an important enabler of information accessibility for open-source communities. Information accessibility is considered as a key objective in the spread of open source across a large number of stakeholders, which is not fully achieved today [5]. The approach we present here is to consider the existing developments based on a literature review and analyze them at the light of open source.

Besides, design reuse has been an important topic in industry along the last decades. Indeed, it is a common practice to take existing elements of design either as a source of inspiration or for simply integrating them into ongoing designs. In companies this practice allows to save a huge amount of time and efforts. Especially if the subsystem has been already tested, certified, and the industrial process stabilized. Our objective in this paper is to present a review of the existing approaches that facilitate the reuse of designs in industry. This review examines scientific papers and identifies different approaches of design reuse. We have followed a systematic procedure to identify and select the most relevant papers and classified them. The discussion proposes an approach to make design reuse suitable for the specific domain of open-source hardware.

3. Method

The review of academic design reuse literature relies on a systematic literature review. The systematic literature review is a 4-step process including identification, screening, eligibility, and included that has been applied also by [6]. The method includes the following steps:

Identification:

- Identification of keywords.
- Search articles using combinations of keywords in titles, abstracts, and author keywords (466 articles related to design reuse have been found from Google scholar).

Screening:

- Arrangement of keywords in title, abstract, and author keywords (111 articles have been selected).
- Perform statistical analysis of 111 to find the most frequent keywords. So, 90 possibilities of arrangement have been considered. (53 articles were found).

Eligibility: systematic review of the abstracts to select the relevant articles.

Included: screening of the 53 papers and selection on the basis of the previous phase to ensure that high-quality (i.e., SCOPUS or WOS) relevant work is included (33 articles have been selected eventually).

The 33 articles have been deeply analyzed to identify and collect the categories related to design reuse approaches and their sub-categories. In order to have a synthetic representation of this analysis we translated the results into a knowledge graph (figure 1). In this graph, the nodes correspond to the concepts and the numbers associated stand for the reference of the paper that can be found in the reference list at the end of the paper.

4. Results

The analysis of the graph figure 1 shows that, in the first level we have categories related to: product model, modularity, design rational, data management system, retrieval system, information models. Those categories reflect the aspects raised by the scientific literature regarding design reuse in industrial practices.

Product model, in this context, entails the various standard digital exchange formats (for example STEP or STL), proprietary geometric formats (features-based approaches, parametric approaches…), but also drawings that contain technological information. Besides the CAD models, bill of material is seen as an important vector as well as assembly instructions. We consider these elements as part of the product model as they are capturing different aspects of the product representation.

Modular systems, refers to modularity as it is a key concept in engineering and more generally in every production activity. Making a part modular, defining proper interfaces allows interoperability, interconnection between sub-elements, without redesigning the whole system. Therefore, modularity has become a key concept in industry today just like in software development. In our context, being able to reuse part of a solution and integrate it in a new system without redesigning the interfaces is a real plus.

Design rationale is a very classical category when we come to design reuse. However, it has relatively poorly been implemented in software tools despite a relatively long history in academic literature. Amongst design rational approaches we have identified project and corporate memories, argumentation-based approaches, and descriptive approaches (including capture of meeting minutes, notes, emails, etc.) are identified amongst design rational approaches. As design rationale entails all the documents produced that contain elements of justification, argumentation, knowledge elicitation, explanation, context, etc. that potentially allow to understand why a solution is how it is, we consider this category of particular importance in our research.

Data management systems such as product data management systems (PDM) or product life cycle management (PLM) have been identified by researchers as important factors for design reuse in industry. Information systems such as PLM are heavy and complex to implement and, even if the price and complexity decreases, only relatively big companies can still afford them. In big companies these information systems are used on an everyday basis and therefore it is easy to use these resources to implement some design reuse procedures. In the context of OSH is not. However, the principle of having an information system that supports design reuse and more generally the design process remains an important factor in OSH.

Information models and modelling languages support the designers in the structuring process of the information produced during the design process. As we stressed the importance of rich information contents, the modelling tools and language can play a key role in the information structuring process for design reuse. These models can span from formal language like UML to less structured models such as block diagrams, functional models, etc.

Retrieval systems, web-based environments, semantic driven modelling tools appear as key elements for design reuse in our literature search. Sematic modelling appears as a key factor and ontology development that facilitate complex semantic search is an important factor for enabling design reuse.

