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Framing Open Design through Theoretical Concepts and Practical Applications: A Systematic Literature Review

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This study reports on the results of a systematic literature review on 'open design' in academic fields including and beyond design and HCI. The review investigates how studies are framed as open design and open-source design (including 'open hardware'): how researchers contribute to conceptual theorizing about open design or study its practical operationalization, in do-it-yourself 'making,' manufacturing and practices in-between these domains. Most of the papers reviewed were empirical studies from diverse fields. Open design was analyzed not only as contributions and solutions, but also as open-to-participate processes, openly shared processes, and open, closed, and modular (open and closed) outcomes. Various research fields presented an open design framing as an alternative to the status quo: new ways to do business and/or to foster socio-environmental sustainability. On the manufacturing side, open design was sought especially to accelerate innovation cycles; on the making side, it was espoused to foster democratization. However, the studies reviewed indicated that companies do not appear to develop much beyond business-as-usual. From the research perspective, the conceptual potential of open design to promote sustainability saw little practical exploration. Additionally, issues around open design community governance

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and ownership, safety and reliability of open outcomes require further investigation.

1. INTRODUCTION

'Open design' has emerged alongside and as part of phenomena displaying ever-increasing citizen, consumer, and user agency in post-industrial economies. Interest in 'openness' is apparent across varied sectors in many regions, from expanding participation in political decision-making processes, to online cultural production and open-source software development, to peer-to-peer production of services. Open design as a topic of attention for researchers and research-practitioners denotes that openness, inclusion and 'democratizing' is also increasingly desired in design and production by both informal networks of makers and professional, industrial actors, whether this means openness of product blueprints and instructions, openness to participation in design processes, or openness in sharing design-related knowledge and information. Open design is thus an activity and a line of inquiry that actors have been pursuing for some time, with various capacities and terminologies, but it is now being named and denoted and certain practices are arguably becoming formalized. This paper presents the results of a systematic literature review that aimed to capture how open design is studied in academia and by whom.

Particularly in practitioners' non-academic literature, but also increasingly in academia, open design is seen and conceptualized as alternative manufacturing or fabrication, a new way to organize and manage design, acts of prosumption or peer production, alternative material culture, and/or explorations in horizontal community organization (Boisseau, Omhover, & Bouchard, 2018; Manzini, 2015; Raasch, Herstatt, & Balka, 2009; Thackara, 2011; Tooze et al., 2014; van Abel, Evers, Klaasen, & Troxler, 2011). Researchers interested in 'openness,' whether in product design, engineering, HCI, media and communications, management studies, or the natural sciences, appear to be taking up the notion of 'open design' and 'open-source design' to frame their studies. This increased attention may be due to the number of research-practitioners who both experiment with open practices, processes, and outcomes, but also wish to examine them more systematically using conventions from various study fields. Presumably, it is seen fruitful to present their findings in academic channels (not only websites, blog posts or Github), to reach new audiences and like-minded colleagues, but also to persuade incumbents that these new open-oriented practices are worth considering by informing about and advocating them. The benefits of open design are thereby articulated in various ways, from a strategy to attract new markets to a means to allow communities to meet their own needs in less ecologically impactful ways.

As researchers and research-practitioners of open design ourselves, we found the increased espousal of open design compelling. However, are these benefits simply proposed or are they examined empirically, and by whom? In 2011, a volume titled *Open Design Now* (van Abel et al., 2011) was published that became seminal to European designers. The book contributed to consolidating open design as a design direction of note, particularly as it was supported by the official design promotion body in the Netherlands. It made visible and lent a name to the grassroots, alternative, digital-DIY 'making' activities that were burgeoning in the Netherlands at the time (Troxler, 2014). Likewise, well-cited studies such as Raasch et al. (2009) have promoted the use of the term open design to describe new, decentralizing, user-involving manufacturing practices that go 'beyond open-source software,' from the perspective of innovation and R&D management.

Several years have passed since these early, still well-cited examples. It is hence timely to re-examine this research terrain, to map the current state of open design as a research topic. To this end, the objectives of this literature review are:

- to map and summarize the activities, audiences and directions in academic research on open design: what types of studies are conducted and in what fields;
- to examine how researchers present the implications of and motivations behind open design, their own and/or the motivations of their research participants: what directions, future visions and/or normative intents lie behind the studies;
- to examine how DIY making, new manufacturing and in-between practices are represented in the studies: how is open design seen to contribute and what projects, practices and concepts are salient; and
- to make sense of the current use of the term 'open design,' where various definitions within the literature appear dispersed and disparate while sometimes overlapping.

In undertaking this review, we are interested in the *contents* of the studies as knowledge building on open design, but also the *activities* and *directions* of open design research aiming to promote a particular practice. We build upon our own work in sustainable design research, from the perspectives of open product design processes (Bakırlıoğlu, 2017) and open design DIY maker communities (Kohtala, 2016), to satisfy our researcher curiosity about where open design really is now: what is open, for whom and why? This has implications for readers in design and HCI research working in areas where science, technology, design, and innovation merge, where the boundaries between grassroots 'making' and incumbent manufacturing, and between designer and user, are becoming increasingly blurred. The following section will introduce open design as a research interest and outline our motivation to conduct such a literature review. The methodology is described in section 3. Section 4 provides a descriptive overview of the literature and maps its positionings as research inquiry, section 5 synthesizes key insights in the literature regarding the core of open design, and four key cross-cutting themes prominent in the literature are summarized in sections 6 and 7. We then highlight the key implications of the review in discussion and conclusions in section 8.

2. RATIONALE

Our motivation for embarking on this literature review stems from our long-term observations of design discourse, particularly in the European post-industrial context: how it is to be understood, analyzed and practiced (e.g. Björgvinsson, Ehn, & Hillgren, 2010; Bonsiepe, 2006; Manzini, 2015; Sengers & Gaver, 2006), but also how it is actually being enacted at the grassroots level in novel ways enabled by digital communication and production technologies, often informed by free, open-source software (F/OSS) development and hacker communities (van Abel et al., 2011). More designers (researchers and practitioners) appeared to be adopting 'open design' as a framing for their work, but the term was also being adopted outside the arenas of design and HCI. We wanted to know more precisely what was meant when open design was referenced in these various contexts, if it was in danger of becoming an empty buzzword, or if there was potential for cross-fertilization of knowledge and insights from these disparate endeavors. In this section, we discuss this background to the review and why we think it is timely, what we see as key moments in how open design has developed as a concept, and how influential references have characterized open design processes.

Open design has emerged at, and been informed by, the intersection of open-source software development, DIY maker culture, hacker culture, and new understandings of the designer-user relationship. Marttila and Botero (2013) have framed these developments in design discourse as the "openness turn," particularly in the arena of *co-design*. These authors see open design as having two main strands in research and practice. The first strand they identify is openly shared, publicly available designs (e.g. blueprints) (p. 105). This involves the free sharing and adopting of designs, following the Do-It-Yourself (D.I.Y.) movement that dates back to early projects such as *Nomadic Furniture* (Hennesey & Papanek, 1973) and *Autoprogettazione?* (Mari, 1974: 2014). It has evolved through accessibility to data thanks to Web 2.0 technologies and user-generated content (e.g. IkeaHackers.net, Openstructures.com; Instructables.com). This conception of open design is also linked to other lines of inquiry into design, such as peer production (Marttila & Botero, 2013, p. 106). Peer production is open source production of – originally software but now increasingly also – tangible products. As a focus of research, examining peer production often foregrounds how communities create, define, relate to and act to protect or exploit various shared *commons* (see Hess & Ostrom, 2006). Benkler's notion of *commons-based peer production* (2006) thus also weighs in when researchers and practitioners are discussing and writing about open design, such as considering open-source designs and design knowledge as contributing to a commons that ought to be open and freely available.

The second strand Marttila and Botero (2013) identify is open-ended design activity. The authors connect this strand of research and practice to the type of open design promoted in the *Open Design Now* volume, which suggests people participating in design activities to produce products (especially in fab labs and makerspaces). They also point to co-design proper, particularly participatory design (Marttila & Botero, 2013, p. 106), and how it is becoming increasingly open-ended. Participatory design was initially developed in workplace studies to enable the people affected by a design solution to influence design early on (Bjerknes, Ehn, Kyng, & Nygaard, 1983; Greenbaum & Kyng, 1991). As a practice that brings stakeholders democratically into designing (Björgvinsson et al., 2010; Ehn, 2008), it is 'open' by definition, and framed as user engagement or participation, but Marttila and Botero (2013, p. 106) argue that openness per se is not directly addressed. Open-ended design activity is also highlighted in Jones's (1983) depiction of a design process, inspired by the then evolving software technologies and their process of making, changing, modifying and updating. By shifting the focus of design activity from outcomes to the process itself, a continuous designing and redesigning process can respond to changing contexts and needs, and divergence can be achieved through collaborative designing (Jones, 1983).

The contexts of where open design is seen to happen are also important. The term itself is credited to, first, Ronen Kardushin, who many in Europe cite as coining the term 'open design' in his 2004 Master's thesis (Troxler, 2011). Secondly, in the context of manufacturing and production management, several studies (e.g. Raasch & Herstatt, 2011) attribute 'open design' to Vallance, Kiani, and Nayfeh (2001), as innovative, open-source machine development. Both sets of authors aimed to bring open-source software principles into the arena of tangible designed products and equipment, to enhance modifiability by oneself and future others. Kardushin targeted openly shared designs that could be directly fabricated by designers or users, without the need or cost of extra tooling; Vallance et al. wanted to improve the agility of manufacturing. Both entailed resistance to incumbent practices that were seen to inhibit participation or influence, learning, adaptation, creativity, and innovation. Here, then, we see early instantiations of open design in two contexts, D.I.Y. making and commons-based material peer production, and new manufacturing initiatives, both espoused as better, more democratic alternatives to existing modes of production.

In non-European contexts, openness of design and innovation processes has been characterized in varying terms, such as *shanzhai* or *gongkai*, and from various positionings, such as innovation, material culture and postcolonial computing (Huang, 2014; Irani, Vertesi, Dourish, Phillip, & Grinter, 2010; Lindtner, 2015). Some lines of enquiry adjacent to, and useful for, open design, such as explorations on *gambiarra, jugaad*, hacking, and repair (Fonseca, 2015; Houston et al., 2016; Rangaswamy & Sambasivan, 2011) may draw our attention more to finished consumer products that are hacked, rather than open design blueprints and the openness and democratizing of actual design and production processes. Some therefore argue that outcomes throughout this open and continuous process, to be even more 'democratic' and having the ability to be modified and personalized, thereby need to be *pre-hacked* (Richardson, 2016). In these contexts outside mainstream European design that are easily overlooked, but which carry valuable lessons for more responsible, equitable post-industrial and postcolonial design and production with global ramifications, it is compelling to examine the adoption of 'open' terminology to see where and if such cross-fertilization of knowledge and discourse occurs.

