A Review of the DesignX Discourse: Knowledge Diffusion and Integration Across Disciplines

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Abstract. Design research and practice is increasingly expanding into new areas and merging with other disciplines, yet empirical research that investigates the interdisciplinary knowledge structure of these emerging areas remains scarce. This paper explores a novel front in design research inspired by Norman and Stappers's 2015 article "DesignX: Complex Sociotechnical Systems." The aim here is to depict the transient knowledge structure of an interdisciplinary domain started from inside design. The present empirical study uses mixed methods combining the VOSviewer knowledge mapping technique with text-based qualitative analysis. Results from these quantitative and qualitative methods frame rich insights into patterns of knowledge diffusion and integration in DesignX-related research. I argue that knowledge mapping techniques and qualitative analysis complement each other and can yield not only macro knowledge patterns about the examined area but more fine-grained meso- and micro-level knowledge of that area. The paper further reflects on the development of the DesignX approach.

Keywords: DesignX · Sociotechnical systems · Mixed methods · Knowledge mapping · Design discipline · Interdisciplinarity

1 Introduction

Collaboration and the integration of learnings across the boundaries of individual disciplines gives rise to interdisciplinary domains and expertise uniquely suited to addressing multilayered and multifaceted challenges. The design discipline can be applied across countless domains, and its scope continues to expand, reaching beyond its conventional, artifact-centric focus to address complex systems for living, working, playing, and learning. The pragmatic nature of design supports the quest for connection and the integration of useful knowledge from other disciplines "for new productive purposes" [1]. This understanding has gradually grown into a common view in the design field, though not without a certain degree of friction. And yet, the ambiguity clouding the ontology of design means design faces constant challenge. Two questions have plagued the design community for decades: If design is inherently interdisciplinary, what constitutes the unique body of knowledge that makes design different

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from other disciplines? And, how interdisciplinary *is* design, in fact? Both questions beg for inquiries into design knowledge, its structure and foundation, and its evolution.

As a small, experimental response to this broad topic, here I attempt to depict the transient knowledge structure of an interdisciplinary area initiated from inside design—specifically an emerging research domain related to a position article in design published in 2015. I adopt a quantitative knowledge mapping technique called VOSviewer in addition to a textual analysis-based qualitative review approach to explore the feasibility of studying the interdisciplinarity of the design discipline using mixed methods.

2 What is DesignX?

2.1 A Brief Account

In October 2014, a small group of design scholars and educators[1] announced their determination to explore how design can address the complex issues the world faces today. They called their initiative "DesignX," with "X" referring to the turbulent, unknown future of design. The fruit of their first discussion was a document called "DesignX: A Future Path for Design" [2].

A two-day follow-up working conference on DesignX was hosted by Tongji University in 2015, aiming to advance understandings about how design and designers can contribute to tackling complex sociotechnical systems problems. Norman and Stappers invited around 30 scholars and practitioners from the design, systems theory, cybernetics, computer sciences, and cognitive sciences domains to participate. They were experienced in working with complex issues ranging from health care, education, urban systems, financial service, etc. The multi-disciplinary perspectives on DesignX triggered debates, and the participants found it extremely challenging to arrive at a clearly articulated, unified understanding. Norman acknowledged that the complex problems design aims to deal with today were not new, but that implementing solutions in the real world was and is the biggest challenge to designers in that it requires interdisciplinary collaboration. Based on these developments, Norman and Stappers penned an article titled "DesignX: Complex Sociotechnical Systems" [3] and published it in *She Ji: The Journal of Design, Economics, and Innovation* in December 2015.

2.2 Norman and Stappers on DesignX

In 2014, the DesignX Collaborative defines DesignX as "a new, evidence-based approach for addressing many of the complex and serious problems facing the world today" [2]. In the follow-up article, Norman and Stappers [3] map out the context from which DesignX emerged, elaborate on its subject matter, outline the characteristics of the problems DesignX aims to address, and argue for a possible approach to designing for complex sociotechnical systems.

[1] The initial DesignX Collaborative includes (in alphabetic order) Ken Friedman, Yongqi Lou, Don Norman, Pieter Jan Stappers, Ena Voûte, and Patrick Whitney.

Norman and Stappers situate DesignX where complex challenges arise: at the crossroads of all kinds of sociotechnical systems used to support our caring, feeding, dwelling, moving, and policymaking. According to Norman and Stappers [3], DesignX problems have nine principal properties that they organize into three categories: human, social/political/economic, and technical. To appropriately address DesignX problems we need knowledge and expertise from a variety of disciplines and multi-stakeholder collaboration. This implies a shift in focus from inside the design discipline as well.

For Norman and Stappers, DesignX practice is a muddling-through. It involves a modular approach with incremental steps which break up the whole into an assembly of more manageable and relatively independent parts. The authors emphasize that real world solutions implementation is of central concern in DesignX, and that designers must play a more active role in implanting and developing their solutions—"the design process never ends" [3]. The implications of the DesignX arguments require the design discipline to develop new expertise and call for design education to prepare future designers with adequate knowledge and skills.

As the managing editor of *She Ji*, I witnessed the birth and the ensuing discourse surrounding DesignX.[2] I became curious about the influence the DesignX article had on the research fields where it had been cited. Has the idea of DesignX spread into any other disciplines during the past three years? Is the research area inspired by DesignX an interdisciplinary one? What kind of knowledge supports such a discourse? And, has the idea of DesignX evolved? I wanted to explore the possibility that there might be a new frontier in design research related to DesignX.