The evaluation of the relative importance of the concepts is done through the citations in the articles. Even if we are aware of the fact that counting the number of occurrences of a concept is a questionable measure of its importance, we however have an indication at least of its fame.

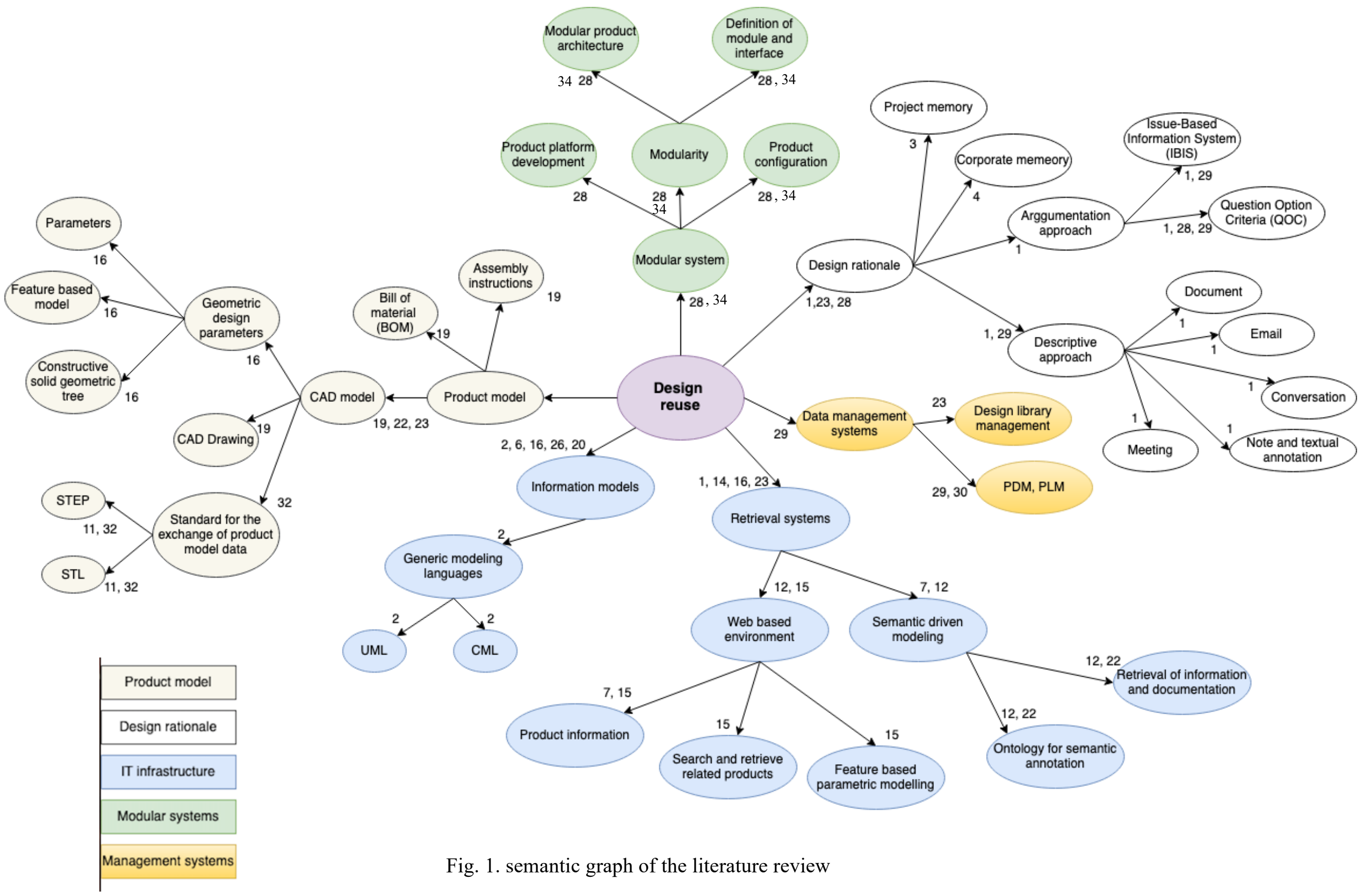

Fig. 1. semantic graph of the literature review

The most and less mentioned concepts, according to our systematic review are (see figure 2):

- Information models (mentioned by 4 articles)
- Retrieval systems (mentioned by 4 articles)
- Design rationale (mentioned by 3 articles)

If we consider the whole categories under retrieval systems, this cluster is the biggest one (8 articles). On the top of that if we add the fact that information model is also one of the most cited concepts, we end up with a bigger cluster composed of information-based approaches for design reuse. This is certainly something to consider in the future.