In sum, open design suggests limitation-free 'design knowledge' sharing and calling for participation of people with varying backgrounds to develop and iterate design solutions. Among participatory design approaches, it holds a rather unique position, as it is not a goal-oriented, linear process of developing finalized design outcomes, but rather a set of branched processes with differing goals shaped by different contributors who self-select. In early (also well-cited) work on "open p2p design," Menichinelli emphasized that openness can and should be designed into the process, with the team deciding what phases would be open to others and what would be done by a specified group (Menichinelli, 2008). Tooze et al. (2014) furthered the examination of open design in design research, illustrating variations of an open design process: open and/or non-open design contributions lead to open and/or non-open design solutions. Furthermore, open design solutions can reconfigure into different solutions with further contributions (ibid), becoming a continuous design and redesign process (Jones, 1983; Richardson, 2016). Other early well-cited work highlighted how design solutions, parts, and components should be accessible, replaceable and modifiable: i.e. the strength of modularization (e.g. Raasch et al., 2009). As long as parts and design solutions remain open, the open design process can theoretically branch towards different goals according to the contributions made by different self-selecting contributors. Open design thus differs from the outcomes of other participatory approaches, in which participants reach a consensus that is reflected in the final design outcome. In fact, for insiders, the sign of a healthy open source community (and open design by implication) is the 'competition' among solutions and the possibilities for contributors to branch or 'fork.'

Whether democratizing, open co-design processes, open hardware, open product development or new manufacturing practices, open design has been espoused as socially beneficial, by offering new opportunities for embodied creativity and invention through making, in contrast to passive consumption, or empowering individuals to influence what is produced (Manzini, 2009). It is espoused to bring economic benefit, by providing new types of enterprise and entrepreneurship and new ways to manufacture more attractive products (Raasch & Herstatt, 2011). And it is also often espoused as environmentally beneficial, fostering material and resource eco-efficiency, localizing production, closing loops and empowering communities to meet their own local needs, as well as needs of citizens in the future through open, adaptable solutions and knowledge sharing (Kostakis, Niaros, Dafermos, & Bauwens, 2015). Examining the literature to determine how far research has come in providing empirical evidence to support the many espoused benefits of open design, was a key rationale for this review.

Interestingly, while not surprisingly, others have identified the same research interest, with a recent literature review examining open design in the context of product design and design science (Boisseau et al., 2018). These authors' review is both wider (in terms of types of publications examined) and narrower (only Scopus was used as a database), and it is directed to a product design audience.

We agree with Boisseau, Omhover, and Bouchard that more and more products and product-systems are being "openized" (2018, p. 22/44). Not only products, however: open design is embedded in various kinds of productive knowledge-building networks that aim for something new, whether a new, more relevant product or a more convivial, cooperative neighborhood where more citizens can be self-sufficient. Academics in this realm are often researcher-practitioners and even researcher-activists. Examining the research terrain on open design (and the gaps in it) can tell us much about how the academic community positions itself: how it negotiates the epistemological terrain between theoretical conceptualizing and practical experimentation, to whom it wishes to present arguments, and how it communicates the relationship between new making practices and conventional, commercial design and manufacturing. We go on to describe our methodology in the following section.

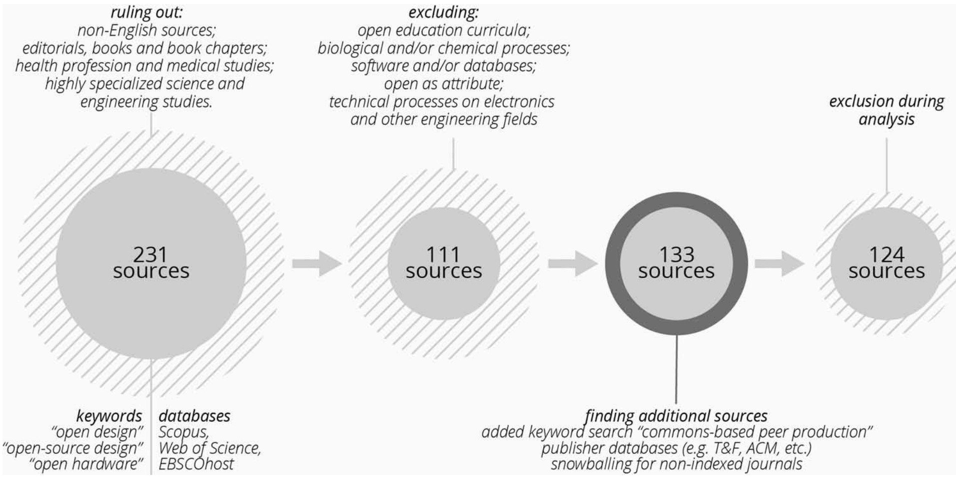
3. METHODOLOGY

The purpose of this study was to identify peer-reviewed journal and proceedings articles that present practical explorations and/or theoretical concepts framed as open design to identify how open design is discussed in academic settings. The aim of a systematic literature review is to aggregate all sources on a defined topic and synthesize them (Pattinson, Preece, & Dawson, 2016; Pittaway, Robertson, Munir, Denyer, & Neely, 2004).

We identified three search keywords (i.e. exact phrases *open design, open-source design*, and *open hardware*) that would provide a satisfactory snapshot of the current literature on open design when combined. (*See* Appendix, Inclusion criteria.) We ran search queries in three academic databases (i.e. EBSCO Academic Search Elite [Title, Abstract, and Keyword fields], Scopus [Title, Abstract and Keyword field] and Web of Science [Topic field]) separately for each keyword. After eliminating trade magazine articles, book chapters and the like, retaining only full-text, peer-reviewed journal articles and papers from peer-reviewed, indexed conference proceedings, the search query yielded hundreds of results from which we eliminated sources on, e.g. open education and other irrelevant topics (Figure 1).

From the eventual list of 111 articles, we again examined the titles, abstracts, keywords and in some cases full text. At this stage, several articles relating to open meaning open-ended or unsolved, open and not physically closed, or open-minded were excluded. To ensure the final list included all the related scholarly articles that fit the criteria, a final search query was performed on publisher databases (e.g. Taylor and Francis, ACM Digital Library) and we examined our own bibliographies for relevant studies in journals not indexed by these databases, such as *Disegno* (having had a relevant special issue) and the *Journal of Peer Production*. During the analysis stage, some further articles were excluded, resulting in the final list of 124 articles published until the end of 2017 (Figure 1 and Appendix).

FIGURE 1. Source search phases.



The search process itself was fraught with challenge, as 'open,' 'design' and 'open design' are widely encompassing terms. We therefore conducted several searches with varying limits until we uncovered no new papers (such as Boolean operators with varying combinations of 'open,' 'source,' 'design,' and 'hardware'). 'Open design' most saliently refers to open design methodology in medical studies, as well as open design methodology in engineering (Franksen, 1965). Most subject areas related to medicine and health (such as psychiatry or pharmacology) and engineering and natural sciences (such as nuclear science technology) could be safely excluded from the search from the outset, but we found that too rigorous a limited search-string meant that some health-related yet relevant studies (such as the open-source design of assistive devices) were excluded. In architecture and design, 'open design' often referred rather to physically open space (in contrast to physically closed) and open-ended design problems, particularly presented in design education. In these cases, titles and abstracts had to be examined manually to determine relevance, rather than eliminating whole sub-sets of studies using limiters in search strings.

Similarly, there were many borderline articles in the area between open design and open hardware. Such articles often concerned instrumentation and the open design (as in open blueprints to be shared subsequently) of instruments and measurement devices. Another borderline fuzzy area concerned design and design engineering studies on end-user involvement, framed as co-design, end-user development, user involvement and the like, in topics related to mass customization, participatory design, user innovation, and designer-user relations. We discussed the borderline cases to achieve consensus. While the Appendix presents the inclusion/exclusion criteria of sources, we see the fuzziness of the boundaries of this review, where our subjective interpretation led to an article being included or excluded, is as much a point of interest as a limitation of a systematic literature review (MacLure, 2005). It is therefore important to make this visible to the reader, and we have illustrated the scale of relevance of the articles in the next section in Figure 5, where the number of articles clearly referring to 'open design' and 'open source design' in article title, abstract, keyword and/or main text are depicted. Attention was paid to the quality of the papers, but more emphasis was placed on the relevance to the research question of this literature review. As we wished to see what researchers classify as open design, we therefore did not wish to discard papers on quality criteria but rather merely noted the subject area and methods used. Papers that were most clearly relevant and of sufficient quality regarding robustness of the research were examined further for their contents and approaches (*see* Appendix, Quality Assessment). In addition, we recognize that a systematic literature review can appear coarse on some topics in an attempt to code and quantify a literature area (MacLure, 2005). Hence, we explicate our analysis process in the following paragraphs and when describing the findings, to aid readers' interpretation of the results.

The analysis of the final list of sources was done in two steps. The first step mapped the origins of studies and their focuses through their meta-data (i.e. subject classifications of journals and conferences, keywords of articles). These analyses were conducted by the two authors independently and discussed in co-analysis sessions. Each source was accorded a primary and a secondary subject area keyword based on the classification system used by Scopus and SJR rankings for journals and proceedings. The field of Design is central to the study of open design but does not have its own subject area, falling rather in the areas of Computer Science (Computer Aided Design) or Arts and Humanities. The design journals were therefore accorded their own keyword Design and the secondary keyword of the given subject area. (Therefore *The Design Journal* was primarily Design and secondarily Arts and Humanities, while the *International Journal of Design* was primarily Design and secondarily Management.) This tactic was adopted to maintain the audience differences among journals otherwise in the same subject area, as well as to attempt to account for transdisciplinary journals. The distribution of the articles among the subject areas is illustrated in Figure 4, which is described further in section 4.1. The articles were also grouped according to topic and positioning by analyzing and mapping the article keywords (using Nvivo software) (*see* section 4.2). Beyond this overview of the research terrain, this analysis failed to generate a meaningful classification of open design processes and outcomes on the spectrum of making and manufacturing.

In the second stage, therefore, we further coded the sources inductively, without previous categories in mind. An initial coding of 30 papers revealed several classifications that could provide meaningful results. Categories that emerged related to *community, ownership*, how or if *sustainability* (social or environmental) was represented, and how or if ideas about *alternative (new) forms of business* or even economic paradigm (such as 'degrowth') were represented. In addition, we recognized the range of definitions of open design adopted in the literature, and, instead of trying to shoehorn them into a coherent yet reductive definition, we mapped the studies according to what was 'open' and what kind of 'open design' was being invoked, the studies' positions in the making-to-manufacturing spectrum, the scale of the study focus, and to what the studies aimed to contribute.

As a result of this two-stage analysis, section 4 presents a descriptive overview of the studies. Section 5 categorizes the key differences among various kinds of open design presented in the reviewed papers and to what they refer on the spectrum of making-manufacturing. Section 6 focuses on alternatives espoused through open design about sustainability and businesses, presents a more in-depth analysis of the contents of the studies, and expands on what is conceptually illustrated, empirically observed and/or practically explored. Section 7 presents key issues of open design with regards to ownership and communities.

4. OVERVIEW OF RESEARCH ON OPEN DESIGN

4.1. General Description of the Studies

There are 124 papers in this review, listed in the supplemental file to this paper. Their distributions are illustrated by year and according to subject area (Figure 2), by country or territory of the first author (Figure 3), by subject area and journal (Figure 4)

FIGURE 2. Reviewed papers by year and subject area (according to journals' or proceedings' subject area classification).