3 Methodology

There is a robust body of research on the development of science, knowledge, and interdisciplinary trends. One of the best known fields supporting such studies is scientometrics [4]. However, there are very few studies dealing directly with the design discipline in this field. The ambiguous boundary surrounding design and the absence of a subject category compatible with design in dominant science databases are probably significant barriers. For example, there are no ready-made subject categories available in the current 254 subject categories listed in the core collection of Web of Science (2018) covering the three major indexes (SCI-E, SSCI, and A&HCI). Scientometric studies on interdisciplinary trends rely on using subject categories assigned to each publication indexed by the dominant citation indexing services (Web of Science and Scopus) [5]. Hence, this well-established approach to interdisciplinary studies cannot be directly applied to design.

Within design, there is a plethora of literature emphasizing the viewpoint that design is interdisciplinary, but there are few empirical studies examining its interdisciplinary characteristics. Some scholars have undertaken the task of constructing a framework of design knowledge, however. Most of these are expressed via viewpoint articles [6, 7], while existing empirical studies on design and the emerging knowledge

[2] This article has been downloaded 23,138 times globally via ScienceDirect by October 2018.

areas within it rely largely on qualitative approaches based on guidelines derived from expert interviews [8, 9] and textual analysis [10].

Scientometric studies can measure the development of disciplines based on quantitative features at a macro level. They focus on information about a discipline, not the contents of the discipline per se. Qualitative literature review based on textual analysis captures fine-grained knowledge and deep insights of a specific research field at the micro level, but its capability to grasp disciplinary patterns tends to be weak due to limitations in data size and time-consuming methods.

The powerful scientometric tools used for knowledge mapping seem to have started to attract design researchers' attention recently. The results of these pioneering studies [11, 12] do not seem to differ greatly from a scientometric researcher's inquiry. Finding ways to link macro level findings with the discourse taking place within the discipline on a micro level is a valuable direction that I attempt to explore through combining the two approaches in this study.

3.1 Collecting Data

I searched publications that cited Norman and Stappers's DesignX article. The first difficulty I encountered was that there were too few design journals indexed by major indexing sources Web of Science (WoS) and Scopus [13]. My search in WoS only resulted in 17 articles. So I widened my search to include results from Scopus, Google Scholar, and CNKI and expanded the types of publication I included from journal articles and conference papers to books (book chapters) and theses. The initial, expanded search resulted in a list of 82 documents (February 24, 2019). I then downloaded all available full texts, read the title and abstract of each, and verified whether the DesignX article was properly cited in the text and listed in the references. After removing 5 items that were repeatedly indexed by Google Scholar, I further eliminated the following

- 6 documents whose complete texts were not available;
- 1 thesis in Swedish and 2 journal articles in Spanish and Japanese, which remain beyond my language capability;
- 1 Google Scholar indexed journal article showing problematic referencing;
- 2 conference papers (Google Scholar) that were published as indexed journal articles with minimum revision.

I then added 10 *She Ji* articles (6 full-length articles and 4 short communications) that cited the DesignX article. Although *She Ji* is indexed by Scopus, the bibliometric information offered by Scopus excludes cited references. This is possibly due to the fact that *She Ji* uses a footnotes system and does not include a reference list at the end of each article. That lack of bibliometric data also exists on Google Scholar.

The final dataset contains 75 full-text DesignX-related documents (17 indexed by WoS, 23 indexed by Scopus, 35 indexed by Google Scholar).

Among the set, there were 10 documents that had no keywords, as they were either viewpoint journal articles (non-peer reviewed) or book chapters. Since keywords analysis is critical to reveal the knowledge clusters in the examined field, I decided to construct keywords for these items by carefully reading them entirely. I identified the most relevant subject terms for each document as "added keywords." My status as a journal editor comes with the capacity to accomplish this step.

The scientometric tool requires all bibliographic information formatting to be consistent. Converting incompatible data formats and completing missing information is crucial if the results are to express the examined area as accurately as possible. WoS is the best source for scientometric data, because it carries the most accurate and complete documentation information as compared to Scopus and others. So I converted bibliographic information obtained via Scopus into the WoS format manually, and coded by hand information from documents that were indexed by Google Scholar. To do this I searched the website of each document's source publication, collecting as much publishing information as possible. Although it was time-consuming, it was doable due to the modest size of the DesignX-related document set.

3.2 Analysis Using Mixed Methods

Data analysis was divided into two parts: (1) experimental analysis using the VOSviewer knowledge mapping tool to visualize the resulting knowledge networks and decipher their meanings, and (2) coding of the 75 documents based on a set of DesignX themes through textual analysis. VOSviewer is a software offering a relatively easy way for visualizing bibliometric networks [14].

The first stage of the research (Part 1) sought to reveal

- which disciplines had incorporated the DesignX concept
- the kind of knowledge being used to support DesignX as a research field, and
- the research communities who were using the DesignX concept.

The second stage of the research (Part 2) looked at

- how the Norman and Stappers DesignX article was used in the literature.

Part 1 and Part 2 together provide a holistic view of

- the interdisciplinary structure of emerging DesignX-related research
- whether the DesignX concept had evolved or not.

These two parts of analysis unfolded in parallel. Insights obtained from reading and qualitatively analyzing the documents informed the interpretation of the results presented by VOSviewer. And the VOSviewer results provided insights into the structure of the examined area and clarified the patterns embedded in the qualitative analysis. They became mutually supporting phases of study.

4 Results and Analysis

4.1 Part 1: Mapping the Knowledge of DesignX-Related Research

Norman and Stappers's article envisions a potentially new research frontier related to design. The 75 papers citing the work published in the three years after its date of publication implies considerable interest in the topic—although this number may seem small for the sciences, it is nonetheless notable for a developing discipline such as design. This small but important body of literature signals an emerging research area, which I have tentatively labelled DesignX-related research.

In information science, a specialty is conceptualized as a time-variant duality between research fronts—frontiers in research—and intellectual bases [15]. Price [16] first introduced the concept of a research front to characterize the transient nature of a research field. Persson [17] coined the concept of an intellectual base to clarify the nature of a research front. A research front therefore represents the state of the art of a line of research; what this research front cites forms its intellectual base [15].