On the other end, the less cited approaches are:

- Modular systems (mentioned by 2 articles)
- Data management systems (mentioned by 1 article)

This can be seen as relatively surprising as for example modularity has been hugely studied in the scientific literature in the last 20 years. May be this concept has been put forward for other reasons than design reuse. The relatively low number of instances is also due to the very narrow scope that we choose in this literature search.

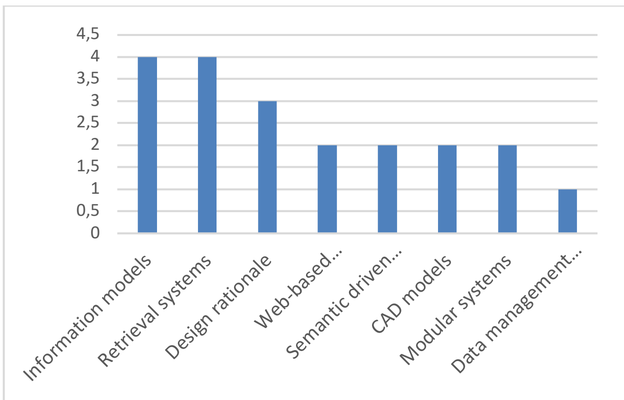

Fig. 2. summary of the relative importance of the categories according to the literature review.

Information models and retrieval systems seem to be the most important factors to consider that facilitate design reuse. It is not surprising that the studies related to design reuse highlight factors that are massively knowledge dependent. Indeed, information models capture some important bits of knowledge under various formalisms (functional, behavioral or

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structural). Retrieval systems are by definition based on ontologies that capture expert knowledge and design rational captures the justifications and contextual elements that represent contextual knowledge. Besides, web-based environments and data management systems refer to information tools and semantic driven modelling, and CAD models and modular systems refer to design strategies or best practices. We have therefore a tripod on which design reuse sits: knowledge, tools and strategy. Based on these results we propose to operationalize knowledge, tools and strategies by using a goal-oriented approach.

5. Towards a goal-oriented approach of OSH design reuse

About fifteen years ago, Design for Excellence was introduced as a design strategy that aimed at integrating downstream constraints (e.g. Design for X, X = Assembly, Manufacturability, etc.) during upstream design phases. Design for X is intrinsically dependent on the goal the team is pursuing. Similarly, the reuse strategies of existing designs depend on the pursued reuse goal too. For example, if one wants to acquire new Arduino knowledge, one solution is to access Arduino files on web-based open-source projects and to study the source code (Design Reuse for Studying). Similarly, when one wants to make a part, the first action is to search for an existing STL file stored in a web-based open-source hardware platform before 3D printing it (Design Reuse for Making). One might also reuse an existing part with or without modifications to accelerate the design process or to reuse sound design features (Design Reuse for Modification). All these aspects are specific to OSH. The context of use and reuse is depending on factors related to the objective of the makers. In our literature review, which was referring to engineering design of industrial products, these dimensions are absent. Thus, in order to structure the best design practices that influence design reuse in the OSH context, we propose to use a goal-oriented analysis (figure 3).

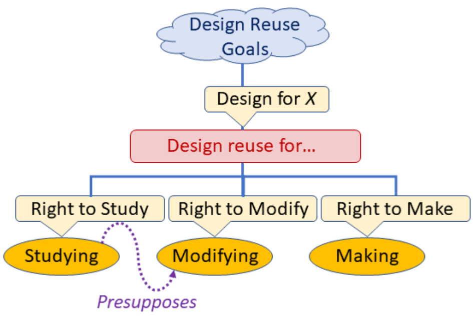

Fig. 3. Fundamental goals of design reuse.

As recalled in the standard DIN SPEC 3105-1 "Open-Source Hardware - Requirements for technical documentation" [7], and following what is mentioned in the introduction, the four freedom of open-source hardware are: the right to study, the right to modify, the right to make, and the right to distribute. Based on these freedoms, we derive an initial set of three fundamental goals of design reuse: Design Reuse for Studying, Design Reuse for Modification, and Design Reuse for Making. The right to distribute has been left aside here because it is more a business-related freedom that does not implies extensive design activities. As mentioned in the DIN SPEC 3105-1 (2020), the right to study precedes the right to modify (as we can see figure 4). Therefore, to achieve the goal "modifying", one should first satisfy the goal "studying". However, in most cases, it is not necessary to understand and modify an existing design to make it.