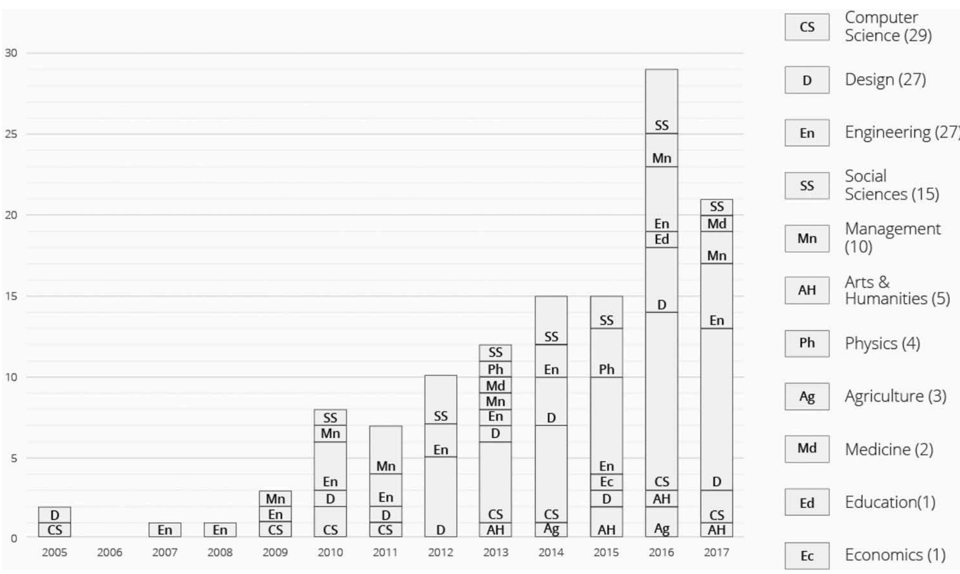
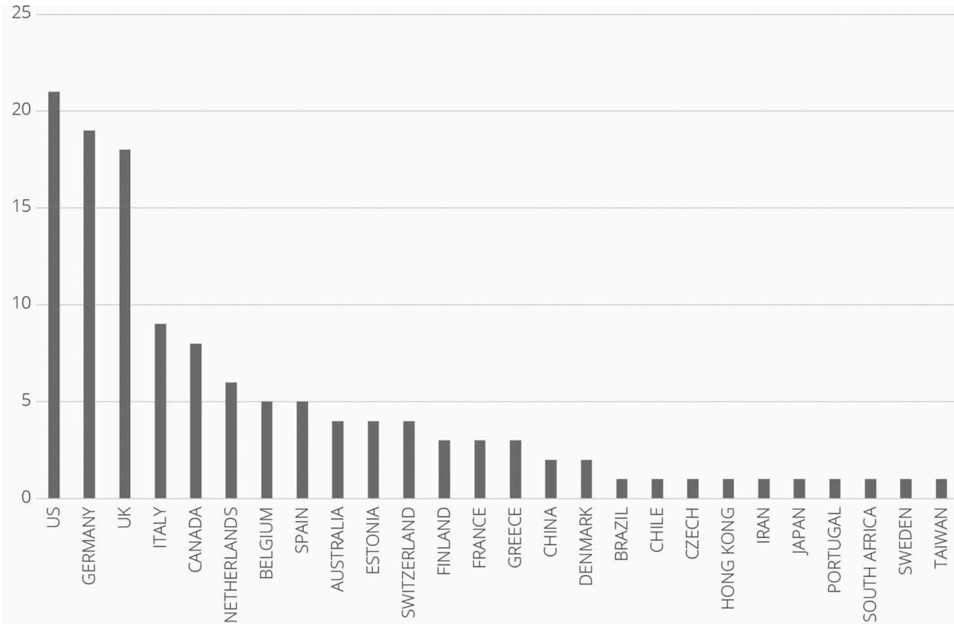


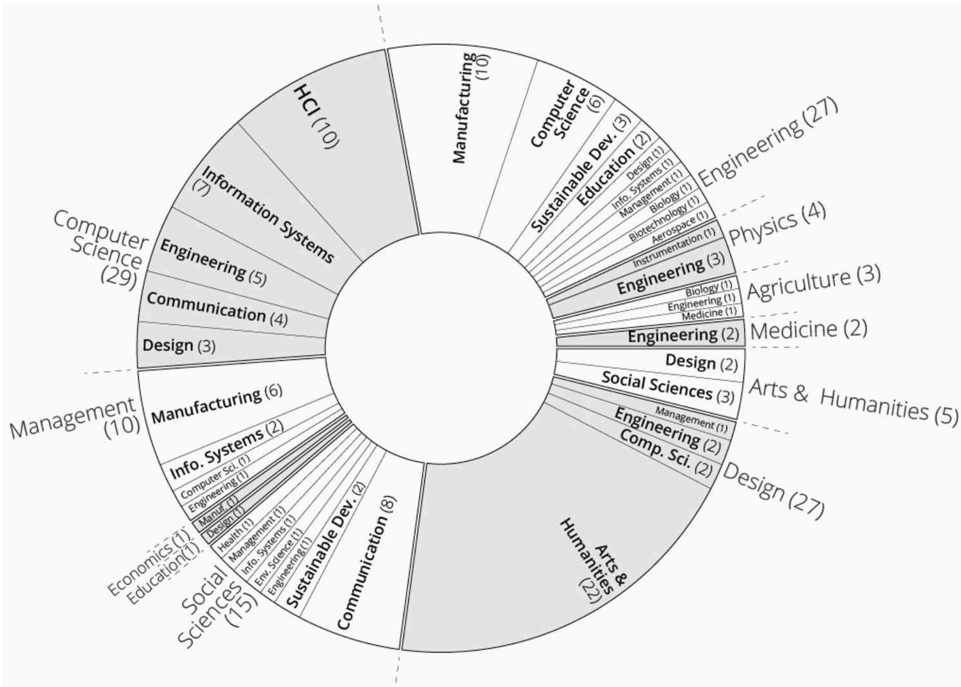
FIGURE 3. Countries/territories of the first authors' affiliations.



and by the focus area of each study (Figure 6). We classified 95 papers as empirical (including 26 technical experiments), 28 as conceptual papers and there was one review article (Seo-Zindy & Heeks, 2017).

Most papers were contributed by authors based in North America or Europe. However, it should be noted that Figure 3 only reflects the affiliations of authors and in which countries they are based, not their focus. For example, issues related to open design in the global South were raised, such as the potential of fab labs and makerspaces to foster frugal innovation in these regions (Redlich et al., 2016; Seo-Zindy & Heeks, 2017). The review also includes an empirical study on makers in China and their position with regard to China's manufacturing culture (Lindtner, 2015). A cluster of papers referred to the open-source design of *appropriate technologies* in emerging economies, to stimulate economic activity and address clear societal needs such as solar PV panels to provide electricity (Kostakis & Papachristou, 2014; Moritz, Redlich, Grames, & Wulfsberg, 2016; Pearce, 2012; Pearce & Mushtaq, 2009; Redlich et al., 2016; Woolf, et al. 2017; Zelenika & Pearce, 2014). The papers classified as technical experiments, which often featured the design of lab equipment or tools in science research or education, also positioned their work as open-source design or open hardware, explicitly stating the wish to share their work with colleagues in contexts with fewer resources.

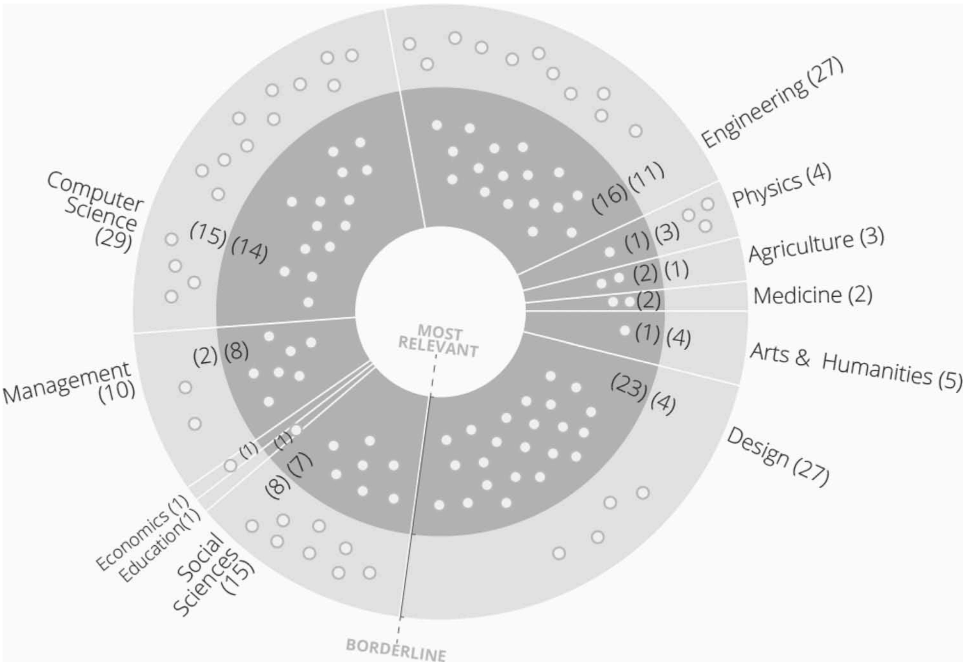
FIGURE 4. Distribution of the reviewed papers by journal/proceedings subject area and indicating the secondary subject area of each publication.



The high number of empirical studies was rather surprising, as study topics seen as emerging and of high interest (as open design may be perceived) are often marked by conceptual papers aimed at delineating territory, defining terms, laying out hypothetical barriers and opportunities, and advocating the topic as one worth further research. Very few conceptual articles were only presenting unsubstantiated claims in a superficial manner, which can be a symptom afflicting new and emerging topics of interest. Instead, the conceptual articles in this review included meta-analyses and 'roadmaps,' philosophically grounded essays, presentations of frameworks or conceptual models and the like. One article reviewed the recent history of open design as a cultural and political phenomenon in the Netherlands (Meroz & Griffin, 2012), which we nevertheless classified as conceptual. We considered the contribution of each conceptual paper according to MacInnis's framework (2011) and those papers not making a clear contribution were not included in further analysis.