On the other hand, rather than delimiting the boundary of a research front in terms of collection of state-of-the-art articles, Chen [15] defines a research front as "an emergent and transient grouping of concepts and underlying research issues" and its intellectual base as "an evolving network of scientific publications cited by research-front concepts." This understanding supports the design of the knowledge mapping part of the current study.

The keywords extracted from the 75 documents examined represent a research front. The publications co-cited by these documents can be regarded as the intellectual base, i.e., the knowledge underpinning ongoing DesignX-related research. Both can be visualized by VOSviewer.

4.1.1 The Research Front of DesignX-Related Studies

The 75 DesignX-related documents (spanning from 2015 to 2019) contain 386 keywords employed by 139 authors from 73 organizations and 20 countries. There are 2,992 references cited by these 75 documents, and 2,088 authors cited in total.

Keyword co-occurrence mapping resulted in clusters of themes and topics. Given the small size of the data, I set the keyword occurrence threshold at 2. Figure 1 lists a total of 9 clusters of 58 keywords co-occurring with other keywords in the same network in at least 2 DesignX-related documents. The links (L), link strength (LS) value, and number of occurrences (O) of a keyword indicate how many other keywords it is related to, its total strength of co-occurrence relations with other keywords, and how many documents it appears in, respectively. These keywords form concepts and represent the underlying research concerns of DesignX-related research, denoting its research front.

VOSviewer provides distance-based visualizations of bibliometric networks, i.e., the distance between two nodes approximately indicates the relatedness of the nodes [14]. Figure 2 shows the network of keywords. The size of the keyword indicates the frequency of its occurrence, its amount of links, or total link strength; the thickness of the line connecting two keywords indicates the number of co-occurrences one word has with another, i.e., it illustrates the strength of relational co-occurrence between the pair.

The resulting network, when visualized, looks relatively sparse. Among the nine clusters, seven contain only a couple of keywords that are strongly co-occurring with another keyword. This lack of occurrences implies that DesignX-related research is still in its infancy. On a separate note, the transient structure indicates an interdisciplinary character, rather than one that is discipline focused.

Cluster 1	**L***	**LS**	**O**	**Cluster 2**	**L**	**LS**	**O**	**Cluster 3**	**L**	**LS**	**O**
co-design	5	3	3	**complexity**	**8**	**6**	**7**	Constructivism	6	2	2
community	4	2	2	context variation	3	2	2	embodied sensemaking	3	2	2
emergency department	7	2	2	engineering design	5	2	2	multi-stakeholder	4	3	3
experience	5	2	2	design methodology	4	2	2	product-service system	6	3	3
health care	7	3	3	emotion	1	1	2	sensemaking	6	2	2
hospital	7	2	2	innovation	5	3	3	social systems	10	3	3
human engineering	9	3	3	interaction design	5	2	2	**systemic design**	**9**	**3**	**4**
human-centered design	**11**	**5**	**5**	performance	5	2	2	systems thinking	6	2	2
human-computer interaction	**6**	**4**	**4**	systems	4	2	2	visualization	6	2	2
human-systems integration	7	2	2								
service design	**6**	**4**	**4**								

Cluster 4	**L**	**LS**	**O**	**Cluster 5**	**L**	**LS**	**O**	**Cluster 6**	**L**	**LS**	**O**
complex adaptive systems	2	1	2	community of practice	5	2	2	**design thinking**	**7**	**4**	**4**
design activism	4	2	2	**design education**	**9**	**5**	**6**	socio-technical transitions	3	2	2
design-led innovation	3	1	2	design method	4	2	2				
designX	**16**	**10**	**10**	design practice	4	2	2	**sustainability**	**8**	**6**	**6**
resilience	1	2	2	design research	5	2	2	transition design	4	3	3
social innovation	4	2	2	public sector innovation	4	2	2	**wicked problem**	**7**	**5**	**6**
sociotechnical systems	**16**	**10**	**12**								

Cluster 7	**L**	**LS**	**O**	**Cluster 8**	**L**	**LS**	**O**	**Cluster 9**	**L**	**LS**	**O**
applied computing	4	2	2	**design**	**15**	**7**	**7**	community energy storage	3	2	2
decision-making	4	2	2	failure	3	3	3				
e-government	4	2	2	ubiquitous computing	6	3	3	energy transition	3	2	2
multi-criterion optimization	4	2	2	user study	3	3	3	responsible innovation	3	2	2

* L = number of links; LS = link strength; O = number of occurrence.

Fig. 1. The 9 clusters of keywords that occur in at least 2 out of the 75 DesignX-related documents based on the co-occurrence algorithm of VOS.

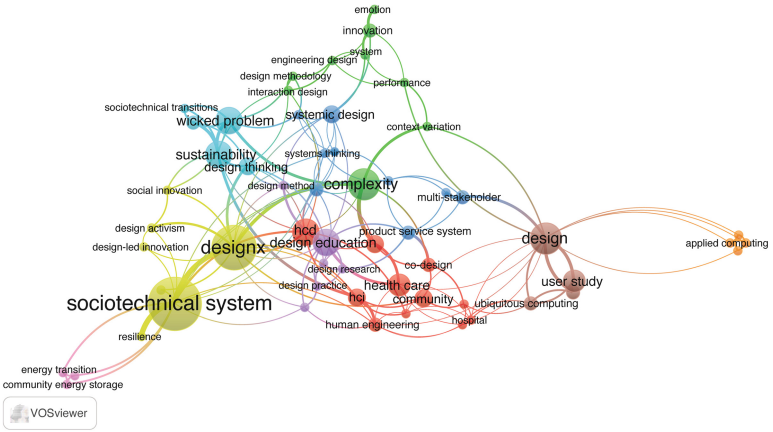

Fig. 2. The network mapping of keywords from DesignX-related documents (occurrence threshold 2) using VOS approach. (Color for each cluster: C1—red; C2—green; C3—blue; C4—yellow; C5—purple; C6—sky-blue; C7—orange; C8—brown; C9—pink.) (Color figure online)