We should keep in mind that these fundamental goals of design reuse are services provided to stakeholders.

The documentation requirements highly depend on the pursued goal. It is therefore necessary to align design reuse goals with the best design practices that influence design reuse. Nevertheless, the three fundamental goals are too broad to finely structure the best design practices. Consequently, we break down the goals into sub-goals by asking the question: What shall we do to facilitate design reuse for studying/modifying/making? For instance, the reuse of an existing design to acquire new skills requires to: 1) specify the needs, 2) find an existing solution that satisfies similar needs, 3) access the sources of the existing design, and to 4) understand the sources (figure 4). We stop the refining process when we consider that sub-goals are sufficiently detailed to allocate best practices. For instance, to the goal "Specify the needs", we could associate the design practice "Document the functional analysis including the environment, functions, performances, constraints, and operating scenarios" (figure 4). Note that the documentation requirement is depending on the level of abstraction. The documentation guideline may require "To make the design reusable for study", or "To specify the needs", or "To specify the functions, performances, constraints, and conditions of use", etc. Therefore, we should be able to sufficiently refine the goals to meet the recommendations that would guarantee a trade-off between goals decomposition and the number of design recommendations at each decision point. Additionally, as exposed previously, the right to study precedes the right to modify simply because logically one should be able to study a piece of design before being able to modify it. Therefore, as shown in figure 4, the goal "studying" is a sub-goal of "modifying".

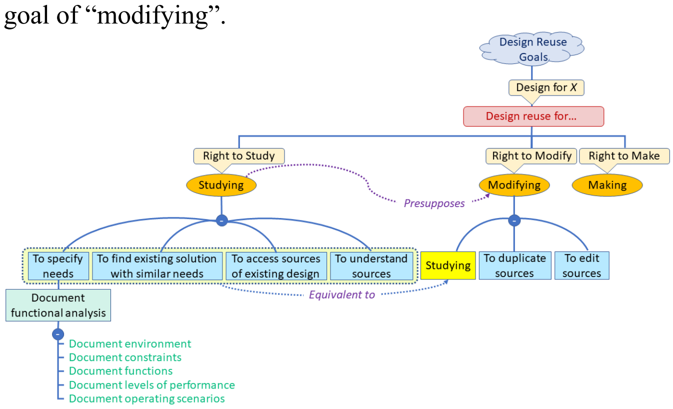

Fig. 4. Illustration of how design guidelines relate to design reuse goals.

In the example of Figure 4, the guidelines that encourage documenting the functional view of a product are not explicitly stated in the reviews section of Section 4, however it is embedded in the category "information models" (figure 2) which encompasses all the models of the product at each level or step of the design process. We have noted that incomplete design documentation is one of the most influential factors that makes the reuse of existing designs difficult. Moreover, when observing web-based OSH repositories (category information system of figure 2), one notice that the functional view of a product is hardly documented even though it is a well-established practice in industrial and academic works. In the OSH context, the functional view is of tremendous importance for making explicit the context of use, the stakeholders and the needs. After our analysis, we can claim that a functional analysis of the OSH product should be systematically published as part of design documentation in order to support design reuse process.

6. Conclusion

Design reuse has been an important research topic at the turn of the 21st century. From an empirical point of view, it a very natural practice for every designer. From an industrial point of view, it is however relatively complex to implement either for technical reasons (what is the relevant format, level of details, etc. I must store?) or for cultural ones (I prefer to redesign the thing instead of trying to understand what has been done by another colleague I do not trust). We have tried in this paper to identify the important concepts that have been studied and put forward as important drivers of design reuse. In the context of open-source however, the design practices are relatively little structured and framed as they could be in industry. Therefore, the direct transfer of industrial approaches is not possible. Consequently, we propose to rely on the OSH well established framework of the OSHWA that represent ontological elements of OSH practices: right to study, modify, make and distribute. Based on that classification, we are in the process of identifying the form, structure and contents of the documentation and the associated recommendations. As identified in the literature review, the recommendations should include rules for documenting design rational (argumentation, justifications, …), product models (functional, structural or behavioral). On the other hand, search and retrieval of existing designs is also a key practice. As identified in the literature (semantic modelling, retrieval systems and web-based environments). A work is currently ongoing to determine a meta-data structure that would facilitate search and retrieval of elements of designs based on functional, structural or behavioral elements.

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