The conceptual papers often used specific examples to illustrate arguments, and it was noteworthy how both conceptual and empirical articles tended to use the same projects as emblematic cases of open design – as Wikipedia and Linux are used to exemplify peer production of digital artifacts. The most commonly referenced

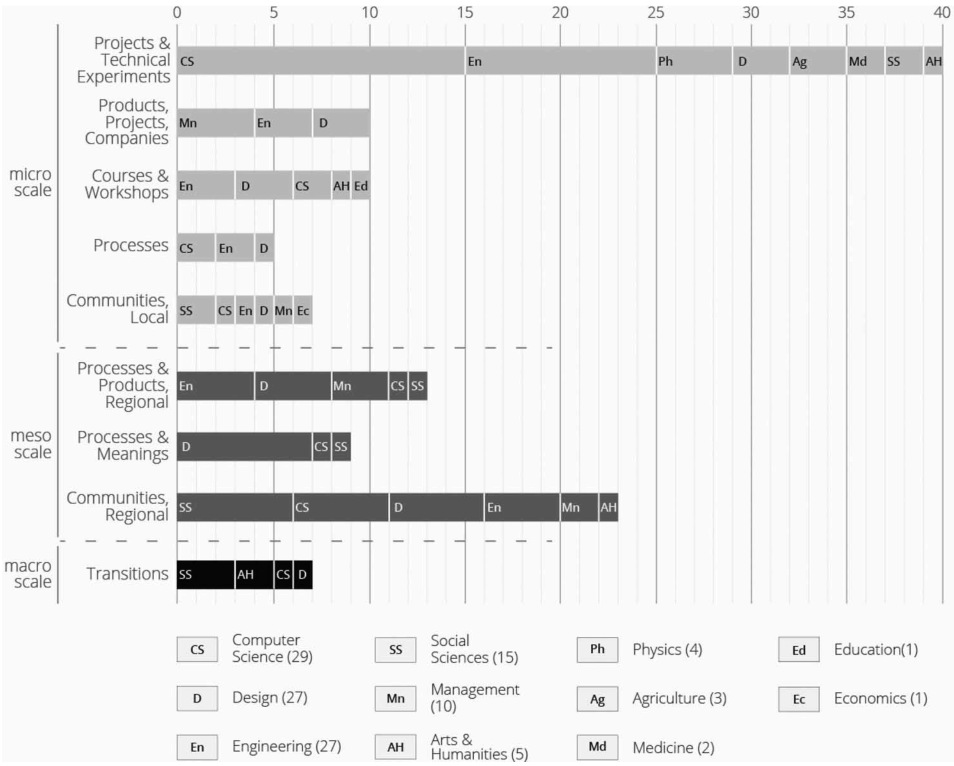
FIGURE 5. Mapping of articles' relevance. The most relevant articles (having 'open design' or 'open source design' in the title, keywords or abstract) are represented as small circles towards the center of the diagram.



examples were RepRap (mentioned in 34 papers), Arduino (as an exemplary case of open hardware, not only as a tool in use, in 33 papers), Thingiverse (21 papers), Open Source Ecology (12 papers), OScar (12), Fab@Home (10), OpenMoko (9), Local Motors (7), and Open Structures (7). That the open design of vehicles is so compelling is also noteworthy, being the focus of four papers (Malinen, Mikkonen, Tienvieri, & Vadén, 2011; Müller-Seitz & Reger, 2010; Richardson, Vittouris, & Rose, 2010; Seidel & Langner, 2015). Thingiverse also featured as a subject of four studies, which examined the designs or business strategies (Kuk & Kirilova, 2013; Kyriakou, Nickerson, & Sabnis, 2017; Özkil, 2017; West & Kuk, 2016). Rather surprisingly the open design of fashion did not feature highly, even if it is a popular topic in non-academic literature and among practitioners.

That a search for 'open design' would find many design articles (and relevant ones) is obvious. What is noteworthy is how other fields are adopting open design as a phrase and/or framing concept. For instance Hall and Lobo (2017) presented an assistive device for children, a garment-based exoskeleton, as 'open source design' in a health and medicine-oriented journal, where the researchers' design process was explicitly denoted as an alternative to "the traditional medical model"

FIGURE 6. The distribution of the papers according to study focus.



by being "interdisciplinary, user-centered, and addresses the broad needs of users, rather than device function alone" (n.p.). The study by Callahan and Darby (2014) not only documented the design of an agricultural harvesting machine for an agricultural engineering conference proceedings, but also framed it as "open source design practices" (p. 1). The authors pointed to the 'design-in-use' characteristics of agricultural technology communities and examined incentives to participate in open source projects: how such communities should be rather seen as a "design-use community" also capable of innovating (p. 1). Design-in-use is, of course, an important notion in design and HCI, where responsibility for design is acknowledged as going beyond the product launch (Henderson & Kyng, 1992), and it is compelling it should be taken up by agricultural technology researchers.

Most of the papers reviewed examined single projects or technical experiments (40, see Figure 6). Surprisingly many (23) examined communities at regional levels, meaning networks of actors and/or artifacts (e.g. repositories) (e.g. Özkil, 2017; Tamminen & Moilanen, 2016); industrial networks or clusters (e.g. Balka, Raasch, & Herstatt, 2010; Rebensdorf, Gergert, Oosthuizen, & Böhm, 2015); communities (explicitly using the word) over a longer time frame (e.g. Lindtner, 2015; A. Powell, 2012); and/or communities or networks where meso-level impacts were discussed. Papers that examined processes and products at the meso-level (13), in contrast, rather examined open design contributions and how they shaped product design in large networks (e.g. Kyriakou et al., 2017; Qin, Velde, Chatzakis, McStea, & Smith, 2016). Many design courses and workshops in formal and informal education were also examined (10). Studies that examined processes and meanings (9) did so in terms of design as culture, the ethics of design or the meaning of open design in shifting production and consumption patterns (e.g. Cruickshank & Atkinson, 2014; Richardson, 2016). Larger transitions to new paradigms enabled by open design practices were discussed in seven papers, invoking alternative economic models such as degrowth and distributed production (e.g. Quilley, Hawreliak, & Kish, 2016; Ramos, 2017). There was also concern that "generation open" could be as fragile and precarious as that without such devotion to openness, and "open everything" could render everything – and therefore nothing – as empowering (Busch, 2012; Pomerantz & Peek, 2016). Articles in the HCI subcategory (10) tended to focus on micro-scale implications of open design, mainly on projects and technical experiments (8). This suggests that open design is not yet adopted by HCI researchers as a framing. We will elaborate on this further in the Discussion section.

Many of the reviewed articles also made contributions by providing conceptual models, business models, frameworks and guidelines. Prominent examples in the review are listed in Figure 7.

This section has provided a descriptive overview of the studies reviewed. As a concept, open design appears to be mainly employed in Euro-US contexts and largely limited to smaller projects and design processes. Nevertheless, other scientific fields are increasingly adopting the term to emphasize the benefits of openness. Activities examined elsewhere, particularly in Africa and Asia, are also being connected to open design and open hardware framings to raise the visibility of these democratizing efforts. Further discussion on how open design was represented and positioned in relation to overlapping or adjacent concepts will follow in the next section.

4.2. Open-X: Examining the Keywords

To illustrate the scope of the reviewed papers and the various terminologies adopted, this section presents a categorization of the articles' keywords relevant to open design. As an evolving and popular term, 'open' is used repeatedly in different contexts, to indicate varying attributes of outcomes and practices that may overlap or completely diverge. In their attempt to collate all the uses of 'open,' Pomerantz and Peek (2016) group them into seven categories: rights, access, use, transparency, participation, enabling openness, and aligned with open principles. In the case of open design, the varying definition of open is stretched even further with design-as-act and design-as-outcome, and different lines of inquiry, with varying approaches to design, align with different concepts, whether 'collaboration,' 'participation,' 'peer,' or

FIGURE 7. Examples of contributions as business models, frameworks, guidelines, taxonomies.

Source	Contribution
Abdelkafi, Blecker, & Raasch, 2009	Commercialization models of products developed according to open source principles
Aitamurto, Holland, & Hussain, 2015	Framework for open design practices (three-layered)
Balka, Raasch, & Herstatt, 2009	The open source innovation framework
Basmer et al. 2015	Criteria of social sustainability fostered by Open Production
Bonvoisin & Boujut, 2015	Four dimensions for successful open design projects (Community management, Convergence of the development process, Knowledge and quality management, Supporting co-creation)
Bonvoisin, Galla, & Prendeville, 2017	Design principles for DIY production
Buitenhuis & Pearce, 2012	Business models for the solar PV industry (partnership model, franchise model, secondary industry model, fully open-source design model)
de Couvreur & Goossens, 2011	Design for (every)one macro framework (for community-based rehabilitation contexts and co-design of assistive devices)
Kortuem & Bourgeois, 2016	Technology openness matrix (regarding e.g. risk and partner visibility)
Kostakis, Niaros, Dafermos, & Bauwens, 2015	DG-ML (Design Global Manufacture Local) model and framework
Menichinelli, 2016	Framework for understanding possible intersections of design with open, p2p, diffuse, distributed and decentralized systems
Raasch & Herstatt, 2011	Taxonomy of (four) business models in open design (Tier specialist, Focal company, Seller of complements, Commercial user)
Rebensdorf, Gergert, Oosthuizen, & Böhm, 2015	Open Community Manufacturing system concept
Tamminen & Moilanen, 2016	Spin model of the method of operation in the open design community
Tooze et al. 2014	Models of open design: variations of open and non-open design, collaborative design, open design solutions
Troxler & Wolf, 2017	Building blocks for business models of digital maker-entrepreneurs
Wulfsberg, Redlich, & Bruhns, 2010	Open Production framework for designing value creation

'mass.' The alignments are evident in the keywords the authors choose, and the conceptual relations are usually discussed in the articles' background sections. Figure 8 presents keywords related to different aspects of open design and categorizes them according to implications suggested in selected sources.

In the reviewed papers, more general terms related to accessibility and sharing of knowledge were employed within the context of design to identify differing attributes. *Open access* denoted the availability of academic content to anyone, regardless of affiliation (Pearce, 2012). *Open knowledge* denoted accessible and usable knowledge about physical objects for any purposes, without legal repercussions (Powell, 2015; Wolf, Troxler, Kocher, Harboe, & Gaudenz, 2014). *Open education* was presented as a term older than the internet, referring to the accessibility to education for people who cannot access traditional or formal forms of education (Ostuzzi, Conradie, Couvreur, Detand, & Saldien, 2016). In the context of open design, the term was applied in an educational design project on developing open solutions (ibid). *Peer to peer mentoring* was a proposal for the design and distribution of training programs on building capacity in projects that aim to have a more positive societal impact (Cangiano, Romano, & Loglio, 2017).

FIGURE 8. Categorization of keywords used in reviewed articles.

	Open & Open-source	Collaboration & Participation	Peer	Mass
Accessing Knowledge	open access (1) open education (1) open knowledge (1)		P2P mentoring (1)	
Communication & Organization	open source networks (1) open source intelligence (1)	collaboration (4) participation (2) participatory (1)	peer to peer (2)	crowdsourcing mass-collaboration (1) mass-participation (1)
Idea-generation & Design Detailing	open innovation (7) open service (1)	co-design (9) co-creation (4) co-construction (1) user participation (1) consumer participation (1)		mass-individualization (1)
Accessible and Adaptable Solutions	open technology (1) open hardware (11) open source design (4) open source software (8) open source hardware (2) open design platform (1) open-ended design (1) open authorship (1) meta-models (1) pre-hacked (1) open architecture (1)			
Producing / Fabricating	open fabrication (1) open manufacturing (1) open production (1)	participatory making (1) participatory prototyping (1)	peer production (3)	mass production (1)

Besides sharing of knowledge, other keywords referred to enabling accessibility and communication among contributors of open knowledge. *Open source networks* enable independent actors to share knowledge and collaborate with one another, bypassing larger institutions (Quilley et al., 2016). In this reference, it was discussed in relation to distributed fabrication (ibid). *Open source intelligence* referred to collective intelligence of micro-tasking people in such networks, presenting the ability to undertake certain tasks better than a small number of experts (Aitamurto, Holland, & Hussain, 2015). The organizational structure suggested by *open source intelligence* is similar to *crowdsourcing* (Gasparotto, 2017; Howard, Achiche, Özkil, & McAloone, 2012; Qin et al., 2016; Zelenika & Pearce, 2014), *mass-collaboration* (Panchal & Fathianathan, 2008) and *mass-participation* (Menichinelli, 2016), as they all hint at the potential of collaboration generated by a larger number of people working on various tasks. These terms are compatible with the notion of *peer-to-peer*, which suggested a more lateral, less hierarchical collaboration among self-selecting participants, and, in terms of design process, it suggested a collaborative development of design solutions through sharing of knowledge and resources (Menichinelli, 2016; Ramos, 2017), without putting such an emphasis on large numbers.