Unsurprisingly, two core terms—"DesignX" and "sociotechnical systems"—are the most popular ones and appear in the same cluster (4). Their family members include "design activism" (the argument that designers must play a more active role tackling complex problems [18]); "social innovation" [19] and "design-led innovation" [20] (approaches to address the complex problems society and organizations face); "resilience" (a key characteristic for society and communities to respond to complex challenges [21]); and "complex adaptive systems" (used to design for governance structures [22]). Clearly, this cluster emphasizes the social dimension of the DesignX approach. Cluster 6's terms, "sustainability," [23] "transition design," [24] and "wicked problems," [25] can be seen as an extension of Cluster 4, with a specific focus on the social sphere.

The strong link between "DesignX" and "complexity" bridges the social concerns with the technological world of DesignX. With "complexity" as the keystone of Cluster 2, this group of keywords penetrates an engineering-based area that focuses on, for example, "engineering design," "systems' performance," and the "context variation" for such performance. The inclusion of "design methodology" and "design method" echoes the long tradition in engineering seeking robust methods and methodologies [26].

Between the "DesignX" and "complexity" groups sits Cluster 3, which explores various topics within systems theory ranging from "systems thinking," to "social systems," "product-service systems," and "multi-stakeholders." The biggest node in this cluster is called "systemic design" [27]—a research area aiming to relate systems thinking with design to address social issues.

Interestingly, although Cluster 4—the DesignX cluster—contains the biggest nodes with the strongest relationships, the cluster does not sit at the heart of the map (Fig. 2). It is on the fringe of other clusters that represent the dominant focuses of the design discipline, for example, the "human-centered design" group (Cluster 1) and the "design education" group (Cluster 5). This location implies the body of research that focuses on DesignX (and hence adopting DesignX and sociotechnical systems as its keywords) emerges at the intersection between design and other possible disciplines.

The keywords "design" and "user study"—two most familiar keywords to the design discipline—locate in Cluster 8, which unexpectedly sits between the main network and the island-like Cluster 7 (bottom right, Fig. 2). By tracing their source documents, I found this cluster of publications to be mainly papers from ACM conferences such as CHI and UBICOMP on applied computing. This might explain the strategy of choosing "design" as a keyword when introducing design concepts or research into a field outside of design. I suspect the big node of "design" is a footprint of design's landing in computer science. Currently, this cluster is small and mainly focused on lessons learned through designing intelligent systems within healthcare environments [28].

Unlike the above seven clusters, Clusters 7 and 9 carry a small number of keywords that are evenly connected to the others. Figure 2 clearly shows that the two clusters (orange and pink) are located in the remotest places on the map, almost cast away from the main network. I went back to the source documents where these keywords emerged and found that Cluster 7 derived from 2 articles [29, 30] on sensemaking of complex systems in the context of public sector innovation; Cluster 9 from two articles [31, 32] on community energy storage. Although the source article numbers are small, these two clusters reflect that the notion of DesignX is drawn on by social science studies examining governance innovation and science, technology, and policy studies on energy systems—two disciplines that are not part of design's foundation, and are probably the remotest disciplines to design so far. The authors' affiliations also suggest the same insight: leading authors respectively come from Data Science Institute, NUI Galway, Ireland; and University of Twente Department of Science, Technology and Policy Studies, the Netherlands. However, the small number of documents supporting these two clusters and the limited author groups also suggests a possibility that these are just incidental, ephemeral cases.

VOSviewer can also visualize the same network based on a given timeline. "Human-centered design" is the oldest keyword in the cluster network (average publishing year 2016.33). This approach is the bedrock of the design discipline. While the notion of wicked problems [33] has a history longer than human-centered design, the keyword "wicked problems" entered into the DesignX-related research lexicon more recently (average publishing year 2017.50). Here I offer a hypothetical explanation for the lag: while DesignX was first manifested as a "new, evidence-based approach" [2], people soon realized that the issues DesignX purported to address are not new—many of them "fall under the rubric of 'wicked problems,' long a staple of economists, management science, operations researchers, and design theorists" [3]. It takes time for researchers to come aware of wicked problems' relevance to designing for complex sociotechnical systems in today's context, and to seek new methods and processes to resolve such problems. Therefore, "wicked problems" appears relatively late. The keywords "design methodology" that it relates to appeared around the same time, and later on "design methods" appeared.

VOSviewer's clustering provides a snapshot of the current structure of the emerging DesignX-related research front. The clusters form an interdisciplinary discourse at the intersections of design, the social sciences, engineering, and computer science. When looked at more closely, the configuration of the clusters points to some noteworthy possibilities.

(1) Within the "human-centered design" cluster (1) health care ("health care," "hospital," and "emergency department") takes a significant place. Healthcare systems are one of the most complex sociotechnical systems that exist, and one wherein designers are called to intervene on a more regular basis. It is probably one of the few areas that provides evidence demonstrating the effects of design interventions, be they positive or negative [34]. It remains to be seen whether more areas will adopt DesignX approaches to problems as part of a human-centered design approach, and the emergence of any convergences merits ongoing surveillance.
(2) Some keywords that are usually closely related (and therefore part of the same cluster) from a design perspective were divided into different clusters. For example, "emotion," which is often examined together with "experience," "human-computer interaction," and "service design," now sits at the edge of a cluster that is tilted to engineering and systems studies. This implies two possibilities: either it signals a novel emphasis on emotional aspects of engineering research as an approach to "innovation" (also categorized in the same cluster); or its occurrence in engineering and systems research is just incidental due to the small size of data and low threshold, and all these terms will be eventually integrated into the foundational definition of design.