The keywords indicated differences with regards to types of design processes. *Open innovation* in the reviewed papers referred to contributions to a design revealed among volunteer developers for collaboration and development, in which contributors have access to others' contributions and cannot exert exclusive rights to the outcome of the process (Raasch, 2011). It also provides a strategy for combining open and proprietary products and parts (West & Kuk, 2016). Some authors regarded it as a collective umbrella term for business collaboration, IP licensing and outsourcing (Howard et al., 2012), or a form of intra-organizational collaboration (Koch, Schulte, & Tumer, 2010). Essentially, it was seen as referring to product development with some adopted open-source software approaches (Müller-Seitz & Reger, 2010), in collaboration with external stakeholders (Zhou & Tseng, 2013). *Open service* was a specific term that referred to the development of product-service systems with external stakeholders such as designers and users, in a similar manner (Howard et al., 2012). While these terms referred to a certain kind of collaboration in product development, they draw similarities to other keywords discussed extensively in design research, such as *co-creation* and *co-design*. The main difference of these uses is the emphasis on users being equal partners in the design process (de Couvreur, Dejonghe, Detand, & Goossens, 2013; Fleischmann, Hielscher, & Merritt, 2016), or their central position in decision-making leading to a commonly agreed solution (de Couvreur & Goossens, 2011; Tooze et al., 2014).

Accessible and adaptable outcomes were represented by different keywords, generally suggesting the sharing of design-related data and knowledge. *Open hardware* referred to solutions with shared schematics (Anlauff, Großhauser, & Hermann, 2010; van den Bossche, Dalce, & Val, 2016) which can be replicated and/or adapted without legal repercussions (Powell, 2015; Trilles et al., 2015). *Open hardware* was generally used to define solutions with electronic components, and there were many articles that used this keyword to present designs, schematics, their development process, and testing, without ever mentioning it in the article's text (e.g. Chacin, Oozu, & Iwata, 2016). *Open technology* referred to the development of accessible, technologically advanced outcomes (Manton et al., 2016), and one source examined the transdisciplinary involvement of social sciences in the development and adoption of sustainable, appropriate technologies (Nascimento & Pólvora, 2015). *Open design platform* referred to a set of predefined standards, parts, assembly details, or software that enable replication and modification of solutions in the context of the platform (Betthauser et al., 2014). *Open-ended design* referred to design solutions that are stripped of their contextual properties to enable easier appropriation and iteration in different local and individual contexts (Ostuzzi, De Couvreur, Detand, & Saldien, 2017). *Open authorship* similarly referred to designing solutions that enable others to interfere, alter and adapt them (Herst & Kasprzak, 2016). These keywords are similar to *pre-hacked* (Richardson, 2016) and *meta-models* (Kyriakou et al., 2017). *Open source software* was used as a keyword to indicate the origins of open design, and the application of similar approaches in the physical realm (Garrido, 2010; Müller-Seitz & Reger, 2010; Raasch et al., 2009), indicating the potential of user-developers independently undertaking the development process and creating physical outcomes (Raasch, 2011).

As this review tries to situate open design on the spectrum of making to manufacturing, keywords related to producing outcomes are of interest. In the reviewed papers, *peer production* suggested a decentralized mode of production (Kostakis et al., 2015) in which self-selection of contributors and transparency of processes are key (Kostakis & Papachristou, 2014; Tamminen & Moilanen, 2016). The development of digital fabrication technologies was mentioned as an important enabler (Bonvoisin, Galla, & Prendeville, 2017). *Open fabrication* referred to the accessibility of said fabrication technologies, through digital fabrication labs (Phillips, Ford, Sadler, Silve, & Baurley, 2013). *Participatory making* (Seravalli, 2012) and *participatory prototyping* (de Couvreur et al., 2013) both referred to real-life collaboration with people in the act of making. On the other hand, *open manufacturing* referred to more immanent production techniques enabling the involvement of designers and users through communication platforms (Gasparotto, 2017; Zhou & Tseng, 2013), which suggests a continuation of open innovation practices. *Open production* as a keyword suggested an in-between approach, relying on customers' ability to self-supply materials and undertake home production and assembly (Basmer et al., 2015). *Mass-production* as a keyword was only used in one article that reflected on the shift from Fordist, rationalist democratization of product accessibility with the help of mass-production, to democratization of the product development process distributed across time and space, and distributed production with open design (Richardson, 2016).

In this section, various perspectives on open design illustrated through the examination of keywords revealed varying ways of utilizing this newly emerging 'openness' paradigm to define collaboration, processes, outcomes, and production. The purpose of this examination was not only to show different, often contradictory, interpretations of open design in the literature but also to illustrate its scope. As this section indicates, researcher-practitioners frame their work as open design from various perspectives, presenting different positionings beyond the design-as-act and design-as-outcome divide and implications on different scales (i.e. micro, meso, and macro). An attempt to reconcile these varying perspectives into tidy definitions or taxonomies through the similarities or goals they share would not reveal meaningful results for this study. Hence, we rather suggest examining the open design research terrain as a system of branches and forks and understanding the implications as well as the research positionings. We address this first as the 'contents' of open design as discussed in the papers in the following section.

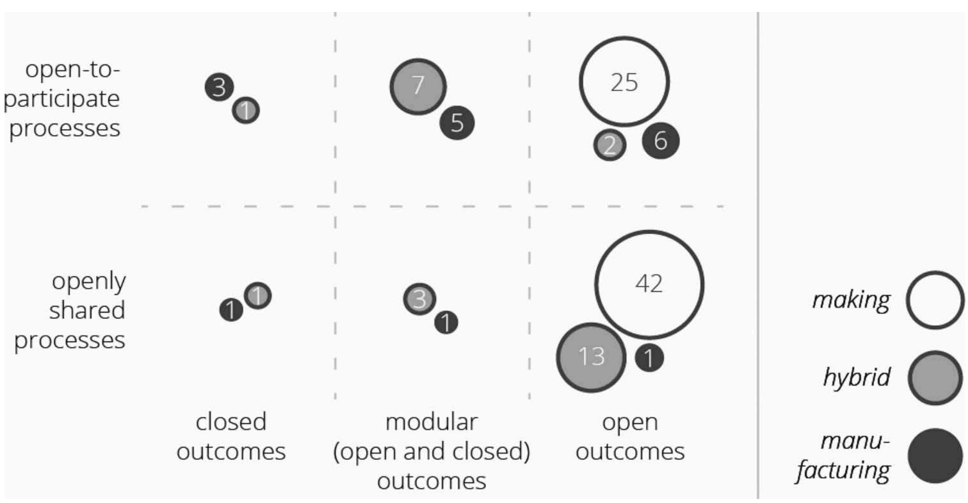
5. ARTICULATING OPEN DESIGN PROPER

In this section we summarize the potentials and challenges of open design discussed in the literature, bearing in mind the differing conceptualizations and contexts to which the authors referred. Excepting the papers that aimed to illustrate reviews of different open design practices, all the sources analyzed presented a clear stance with regards to the design process. We identified a need to differentiate not only open-or-not-open contributions and open-or-not-open solutions, but also to further clarify and distinguish processes – as either open-to-participate or openly shared – and outcomes, as open, modular, or closed. We then mapped these differentiations in relation to the study contexts, whether making, manufacturing or hybrid.

Open-to-participate processes refer to collaborative, ongoing design processes open to self-selecting participants in any context, prior to the sharing of any outcomes. This differs from openly shared processes, which refer to an individual or a team undertaking the design process, documenting it and sharing it upon completion or reaching maturity. There was one paper (Koren, Shpitalni, Gu, & Hu, 2015) that perceived opening only designated end-user processes as open design, which draws similarities to mass-customization, as the user authority to alter the design of artifacts is highly constrained. The distinguishing of outcomes is rather straightforward. Open outcomes are digital and physical artifacts with design details, ways of producing, schematics, test results, and so on, openly available for anyone to replicate, adapt and alter. Closed outcomes are proprietary, black-box artifacts, with no knowledge or right to replicate or adapt disclosed. Modular outcomes contain both open and closed modules, leveraging different strengths of both for different purposes. Figure 9 represents this terrain in a simple two-by-three grid and illustrates the number of academic sources falling into each intersection.

As expected, most sources fall in the right side of the matrix. Making was examined in the literature as having only open outcomes (again, as expected), while sources discussing modular outcomes tried to reconcile existing

FIGURE 9. Openness in processes and outcomes in the literature.



manufacturing processes with newly emerging making practices. Open design was conceptualized quite differently comparing studies on making to manufacturing. When open design concerned making, open design solutions and iterations were actively fabricated-produced, while with manufacturing, the solutions can stay completely conceptual or digital until produced in large volumes (e.g. Basmer et al., 2015; Bonvoisin & Boujut, 2015; Lamontagne, 2013; Panchal & Fathianathan, 2008; Phillips et al., 2013; Qin et al., 2016; Rebensdorf et al., 2015; Tan, Tang, Wang, & Yang, 2016; Zhou & Tseng, 2013). These sources all promoted the potential of open-to-participate ideation and know-how sharing, as well as peer-review of finalized design solutions to better ensure rapid innovation cycles in manufacturing. None of the papers included others (i.e. other manufacturers, people outside their network, etc.) manufacturing these solutions, realizing and adapting them in physical form. The decision-making, finalizing and producing the design solutions were left to the manufacturer, who in turn will benefit from the produced outcomes. This process differs little from the incumbent ways of producing and consuming, as the process is very much end-result oriented and does not enable branched processes or out-of-initial-context iterations.

As illustrated in Figure 9, open design articles focusing on *making* of artifacts concerned themselves with exclusively open outcomes and conveyed different attitudes about the open design process. For *making*, the primary concern was ensuring the outcome is replicable or adaptable to other contexts, which is scaffolded through schematics, digital models, bills of materials, transparency of processes, triumphs and failures throughout the process, honest assessment of outcomes, and so on. However, the choice of enabling self-selecting contributors to participate in an ongoing open design process presented challenges. As opposed to the processes of open source software (OSS), open design of physical artifacts cannot be easily copied and parallel design processes cannot be undertaken without rebuilding the initial solution from scratch (Malinen et al., 2011). Structured participatory or co-design methods were found to be useful for facilitating open-to-participate processes in:

- *ideation* (Charbonneau, Sellen, & Veres, 2016; de Couvreur et al., 2013; Fleischmann et al., 2016; Kuk & Kirilova, 2013; Schneider, Richter, Petzold, & König, 2010; Tamminen & Moilanen, 2016),
- *decision-making* (Tamminen & Moilanen, 2016),
- *detailing* (Charbonneau et al., 2016; Kostakis, Fountouklis, & Drechsler, 2013),
- *prototyping* (de Couvreur et al., 2013; Hamidi, Baljko, Kunic, & Feraday, 2014; Tamminen & Moilanen, 2016), and
- *reflection and review* (Tamminen & Moilanen, 2016).

However, these processes are generally locally bound and offline, with project updates shared in intervals to call for global contributions. These challenges can explain the tendency to openly share well-documented making processes later, along with the schematics, bills of materials, rationale behind decisions, test results, and so on. In fact, there were many articles reporting the development, outcomes, and testing of open design solutions in such a meticulous manner, as well as scholarly journals recognizing these types of articles as "hardware articles" (e.g. Lupetti, 2017; Pocero, Amaxilatis, Mylonas, & Chatzigiannakis, 2017).

In between making and manufacturing, we also identified *hybrid* practices leveraging both aspects for different purposes. For open outcomes, it may refer to design solutions that are mass-produced but can also be replicated by others in different contexts (e.g. van den Bossche et al., 2016; van der Bij et al., 2013). For these open solutions, the problem with the replication of physical artifacts – compared to OSS – is overcome through mass-production techniques. As for modular outcomes, the purpose of closed parts was generally seen to safeguard value capture in business and manufacturing, while open parts were for enriching platforms or solutions through making practices (e.g. Howard et al., 2012; Lamontagne, 2013; Raasch et al., 2009; Wulfsberg, Redlich, & Bruhns, 2010).

Interestingly, there was no clear pattern of a particular discipline or subject area aligning clearly with either making or manufacturing in their conceptualizing of open design. As we also classified the open hardware technical experiments as 'making' papers, many of these studies fell into the realms of physics, engineering, and computer science. Several studies with made artifacts, particularly assistive devices, emphasized working with end-users on product development, thereby aligning with co-design practices and seeking openness either in end-user input in making and/or designing, or openness of the solution. In one rather charming example, that of a wheelchair for injured dogs, the authors emphasized the importance of synchronous work: working together face-to-face on design (Charbonneau et al., 2016) which is presumably important for projects that are more intimate, dealing with bodies, health, and vulnerable populations. Several studies on making, particularly from the field of design, espoused the empowerment potential (and at times sustainability potential) of craft and materiality, invoking the legacy of William Morris (e.g. Kadish & Dulic, 2015).

As indicated above, a subset of the papers in the manufacturing category was strictly about end-user involvement, clear divisions between producer and end-user, and therefore closer to existing practices in mass manufacturing that are experimenting with mass customization or crowdsourcing (e.g. Piller, Ihl, & Steiner, 2010). Several papers took 'community' explicitly into consideration, as, e.g. 'community manufacturing' (Rebensdorf et al., 2015), to examine how to sustain members' motivations (Seidel & Langner, 2015), or to strengthen social sustainability (Basmer et al., 2015). The studies conveyed a more open conception of the producer–consumer relationship and expanded notions of value beyond only economic value. Again, there was no clear pattern as to what subject area contributed to these different notions of open design in manufacturing.

Similarly, the 'hybrid' papers were more agnostic of the market-nonmarket divide, which aligns with our previous understanding that open-source communities have a variety of motivations to participate in peer production (Benkler, 2006;

Moilanen & Vadén, 2013). Several studies also highlighted the community aspects behind entrepreneurship in open design, indicating that success at work or professional activity is being defined differently (Menichinelli, Bianchini, Carosi, & Maffei, 2017; Troxler & Wolf, 2017). Finally, many hybrid papers were simply examining open design products (e.g. Phillips, Dexter, Baurley, & Atkinson, 2016; Raasch, 2011).

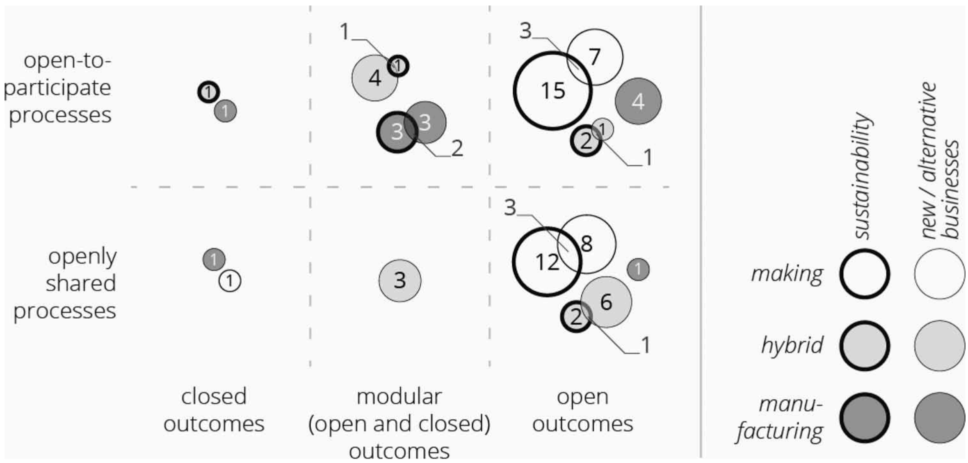
In summary, highlighting the differences between open-to-participate and openly shared processes, and the kinds of open design practices they espouse for making, manufacturing and the hybrid zone in between, allowed a fuller articulation of the varied research positions as well as implications of the studies. Our inductive analysis has been mapped in Figure 9, which provided compelling discussion points with regards to the making-manufacturing spectrum as discussed in this section. There were also opportunities and challenges which will be presented in the following sections.

6. OPEN DESIGN AS AN ALTERNATIVE

The classification of open design presented in the previous section allowed the authors to examine the potential benefits and limitations discussed in the literature in a more comprehensive manner. While there were sources solely looking at patterns of knowledge sharing and development of solutions as open design, there were numerous papers addressing socio-environmental sustainability issues and/or exploring new or alternative ways to do business: in other words, exploring open design as a way to create preferable alternatives to existing practices. Hence, this section aims to map the potential of open design as discussed in the reviewed papers with such clear standings. The same mapping grid employed in the previous section is used to map the number of sources presenting clear theoretical concepts or practical explorations falling into each intersection for sustainability (thick outlines) and new/alternative business (thin outlines) for making (white), manufacturing (dark gray) and hybrid (light gray) practices (Figure 10). We understand these terms flexibly, with new business practices likely involving changing relationships between producers and end-users, as fostered by additive manufacturing capabilities, for example, and alternative business or alternative economies as even envisioning new post-capitalist paradigms.

In this diagram, what is theoretically conceptualized and what is practically explored are not separated; however each cell contains different implications with regards to making, manufacturing, and hybrid practices. In total, 36 sources had clear standings on sustainability (explicit mentions) and 40 sources on new/alternative businesses. For sources discussing implications of open design for new/alternative businesses, one-third of the sources did so in terms of *open* outcomes (27 out of 89) and more than half looking at *modular* outcomes (10 of 16). More papers concerned with sustainability discussed open-to-participate processes (22) than openly shared processes (14), even though overall more papers discussed openly

FIGURE 10. Sustainability and business implications discussed in the open design literature.



shared processes (62 sources, compared to 49 for open-to-participate processes). However, only open outcomes of openly shared processes presented implications for sustainability, while authors examined the sustainability implications of open-to-participate processes regardless of the kinds of outcomes (i.e. open, modular and even closed outcomes). In addition, only 11 sources were intersecting, presenting implications for both sustainability and new/alternative businesses. We will discuss these issues in more detail in the following sub-sections.

6.1. Open Design and Sustainability

Regarding sustainability as an alternative afforded by open design, sources examining open outcomes of both kinds of processes conceptually presented the strength of open design in distributed and decentralized design and production (e.g. Bonvoisin, 2017; de Couvreur & Goossens, 2011; Kostakis et al., 2013; Quilley et al., 2016). This is in parallel to discussions of designing global open solutions for local appropriation (Kostakis et al., 2015) and the necessity for creating globally adaptable versions of locally developed solutions (Ostuzzi et al. 2016). One of the main intentions for such an emphasis on localization was to establish the availability of and accessibility to technology through openly available design solutions (Redlich et al., 2016), hence establishing technology independence for different localities (Pearce & Mushtaq, 2009). In the papers, this was also related to the accessibility of resources and fabrication capabilities through the rise of digital fabrication labs (Redlich et al., 2016) and the ability to create 'high-low tech' solutions addressing sustainability issues in these environments (Kadish & Dulic, 2015). Openly available technology can be utilized to address social issues within communities (Phillips, Blum, Brown, & Baurley, 2014), and social innovation can be initiated through open design toolkits (Cangiano et al., 2017). Another potential benefit of open outcomes conceptualized was the availability of post-use processes (i.e. repair, reuse, upgrading) for physical outcomes, due to their openly accessible technical information, as well as parts and components (Bonvoisin, 2017). With regard to open outcomes and processes, open-to-participate processes were espoused as a crucial element of open design to achieve transdisciplinarity, especially participation from social sciences, which in turn was seen necessary for the cultural aspect of sustainability (Nascimento & Pólvora, 2015).

All these theoretical potentials were discussed in the literature regarding open outcomes of making and hybrid practices, some of which were illustrated through practical explorations. Among the latter, local production through local initiatives or in digital fabrication labs was a common theme (e.g. Kadish & Dulic, 2015; Malinen et al., 2011). Transitioning towards cleaner energy sources through local efforts was also a concern (Malinen et al., 2011). In practice, local production was found beneficial for upcycling of material and reducing transportation footprint of materials (Richardson et al., 2010). However, it was also shown that the practices in digital fabrication labs are not inherently sustainable and they can easily become a part of incumbent production and consumption regimes (Fleischmann et al., 2016; Kohtala, 2017).

Through practical explorations, open-to-participate processes showed potential for developing locally meaningful, sustainable solutions through co-design methods (Ostuzzi et al. 2016) and empowering people with disabilities through technology visibility (Hamidi et al., 2014). The potential of open prototyping as an example of making practices was articulated through creating open solutions that enable independent living for disabled people (Sánchez Criado, Rodríguez-Giralt, & Mencaroni, 2016). The difference between completely online, open-to-participate design processes and a local co-design process was also questioned, favoring the latter for generating greater value for contributors (Charbonneau et al., 2016). However, it was also argued that any locally developed open solution should be iterated for sharing in an adaptable manner, in order to facilitate its adoption (Ostuzzi et al. 2016). In openly shared processes, sharing post-use (i.e. repair, reuse, upgrade) related knowledge along with open outcomes was also a crucial, yet overlooked aspect for actually opening up those processes (Holroyd, 2017).

6.2. Open Design and New/Alternative Businesses

The range of studies framing open design in relation to new/alternative business is also illustrated in Figure 10. Several intersecting sources took into account both sustainability and business. Some studies argued that open design enabled rapid innovation cycles in assistive technologies (de Couvreur & Goossens, 2011) or appropriate technologies (Pearce & Mushtaq, 2009) for further development of solutions and robust testing. However, there was also empirical evidence against this, especially for more complex outcomes such as e-cars (Malinen et al., 2011).

Replicating physical objects was highlighted as more challenging than digital artifacts because they require space, resources and skills for widespread adoption, and parallel development of design solutions (ibid). For hybrid practices, distributed production through local fabrication labs and other mass-production opportunities were claimed to have the potential to empower a local economy, while enabling local adaptations of global designs and post-use processes (Kostakis et al., 2015; Quilley et al., 2016). On the other hand, openly shared processes and open outcomes, together with locally available fabrication possibilities like digital fabrication labs, presented the potential to facilitate a transition towards demand-driven production (ibid). From a strictly business perspective, local value creation chains were seen to be achievable through open, participatory settings (Bonvoisin & Boujut, 2015).