4.1.2 The Knowledge Underpinning DesignX-Related Studies

As introduced above, a research front is the state of the art of a line of research—what researchers at this frontier cite forms its intellectual base [15]. Following Chen [15], the intellectual base of the keyword network identified above are the references cited by papers carrying these keywords. This requires a further shrinking of the dataset. I took an approximate approach here, i.e., I used the co-citation network established by all 75 documents to imply a possible body of knowledge underpinning DesignX-related research. Table 1 shows the 10 references most frequently cited (more than 4 times) by the 75 documents.

Table 1. The body of knowledge supporting DesignX-related research.

	Most frequently co-cited references	Links	Total link strength	Citations
1	Norman and Stappers [3], "DesignX: Complex Sociotechnical Systems"	9	35	75
2	Rittel and Webber [33], "Dilemmas in a General Theory of Planning"	8	15	15
3	Dorst [35], *Frame Innovation*	7	9	9
4	Buchanan [1], "Wicked Problems in Design Thinking"	8	7	7
5	DesignX Collaborative [2], "DesignX: A Future Path for Design"	6	6	6
6	Manzini [36], *Design, When Everybody Designs*	5	6	6
7	Brown [37], *Change by Design*	7	4	4
8	Buchanan [38], "Worlds in the Making"	5	4	4
9	Lindblom [39], "The Science of 'Muddling Through'"	3	4	4
10	Snowden and Boone [40], "A Leader's Framework for Decision-Making"	4	4	4

The full DesignX article by Norman and Stappers is of course the most cited article, given that I used it to demarcate the set of DesignX-related documents. The DesignX Collaborative 2014 manifesto "DesignX: A Future Path for Design," which gave rise to Norman and Stappers' article, is closely related. However, this document was not officially published (distributed via Norman's online blog instead) and it carries initial ideas about DesignX that are less well articulated than those in the full length article by Norman and Stappers. These factors might restrict the manifesto paper's visibility and influences in the literature. Lindblom's article (1959) on what they called "muddling-through" supports one of the core arguments in Norman and Stappers' DesignX approach— adopting small, incremental steps to muddle through the complex situation. These three seem to be the base for understanding Norman and Stappers' DesignX concept.

Rittel and Webber's seminal article on wicked problems is a classic, recently reviving in DesignX-related studies. The close relationship between DesignX problems and wicked problems calls for new approaches to old issues. When allied with the rest of the publications on the list, this article serves to support DesignX-related studies in at least two pivotal ways: it enriches design thinking, as in Buchanan [1] and Brown [37]; and addresses organizational or social innovation, as in Buchanan [38], Snowden and Boone [40], Dorst [35], and Manzini [36].

4.1.3 Research Communities

To understand the research communities who are using the notion of DesignX, I chose bibliographic coupling, which is a method that clusters a set of documents based on the number of references co-cited by each two articles in the set [41]. It can reveal the relations between the examined documents in terms of their authors, sources, organizations, and countries. Figure 3 shows the network of authors and that of organizations in the 75 DesignX-related documents based on bibliographic coupling.

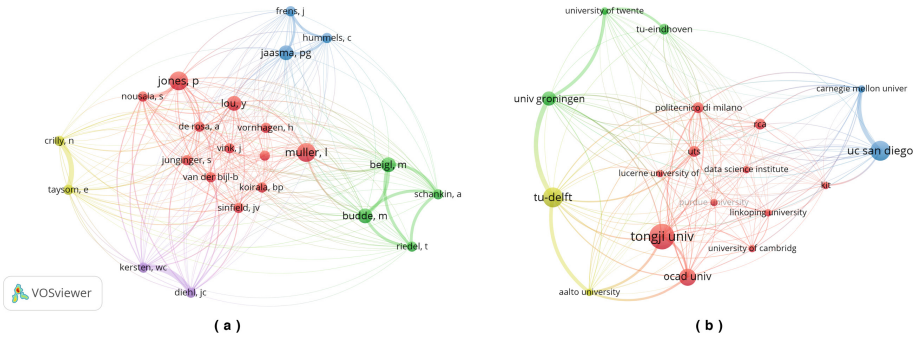

Fig. 3. (a) Authors' network and (b) organizations network based on bibliographic coupling (minimum documents of each node above 2).

In Fig. 3a, the four clusters of authors lying at the edges of the network have the strongest internal links, because they co-authored multiple publications. Aside from these authors, the connections between the other authors remain weak. However, some of these authors are more connected than the map shows, because of the research activities they were engaged in. Peter Jones, based at OCAD University, Canada, for example, is the co-founder of the systemic design symposium RSD. He was invited to attend the DesignX working conference at Tongji in 2015, and later he edited a themed issue of *She Ji* on the topic of systemic design. This also explains a portion of the 75 documents are from the systemic design community (including ones authored by Eloise Taysom, Nathan Crilly, Mieke van der Bijl-Brouwer, Susu Nousala, etc.).

The organizational network in Fig. 3b describes the connections among authors' affiliations. Tongji University contributed 8 documents, UC San Diego 6, and Delft University of Technology 6. Five out of the six DesignX initiators (DesignX Collaborative) come from these three universities. They play an important role in promoting DesignX in their home organizations and research networks. Since the DesignX position article was published these communities have expanded, engaging more universities in Europe and North America in the past three years. The Dutch university cluster stands out significantly, as does the United States cluster linking UC San Diego and Carnegie Mellon University. Tongji University College of Design and Innovation seems to be most productive probably because it is the location where DesignX first started and the faculty is inspired by the DesignX community, especially one of DesignX's leading proponents Yongqi Lou, who is dean of the school.