Among these theoretical implications for open outcomes, field testing and expert peer-review were empirically explored in one study, facilitated through openly shared, manufactured outcomes (van der Bij et al., 2013). The objective of this case study was to allow a manufacturer to undertake the production of complex open design solutions, to reduce costs and allow dissemination (ibid). Similar practices in hybrid production practices were also visible in other practical explorations, including the development of open design platforms (i.e. a set of standards) of open outcomes which could also be provided ready-made (Trilles et al., 2015), or manufactured kits to develop open solutions and adapting them (Phillips et al., 2013). Although design solutions are open, people who lack resources, skills or time may opt to purchase these solutions, especially when they are of complex designs (Callahan & Darby, 2014). On the other hand, the empirical study by Troxler and Wolf (2017) on businesses in maker communities (i.e. community-based business) presented small-scale business models emerging and shaping according to the needs of the community. The study identified making-oriented business models that practice multi-dimensional value creation (i.e. financial and social), exhibit altruism through open design and knowledge sharing within the community, and focus on covering basic costs as opposed to profit maximization (ibid).

Modular outcomes in the context of this review are not the form-factor modularity through a changeable set of parts discussed generally in design, but they refer to modularity in the attributes of parts (i.e. some open and some closed). In the early theoretical and empirical studies on open design (Balka, Raasch, & Herstatt, 2009; Raasch, 2011; Raasch & Herstatt, 2011), modular outcomes were presented as a state-of-the-art value capture strategy through open-to-participate processes in design or production (Basmer et al., 2015; Raasch & Herstatt, 2011). These outcomes were envisioned to be either completely manufactured by one or more manufacturers (Rebensdorf et al., 2015) or closed parts being manufactured and open parts made locally through knowledge exchange and capacitation (Wulfsberg et al., 2010). Open-to-participate processes for modular outcomes were theoretically presented as a strength in product development, through the utilization of the crowd in expertise, testing, peer-review, dissemination and production; through pointing out empirical evidence of makers in open design communities asking for commercialization in exchange for resources to continue developing their designs (Balka et al., 2009; Raasch, 2011); or evidence of the marketing potential of opening some aspects of design projects as complementary assets (Raasch & Herstatt, 2011; West & Kuk, 2016).

The modular outcomes column of the open design terrain is highly theoretical, with empirical studies leading to slightly modified business-as-usual concepts or new forms of manufacturing through the hybrid usage of digital fabrication technologies in localities. The selective reveal of part designs is either for profit or for complying with safety regulations in commercial settings (Cruickshank & Atkinson, 2014; Raasch, 2011), which will be discussed in the following section on issues of ownership and licensing. This characterization of open design outcomes, that is, modular outcomes that are conducive to standardizing and mass manufacturing, may also explain their compatibility with applying principles of eco-efficiency, as in Bonvoisin's study (2017). Furthermore, scholarly sources discussing the implications of open design for businesses were predominantly conceptual and mainly presenting modular outcomes. This seems to suggest there is a rising call from scholars to reconcile incumbent production and consumption with the newly emerging open paradigm and fabrication opportunities.

7. CHALLENGES IN OPEN DESIGN

While there are numerous potentials for open design to foster sustainability and new/alternative businesses, as illustrated in the previous section, there are also challenges that might hinder their realization. During our inductive analysis, two distinct topics came forth: (1) ownership, responsibility and legitimacy, and (2) communities and their governance. In this section, we summarize the current discussions on each topic in their respective sections and highlight gaps in the literature for further exploration.

7.1. Ownership and Licensing of Open Design Outcomes

Although ownership issues regarding open design solutions cannot be cleanly separated from the new/alternative business discussion in the previous section, they were collated into a separate section as many sources suggested or implemented a licensing strategy for various reasons, such as generating trust, reliability of open knowledge or security of users, without implicating sustainability or new/alternative business. Figure 11 collates these strategies among our categories for mapping open design.

Having open outcomes of any open design process in the public domain, for any kind of utilization of said design knowledge and outcomes, is common practice. However, openness of the knowledge and outcomes also makes it vulnerable to exploitation for benefit (Busch, 2012), examples of which are discussed through

FIGURE 11. Licensing strategies discussed in the reviewed open design literature.

	open outcomes	modular outcomes	closed outcomes
open-to-participate process	*Community ownership* *Public Domain:* Creative Commons, no licensing *Trademarking* (for generating trust and some kind of insurance) *ShareAlike:* Open Hardware licenses	*Selective IP:* Some parts patents or copyright, others CC, ShareAlike *All rights reserved:* End-product patenting, (Hi-jacking)	*All rights reserved:* End-product patenting, (Hi-jacking, crowdsourcing)
openly shared knowledge	*Public Domain:* Creative Commons, *ShareAlike:* Open Hardware licenses	*Selective IP:* Some parts patents or copyright, others CC, ShareAlike	*IP exchange:* through Bilateral Agreements or Consortiums

empirical studies in open design communities as well (Tamminen & Moilanen, 2016). The vulnerability of open design processes and outcomes present themselves as cautionary examples in open-to-participate processes with modular and closed outcomes, that may result in hijacking contributions for commercialization (Tamminen & Moilanen, 2016). Hence, ShareAlike licenses (e.g. GNU-GPL-ShareAlike, CC-ShareAlike, CERN-OHL, OHANDA, and other open hardware licenses) ensure the outcomes of open design stay open and prevent exploitation through traditional intellectual property mechanisms. These licenses aim to accommodate emerging practices for knowledge sharing and accumulation of open design while legitimizing them through institutional authority (Powell, 2015). However, as long as these licenses are formulated through existing legal codes with certain cultural norms, they only democratize certain aspects of open designs within limited social worlds, excluding, e.g. DIY practitioners, global South innovators and Shenzhen phone manufacturers (Powell, 2012). In addition, while these licenses ensure the continued openness of outcomes and resultant knowledge, the issue of exploiting contributions of self-selecting participants of open-to-participate processes continues. For offline open-to-participate processes, the resultant open outcomes can be licensed under communities, ensuring the outcomes stay open and contributions of the community are acknowledged (Seravalli, 2012). For online open-to-participate processes, trademarking is an alternative strategy that can be adopted to build trust and ensure protection of the openness of design outcomes and knowledge, while also establishing quality assurance (Moritz et al., 2016).

As discussed previously, outcomes of a modular (open and closed) nature was a concept mainly discussed for its opportunities in business settings or to ensure compliance with safety regulations and standards (Cruickshank & Atkinson, 2014; Raasch, 2011). While establishing institutionally acknowledged standards for safety and security proves challenging (Phillips et al., 2016), using traditional intellectual property mechanisms can be practical for some parts in, for example, medical devices (Cruickshank & Atkinson, 2014). Otherwise, a selective intellectual property strategy aims to safeguard value capture in businesses which leverage the potential for dissemination and acceptance generated by open-to-participate processes or openly shared knowledge. This form of licensing may be acknowledged as inevitable by more recent studies beyond the scope of this review (e.g. Boisseau et al., 2018); however, it also hinders further exploration of new/alternative business as espoused by open design.

Finally, intellectual property sharing within consortia or through bilateral agreements was mentioned under the mantle of open design, as an initial step towards opening knowledge (Buitenhuis & Pearce, 2012). While the envisioned final stage for completely open design knowledge-sharing among manufacturers fits within the open design landscape, application of traditional intellectual property mechanisms and exclusive sharing of knowledge definitely do not.

The issues around ownership and licensing revolve around three specific concerns: (1) safeguarding the openness of outcomes and democratization of the knowledge commons, (2) reliability of open outcomes where, e.g. safety concerns are prevalent, and (3) value capture in businesses through selective reveal. Especially because of hijacking observed in open design communities, safeguarding the openness of outcomes remains an important challenge, which calls for further exploration not only in the community context but also in the legal context. However, the biggest challenge presents itself in the areas where open design is perceived as incapable of generating the same level of reliability and trust as the traditional intellectual property mechanisms that assign responsibility.

7.2. Open Design Communities

Communities were obviously central elements of open design in the papers reviewed, but a particular subset of 32 papers particularly emphasized community, in the analysis (e.g. of design contributors or contributions), as a keyword, or as a distinct and novel way to distinguish from business-as-usual. In this subset, there was variation in how communities were represented, from a community as a product developer (Raasch, 2011) to communities of knowledge makers in citizen science (Phillips, Baurley, & Silve, 2014). The differences are especially clear when seen through the lens of orientation to making, manufacturing or hybrid activities in-between.

Papers dealing with manufacturing contexts discussed the needs and modes for management of communities and their contributions (Bonvoisin & Boujut, 2015; Seidel & Langner, 2015) and community members' motivations (Müller-Seitz & Reger, 2010) in open-to-participate processes. Modularity of tasks and the need to adhere to strict regulations, in vehicle design, for example, were seen as both motivating for members and easier to manage, but in some phases a threshold can be crossed and too strict and confined a task, for regulatory or other reasons, also discourages contributions. In the larger scale of a community (network) of open manufacturers in South Africa, collaboration in sustainable manufacturing was conceptualized to create and capture value locally (Rebensdorf et al., 2015).

About one-third of the papers discussed hybrid practices. For studies where outcomes were modular (both open and closed), the community was represented as that of product developers (e.g. Balka, Raasch, & Herstatt, 2010) and innovators (Lindtner, 2015, in this case in China), wider networks of actors who share design-related knowledge with each other and participate in each other's projects. A subset of papers related to openly shared processes and open outcomes represented open design communities as democratizing of knowledge making in science and technology (e.g. Powell, 2015), as user-innovators in machinery development (Callahan & Darby, 2014) and as citizens developing knowledge for local resilience (Kostakis et al., 2015).

The majority of papers discussing community (almost two-thirds) concerned making and open solutions. Community was an important concept highlighted in papers framed as participatory design, where the involvement of users (citizens or lay experts) in design is facilitated through both open, self-selecting processes and closed processes that are later documented and openly shared (e.g. de Couvreur & Goossens, 2011). The design of assistive devices was especially salient here. Another distinct group of papers explicitly highlighted environmental sustainability as a normative concern, where communities of empowered citizens could collaborate on solutions for local resilience and self-sufficiency (e.g. Moritz et al., 2016). Studies either examined these community endeavors to determine implications for open design practices for sustainability in terms of social interaction in groups, or they piloted a specific project in order to gain competence in open design for sustainability and its technical implications (e.g. Kostakis et al., 2013). Several papers espoused these initiatives as community-based manufacturing or fabrication (e.g. Quilley et al., 2016).

A third group of making papers discussing open outcomes represented community as groups of makers, entrepreneurs, and user-contributors. These groups contribute to open hardware and open design projects or share their designs online, and the studies examined these processes (e.g. Malinen et al., 2011; Tamminen & Moilanen, 2016), or they operate in fab labs and makerspaces and contribute to new meanings and enactments of both entrepreneurship networks and design work in a post-industrial era (e.g. Menichinelli et al., 2017).

A key differentiation between study themes in this subset could be summarized as seeing people as communities of user-contributors or of citizens. In the former case, communities need to be managed in order to elicit contributions and integrate them into product designs. In the latter case, communities are seen as creating knowledge, contributing to various commons and as freely exploring better options for the future, in either the sustainability sense or new types of enterprise. Management is also needed here, but these studies did not address group dynamics or horizontal community governance in detail. The endeavors these latter communities pursue are also more open-ended than the stricter project- and product-oriented initiatives, and modularity, task division and task allocation more challenging. Community management or governance of open design in this sense is therefore both a research gap that could be addressed and a quandary regarding modularity. We discuss these implications further in the next section, as well as research gaps and implications arising from this review.