4.2 Part 2: A Closer Look at the DesignX-Related Studies

Although the knowledge mapping tool is able to visualize who is citing the DesignX article, the maps tell little about how people actually employ this article in their own research. Therefore, I carried out a text-based analysis of the 75 DesignX-related documents. Here I report a few important results.

While reading these documents, I found people tended to refer to distinct facets of the DesignX article for different purposes, and that the depth of use varied significantly. From the DesignX article, I derived 3 categories that I felt constitute a holistic view of what DesignX is about. The three categories are (1) its intervention context; (2) its subject matter and problems; and (3) its practical approach and arguments. Under these categories, there are 13 codes including "challenges"; "the shift of the design discipline"; "sociotechnical systems"; "human aspect"; "social sphere"; "technological world"; "9 properties of DesignX problems"; "human-centered design"; "muddling through"; "evidence-based"; "implementation'; "designers' active role"; "new design expertise and education."

		Context		Subject and Problems					Approach and Arguments					
Level of Use	Author(s), Year	Complex challenges	Shift of design discipline	Sociotechnical systems	Human	Social	Technological	9 Properties of DX problems	HCD perspective	Muddling-through	Evidence-based	Implementation	Designer's active role	New expertise & education
Level 3. Integrating	51. Allen,2017	•		•	•	•	•			•				
	52. Budde, Schankin, & Hoffmann et al., 2017				•	•			•	•				
	53. Cipriani & Rossi, 2018			•						•		•	•	
	54. Davis, 2016	•	•	•				•		•	•			•
	55. Fehr, Müller, & Aronoff-Spencer, 2017	•		•	•	•	•	•		•				
	56. Huang, Poderi, & Šćepanović et al., 2019			•	•	•	•		•	•		•		
	57. Jaasma, Wolters, Frens, Hummels, & Trotto, 2017	•		•		•						•		
	58. Lupetti, Yao, Gao, Mi, Germak, 2017			•	•	•	•	•	•					
	59. Malan, 2018			•		•				•				
	60. Nousala, Ing, & Jones, 2018	•	•	•		•		•		•				•
	61. Aronoff-Spencer, 2018			•	•	•	•		•			•		
	62. van der Bijl-Brouwer, 2017b			•						•				
Level 4. Reflecting & Developing	63. Flach, 2015	•	•	•	•	•	•			•				•
	64. John & Pam, 2018			•				•		•				
	65. Jones, 2015			•	•	•	•	•		•				
	66. Junginger, 2017b			•	•	•	•							
	67. Kersten, Long, Diehl et al., 2017									•				
	68. Kersten, Diehl, & Engelen, 2018									•				
	69. Lou, 2018a	•		•	•	•	•							
	70. Lou, 2018b	•				•					•	•	•	•
	71. Lou, 2017	•	•	•		•	•	•			•	•	•	•
	72. Ma, 2017	•		•						•		•		•
	73. Mulder & Loorbach, 2018	•	•	•		•						•	•	•
	74. Myerson, 2015		•	•					•	•				
	75. Nousala, 2016			•	•	•	•							

Fig. 4. Coding results about how the notion of DesignX is used in the literature (in part).

I coded the 75 documents based on this set of codes. Then I identified 4 ways that DesignX was used in the documents, ranging from (1) labeling and annotating; (2) introducing; (3) integrating; and (4) reflecting and developing. Figure 4 demonstrates part of these coding results.

To sum up, the whole set of 75 DesignX-related documents indicates a pattern in which DesignX aspects have attracted attention from various domains. The most salient aspect of DesignX is the domain of its identity as primarily the area of complex sociotechnical systems (referred to 53 times). The social dimension (involving multidisciplinary and multi-stakeholder perspectives) of such systems (31 times) and complex challenges our society faces (30 times) follow immediately. The muddling-through approach involving incremental and modular strategy (28 times) indicates intensive attention also paid to methodological considerations. The human psychological and cognitive dimension (21 times) and human-centered design (7) show this traditional design focus is also influential to shape DesignX concerns. It is noteworthy

that evidence-based (4 times) is mentioned the least. This probably because "evidence-based" was advocated in the first DesignX manifesto but was not emphasized in Norman and Stappers' article.

I fully recognize that this coding scheme is highly analytic, and does not fully represent the real use of the DesignX article in these 75 documents. Many authors synthesized several aspects as an argument in their inquiries. Therefore the following elaboration helps to build a holistic idea how DesignX is used.

4.2.1 Level 1. Labeling and Annotating

Among the 75 documents, 37 documents referred to the DesignX article briefly by using it as either a quick label or an annotation without further introduction.

The article is used to label a distinct aspect of an approach to complex sociotechnical systems, for example, people and technology [42]; or to label a certain kind of complex problem [43]; or to indicate an increasing research interest from a specific domain [44]; or, as a means of echoing a shift within the design discipline [45].

It is also used as an annotation supporting characteristics of complex sociotechnical systems. For example, "there are complex and non-linear interactions and dynamics among different layers, actors, and technological components of CES (Norman and Stappers 2015)" [31].

In this Level 1 group, most documents cited the DesignX article in their introduction or literature review sections, locating the study in the context of sociotechnical systems or defining what such a system is. Some use the article when discussing their research's implications and future direction, drawing on DesignX's call to change design practice and education. Some refer to its muddling-through, incremental approach. The Level 1 group does not look into the notion of DesignX deeply, and only touches upon very limited aspects among the 13 codes.

4.2.2 Level 2. Introducing

The Level 2 group embraces a deeper or more holistic understanding of DesignX, by considering detailed dimensions spanning across the 13 codes. Barbara McCombs [46], for example, introduces DesignX as it is originally defined: as a sociotechnical systems approach characterized by the human-centered design perspective that includes a muddling-through process of taking small, incremental steps within a modular approach so as to divide the whole into more manageable components. Peppou [47] delves more into the intertwining human, social and technical spheres of DesignX problems. Vornhagen [30] further illustrates the difficulties in making sense of complex sociotechnical systems by referring to the 9 properties of DesignX problems. The call for new skills for designers to tackle complexity is also presented more clearly in this group of documents [48].