8. DISCUSSION AND CONCLUSIONS

In this article, we have presented a review of 124 peer-reviewed journal and proceedings articles, systematically identified and analyzed to present the current snapshot of the literature on open design research. While most of the articles were from subject areas like design, engineering, computer science, social sciences, and management, there were also studies from unconventional fields, such as assistive devices in the area of physiotherapy or open design design-in-use innovation communities in agriculture. Given the high number and relatively wide subject range of studies identified in this review, it appears that interest is rising in empirically and conceptually tackling the topic, and explicitly framing it as 'open design.'

The papers on open design in the area of human-computer interaction (i.e. from journals and proceedings relevant to HCI, including those identified in Figure 4 but not limited to these) particularly feature technical experiments and isolated projects or projects often positioned as co-design or participatory design. This implies that 'open design' as a framing appears to be limited to micro-scale examination. Any meso- or macro-scale issues that have to do with open design as a paradigm shift – such as the blurring of the lines among users, designers, and producers – are not (yet) framed as open design in HCI research but have compelling implications. What does interaction with technology entail when people are no longer only active users but also the designers and producers of the technologies and products? These are issues already being explored but using other terminologies. This may mean there is a missed opportunity for a receptive audience and knowledge exchange between open design researcher-practitioners and the HCI research community, with the 'open design' cluster (in the various fields we discuss in section 4) possibly not finding and building on relevant HCI research and, in turn, HCI studies not building on contributions already made in the open design world.

For our authors, open design is defined as a different kind of participatory design approach, that works with iterations and contributions without limitations of time and space. However, through this literature review, we encountered varieties of definitions and framings of open design. We first parsed out the varieties of open design as defined in the literature. There are open design solutions, processes of which are shared along with other documentation necessary to make them. There are design processes open-to-participate at different levels, such as completely online open-to-participate processes or local co-design processes that enable embodied involvement, which produce open solutions. There are design solutions with open and closed components, open parts of which are developed through the contributions of people from varying backgrounds. Finally, there are open processes that lead to closed solutions through expert decision-making or market exploitation. All these see expression in research on making, manufacturing, and the hybrid zone in-between. We illustrated these differences among processes and outcomes on a two by three grid (Figure 9 in section 5). Every intersection presented compelling reconciliations between modes of production and the nature of open design;

however, discussions around open outcomes provided the most interesting insights regarding a potential paradigm shift. For example, utilizing manufacturing technologies to produce open outcomes is one such reconciliation that is unique to the open design of physical artifacts.

Considering open outcomes, open design espouses democratization of production via accessibility of design-related knowledge (e.g. schematics, bills of materials) for their replication and iteration; however *modular* outcomes incorporating open and closed part designs are conceptually explored in the literature, some scholars even claiming that completely open solutions are impossible from a business perspective. While selective revealing of designs presents itself as a strategy due to concerns with safety, responsibility or ownership, it can also be utilized to reconcile incumbent production and consumption with the rising call for democratization of designs and fail at espousing an alternative knowledge sharing economy. This points to a gap in open design research, where the ways of keeping design solutions open, accessible, replicable, and adaptable while conforming to safety regulations and standards is a challenging topic and remains mostly unresolved. Co-operatives and similar models may suggest community-based ownership and responsibility, but this model is not as open as open design is espoused to be enacted. This affects the reliability of these design solutions, especially when they are not widely reviewed online. Although larger transitions towards alternative economic models are discussed on the macro level, research on how they will be enacted as development, iteration and dissemination of open designs is still an important area of interest.

In the reviewed literature, open design is indeed framed as a better alternative by many authors, especially on topics proposing new ways to do business, prototype alternative economies, and foster sustainability. From a strictly business perspective, the potential of open design is observed mainly as a value-capture strategy and a way to achieve rapid innovation cycles for further development and wide-scale testing. However, open design's relation to enterprise is still largely considered within the current paradigm, while the potential of an open design 'sharing economy' is not yet generally discussed as a way to transform the way businesses operate. Toward the manufacturing side, companies open up their initial processes but do not develop alternative models befitting the sharing economy as suggested by open design. Moreover, it remains to be seen if open design as a research framing remains semantically and ontologically tied to trajectories of business-as-usual (as has been seen in software; see Morozov, 2013), and therefore not a true alternative nor necessarily democratizing; if it is increasingly embraced by research on alternative post-capitalist and postcolonial practices; or if a new term becomes more appealing to the research community and replaces it entirely.

The literature also discusses implications for principles of a more sustainable society as operationalized through open design. Especially for proponents of alternative economies, the open paradigm and open design have clear appeal, by, for example, conceptualizing demand-driven production through open outcomes and openly shared processes for a sustainable society. However, this direction appears to have limited appeal to an academic audience as yet, especially concerning physical artifacts and building a sharing economy around them. The sustainability-oriented literature largely remains conceptual and propositional, and the potential is mainly unexplored in practical terms, making or manufacturing tangible objects. Studies framed as open design are not yet examining how or if production is indeed localizing and what benefits this is delivering. Nor is there evidence of increasing circulation of part and component designs, to enable more environmentally sustainable production or re-manufacturing nor to inhibit current practices in planned obsolescence.

Where there are empirical studies in the review providing more nuanced knowledge on how open design projects get done or how objects are branched and forked, they sometimes challenge long-standing myths: for example, despite the espoused connection between socio-environmental sustainability and open design, as mentioned above, several studies in the review highlight that maker communities are not prioritizing sustainability issues. Another difficult-to-dislodge myth involves open design knowledge-sharing: in practice, studies show how makers face challenges in actually documenting and sharing their work. This challenge has been long acknowledged in practitioner communities, but as yet little addressed in academic research. This leads to the concern if open knowledge related to, e.g. sustainable design and technology solutions is actually diffusing as promised.

Another salient theme in the reviewed articles is who contributes in open design: people are seen as communities of user-contributors or of citizens. Community contributions are discussed in many papers, such as the rather tightly managed integration of contributions in Local Motors projects. This raises the question of how a loose, self-organizing peer production collective achieves results where the objects and problem spaces are not already defined. Several studies thereby highlight the design of open design communities themselves, as well as products, or examine tools for platform and community management. It appears there is not only room for more research on open design community governance; there may also be a fissure here as to what open design can achieve, if the current role models are the most successful, large open source software and digital artifacts.

In other words, open design projects are most successful when they are modularized and tasks are of a grain-size that participants find appealing and doable (Benkler, 2006). Several studies in the review highlight how projects vary in complexity strategically, assuring contributors can participate as they wish. Sustainability of such a project benefits from a large mass of contributors, who are also replaceable by others so tasks do not remain undone, free riders do not hamper progress, and quality control is assured – what Felstiner (2012) has termed *fungibility*. However, as projects become open-ended and communities become loose collectives oriented by e.g. social movement ideals (such as the aim to realize 'cosmopolitan localism' or 'degrowth'), as they increasingly involve both offline, real-world collaboration and online sharing, the very *fungibility* that functions so well in open design is also an open door to exit (ibid). Being a replaceable and 'modular' individual is irreconcilable with a community of like-minded members aiming for solidarity (ibid). This may help explain why the loosest open design collectives struggle to actually document and share their work in a way that makes it evolve and fork and why such collectives are often highly dependent for their cohesive force on a charismatic leader (see, e.g. Eakin, 2013).

The literature reviewed does split ideologically somewhat between making and manufacturing, where the opportunities for open knowledge sharing and openly collaborating throughout the design process are sought especially to accelerate innovation cycles and product development on the manufacturing side, on the one hand. On the other hand, open design is often espoused to foster democratization and the accessibility of knowledge on the making side. But as for disciplines and subject areas of the studies, there is no clear pattern. Whether design, engineering, HCI, or management studies, both making and manufacturing and the zone in-between are of interest, as are ambitions of faster product innovation cycles, new ways to engage with users, new ways to democratize production and new ways to live more sustainably. By illustrating the research terrain on open design, pointing out varying positions, espoused opportunities and observed challenges, we have aimed for an overview useful for current and future open design researchers and research-practitioners to frame their own studies.

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APPENDIX. INCLUSION/EXCLUSION CRITERIA AND QUALITY ASSESSMENT TABLE

Inclusion criteria	**Reason for inclusion**
'open design' as exact phrase in article title, keyword and/or abstract	explicit use of the target term (if not subject to exclusion criteria below where 'open design' has a different meaning)
reference to 'open design'	when phrase was used to refer to collaborative processes (particularly open to designers and non-designers, i.e. a wide range of participants, often self-selecting) and/or openly shared outcomes, in activities related to DIY making and/or manufacturing
reference to 'open design' and 'open source design'	when phrase was used to refer to using open source principles in designing and prototyping
reference to 'open hardware'	when phrase was used to refer to designed and fabricated physical artifacts that were openly shared, where designing according to open source principles was explicitly promoted
reference to 'commons-based peer production'	when phrase was used to refer to activities of designing and fabricating physical artifacts in a peer-to-peer context, where participants self-select tasks and contributions according to their own "intrinsic and self-interested reasons" (Benkler, 2006) and where outcomes are often openly shared
Exclusion criteria	**Reason for exclusion**
languages other than English	
2018 articles	
articles from trade magazines, editorials, notes, workshop summaries, book reviews, books and book chapters	limit to peer-reviewed original research articles from journals and proceedings
articles not accessible	attempts from two universities' libraries unsuccessful
articles from fields related to medical care and related (e.g. nursing, psychology, immunology, veterinary studies); specialized fields in science and engineering (e.g. automation control systems, oceanography, cell tissue engineering, acoustics)	far removed from contexts of open design in making or manufacturing
reference to open design methodology	distinct meaning in medical studies and engineering not relevant to this review

(*Continued*)

(Continued)

reference to open design (e.g. in architecture and product design)	meaning of physically open, not enclosed
reference to open design with other meanings than those listed above	meaning open-ended design process that is not collaborative (e.g. in design education); open education curricula, open course design or course materials; open-minded
main focus on software or databases, cloud computing, etc.	focus of this review is on tangible, physical artifacts, not open source software development
main focus on highly technical, complex products and/or scientific instrumentation (e.g. circuit design)	removed from interest in open design where more people can access design process and/or openly shared design outcome
repetition	conference papers whose studies were later incorporated into an extended journal article were considered redundant
passing reference to open design	some papers only acknowledged ‘open design’ as an area of interest without having it as a key focus of the study
reference to open design as more conventional co-design	co-design projects strictly in the hands of a design team who invite participants into co-design sessions as distinct from openly collaborative (often self-selecting) and open-ended ‘open design’ projects
Quality Assessment	**Analysis**
Do conceptual articles build an argument in a rigorous and critical way? Does it articulate its position and the research foundation upon which it builds?	If yes, include in analysis and articulate contribution (cf. MacInnes, 2011).
Do conceptual articles merely repeat claims (especially in non-academic literature) that are not empirically substantiated?	If yes, include only in subject area and country figures and not in analysis and literature synthesis.
Do empirical articles clearly articulate the nature of the data and analysis methods?	If yes, include in analysis and articulate contribution and focus area.
Do empirical articles use secondary data that is not substantial and/or highly filtered and controlled? (e.g. company’s website texts as sole data source)	If yes, include only in subject area and country figures and not in analysis and synthesis.
Is the empirical article a description of a technical experiment whose outcomes (blueprints, instructions) are denoted as ‘open source’?	If yes, include only in subject area and country figures and not in analysis and synthesis.