4.2.3 Level 3. Integrating

In the Level 3 group, the DesignX article is more comprehensively and deeply used, and referred to in various places in the document including the introduction, methods, discussion, and conclusion. These authors show an observable inclination to integrate some of the essential DesignX arguments into their studies. For example, Fehr and colleagues [49] adopt DesignX as the methodology guiding their study on design for

computing in health care. Allen [50] uses DesignX's modularity and incremental process as the guiding principle to align the implementation of an open professional development strategy. Jaasma and colleagues [51] emphasize the necessity of incorporating multi-stakeholder interaction—a very important feature of DesignX in the social sphere—in the framing of their study on a product-service system design for participatory sensemaking for public issues. Mieke van der Bijl-Brouwer [52] draws on DesignX's call for "the continuous development of multiple interventions" to explain the findings of her empirical study in service systems design.

Compared to the Level 1 group, the 25 documents on both Levels 2 and 3 exhibit a wider and deeper interest in DesignX. They are more inclined to use this notion to explain or support their arguments. However, a critical reflection and development of the DesignX notion is not really present. The articles in the Level 4 group fill this vacancy.

4.2.4 Level 4. Reflecting and Developing

There are 13 documents that directly reflect on the idea of DesignX, and some of them shed light on dimensions that DesignX could possibly flesh out.

While they accept the nine properties of DesignX problems, John and Pam [22] challenge the notion that the muddling-through approach is "unnecessarily defeatist" and would be "cause for alarm" if institutionalized in medical care. They assert that DesignX fails to consider some advanced tools available now including Axiomatic Design, Cynefin, Agent Base Modeling, and data sciences, which can offer workable holistic heuristics while also being able to resolve local and emergent difficulties.

Kersten and colleagues [53] question the operational characteristic of muddling through also, this time from an engineering design perspective. They argue that strategic intent can steer one through uncertainty when such intent is more explicitly present from the outset, as it empowers designers to develop scenarios to guide them through.

These two criticisms seem controversial to me, because DesignX does not ignore the capability of technology or deny the advantage of design being explicitly strategic. The question is whether advanced techniques and strategic intent are sufficient to address DesignX challenges, especially given that complexity and uncertainty are central characteristics of the design context. Such debates need evidence to support any position.

Mulder and Loorbach [24] offer a comprehensive account of DesignX and observed valuable discussions, for example, on the PhD-Design mailing list inspired by the DesignX article. However, the authors criticize the more or less design expert-dominant context of the discussions, as the DesignX article seems to cast the designer as the central figure "in the proposed path-dependent optimization of a design regime" [24]. They argue that for design to deliver more value to society, engaging more with society is inevitable. This possibly implies that although DesignX emphasizes multi-stakeholder involvement in the social sphere of complex systems, the political issues and how to handle such challenges deserve further examination.

Ma [54] notes that DesignX (2015) is too focused on issues of "how" without sufficiently exploring the fundamental question of "what is a system?" Drawing on Buchanan's [55] schema of systems being based on distinct design strategies, the

author attempts to understand DesignX problems (which are not new) from a fresh perspective to enrich the ongoing conversation.

She Ji published invited commentary articles on Norman and Stappers' DesignX article. The purpose was to reflect on and expand the DesignX conversation. All 3 commentary authors participated in the DesignX working conference. Their distinct perspectives helped the future journey of DesignX unfold by looking deeper into cognitive systems engineering, the design tradition, and socioecological systems.

Flach [56] argued that we must recognize that all agents—including the smartest human beings and the most advanced technological systems—are confined by "bounded rationality." He warns of the danger of reinforcing "a tendency … to identify the human as the 'weakest link' that is often the source of 'errors' in complex systems" [56]. His cognitive systems engineering perspective adds an alternative view to more classical approaches in the DesignX agenda such as human factors or human-computer-interaction.

Myerson [57] discusses the difficulties design has embarking on the X journey due to a double mismatch. On the one hand, complex sociotechnical issues require a big picture thinking broader than specialized silos where designers were educated and where they traditionally intervene; on the other hand, the muddling-through approach of taking small, modular steps seems to go against designers' tendency to "think big and bold outside the constraints of any systems," a habit reinforced by project-based design education.

Jones [58] emphasized that understanding the social sphere of DesignX (social, cultural, and political issues) requires a socioecological systems perspective. It deserves its own methodological exploration that Norman and Stappers did not sufficiently cover.

In addition, Lou's effort to develop DesignX is noteworthy. Firstly, he points out that efforts to achieve sustainability involve the most complex sociotechnical systems issues that also need design intervention [59]. Second, he advocated a type of design activism [18] that opens up the DesignX call for designers' to be more active in the implementation phase. Rather than being problem-solving service providers, designers should create visions, initiate projects, integrate resources, drive innovation aimed at social wellbeing, and implement the solutions [60]. Thirdly, evidence-based [18] research is a feature that Lou believes distinguishes DesignX from conventional practices that are largely based on trial-and-error and rule of thumb. All these aspects call for a cultural shift of the design discipline [61].

5 Findings

5.1 Patterns of Knowledge Diffusion and Integration

When combining the results of study Part 1 and Part 2, a more meaningful pattern emerges. Almost half of the DesignX-related studies (37 docs) refer to this notion in a light manner. In Fig. 2, the two keyword clusters that are relatively distanced from the main network—"applied computing" and "energy transition"—come from studies that used "DesignX" as a label. This implies that the DesignX notion has scratched but the

surface of such disciplines as computer science and energy engineering, but the seed has not been deeply sown. However, this label use possibly also implies that, although the DesignX notion is alien to many disciplines, it is so well synthesized—articulating the challenges and problems—that it acts as a kind of ready-made shorthand to indicate a complex (design) situation. Such clarity helps design to communicate with other disciplines.

Not all interdisciplinary encounters remain on the surface level. Some authors from cognitive engineering systems and engineering design did start to weave the DesignX notion into their studies and offered insightful reflections on DesignX. These authors were either invited to participate in the DesignX working conference or had an experience of working with *She Ji*, the journal that published the DesignX article. Collaborative activities and publication platforms (including journals and conference proceedings) help a new design idea to spread beyond disciplinary boundaries and evoke deeper responses. In particular, the close communication between *She Ji* and the systemic design community led by Jones and colleagues resulted in a significant portion of DesignX-related studies across Levels 2 to 4, which better integrate DesignX into other fields and critically reflect on it.

I held a hypothesis before the analysis that documents from disciplines outside design would tend to use the DesignX article in a relatively light manner (on Level 1); those from inside design would be more likely to look deeper into DesignX. However, the qualitative analysis results do not necessarily support this hypothesis. All the four distinct levels of use include many design studies. A more fine-grained pattern of DesignX use—one that is able to clearly illustrate the relationships brought together by DesignX within design disciplines and between design and other disciplines—will require a subject categorization that works for design. This categorization is beyond the scope of the current study but will be further explored in my future work.

The academic impact of DesignX Collaborative scholars has been indispensable to the course of knowledge diffusion and integration of DesignX. Don Norman in particular is one of the best known design theorists and human-centered design promoters. His work, whose topics range from psychology and engineering to design and design education, was cited 94 times in the 75 documents included in this study. His multidisciplinary experience and expertise translates extremely fluidly across various disciplines. In addition, the organizations where he and the other Collaborative scholars are based have become the most influential places supporting DesignX-related studies. These loci of DesignX research include the Design Lab, UC San Diego led by Don Norman; Delft University of Technology where Stappers and Voûte are based; and Tongji University College of Design and Innovation led by Lou. These organizations have served as DesignX ground zeroes: places where these pivotal scholars can develop the emerging DesignX "research community of practice" [62] engage in the early stages of knowledge diffusion, and open the DesignX discussion to their research networks.

5.2 A Future Path for DesignX

Insights obtained through this study on developing DesignX are multi-faceted, and can be summarized as follows.

(1) A better understanding of the technological aspect of the DesignX domain is needed. As evidenced by the results from Part 2, most of the documents in this study emphasize the social and human-centeredness of DesignX issues. The technical aspect is sorely lacking. In fact, all three dimensions of DesignX problems require advanced exploration supported by cutting-edge knowledge from the social sciences, computer sciences, systems studies, engineering, and many more domains in addition to design. Norman and Stappers acknowledged designers' ignorance of knowledge about complex systems that other disciplines have been accumulating for decades [3]. To add to this observation, Lou [59] advocates involving the most advanced technology at our disposal including data science techniques and Artificial Intelligence to address complexity, ambiguity, and uncertainty.
(2) The methodology is ready for further advancement. Re-examining what constitutes "wickedness" in DesignX problems comes with significant implications. Without a methodology that actually works to design for complex sociotechnical systems, the DesignX discourse probably will not be able to move forward. It is an optimistic sign to see that keywords such as "design methodology" and "design methods" recently joined in the conversation. The dialectic on the muddling-through approach and its reductionist feature deserves exploration of a more empirical nature.
(3) A cultural shift in design must be fostered. To tackle complex sociotechnical issues, DesignX must emphasize an evidence-based approach, interdisciplinary collaboration, the goal of sustainability, the spirit of design activism, and more rapid uptake of cutting-edge technologies [61]. All these require a new culture, different from the one reinforced by conventional design practice and research.

The above points offer a rough outline of a possible future path for DesignX. Their implications for design education are massive.

6 Concluding Remarks

This paper has explored an emerging front in design research inspired by Norman and Stappers's seminal 2015 article entitled "DesignX: Complex Sociotechnical Systems." This empirical study adopts a mixed methods approach combining the knowledge mapping technique VOSviewer with textual-based qualitative analysis. Results from both quantitative and qualitative methods disclose the transient structure of DesignX-related research in its knowledge and research communities. Although relatively few documents have become available during a short (±3-year) period, a preliminary interdisciplinary pattern is discernible. Rich insights arising from these results support interpretation and understandings about patterns of knowledge diffusion and integration in DesignX-related research. This paper advances understandings about how a new, interdisciplinary concept, first initiated in one discipline, slowly migrates to other disciplines and evokes studies at their intersections.

However, the domain of DesignX-related research has not reached a saturated and stable state. Based on a very small data set, mapping the DesignX-related research front

is explorative at best. The risk lies in how much the structure is disturbed by the noises that were not filtered out by low threshold settings when applying knowledge mapping technique. The patterns reported in this study are experimental snapshots of a changing area, and are subject to further examination. If the dataset expands, the clustering of emerging thematic topics in this area might change and be able to represent the interdisciplinary structure more accurately. Also more knowledge mapping techniques should be experimented to identify tools that work best for small and medium sized datasets coming from mixed indexing sources. Techniques for correcting and formatting documents' bibliographic information also require further study.

Bibliometric and scientometric knowledge mapping methods and tools work well for revealing structures at the macro-level, and are particularly useful for detecting research fronts for knowledge management and policymaking purposes. To achieve insights that make sense to design researchers on a micro and meso level, I argue that when applying knowledge mapping techniques to the design discipline, researchers should consider complementing perspectives or approaches to help interpretation of the macro views by eliciting more fine-grained findings from within the disciplines concerned.

The systematic review of DesignX-related studies is an experimental attempt to describe the interdisciplinary structure of an emerging research area. The insights and lessons learned contribute to further studies on the interdisciplinarity of design discipline.

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