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A theory landscape of design: mapping the theoretical discourse of the discipline

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Abstract

This paper presents a mapping of theory use in the design discipline based on the corpus of the published ICED and DESIGN conference papers since 2010. We searched the resulting 4,451 papers for occurrences of theories and compared them with an existing ontology of named theories through natural language processing (NLP). The results yielded a variety of analyses, illustrating, for example, the most-used theories and which disciplines these theories stem from. This paper presents a rich overview of the theories relevant to the design discipline and a novel approach to bibliometric analyses.

Keywords: design theory, ontology, literature review, natural language processing (NLP), bibliometric analysis

1. Introduction

A solid theoretical foundation is one of the core pillars of research excellence. However, the design discipline is surprisingly weak when it comes to underpinning research studies with appropriate theory and, more specifically, a well-developed framing of the theory-building-and-testing cycle (Cash, 2018). More specifically, Cash (2018) claims that theory-driven design research shows (1) low levels of theory-building and -testing research, and (2) little use of frameworks to connect empirical with theoretical contributions, among several other challenges. At the same time, there is still little consensus about what characterizes a strong theoretical foundation of a publication, but a lack of theory is often seen as a primary reason for rejecting a paper submission by editors and peer-reviewers (Sutton & Staw, 1995). This situation leads to the question of how the design discipline engages with theory – either by building on and adapting theory from other disciplines or by creating and referencing their own. Hence, the following research question guided our study:

RQ: What is the state of theory use in the design discipline?

Along with this main research question, there are several related sub-questions that we aim to address, for example, what are the interrelationships of (design) theories with other fields, which theories are most used in the design discipline, and where do these theories stem from?
Bibliometric analyses typically focus on quantitative meta-data, such as citations or authors' affiliations, which can be extracted, for example, directly from Scopus. By contrast, insights about qualitative metrics, such as addressed topics, used methods, or referenced theories, typically require a lengthy manual coding and analysis process, depending on the sample size of included articles. With this paper, we strive for a different approach. Since we are interested in the use of *theories* within the design community, which is qualitative by nature, we employ machine learning methods like natural language processing (NLP) and ontology engineering to generate analyses automatically. In that sense, the

contribution of this paper is twofold: First, we present a "landscape of theory use in design," which provides interested design researchers with an overview of the most relevant theories in design, as well as inspiration and references for the theoretical underpinning of their own studies. Secondly, our methodological approach presents a novel approach to bibliometric analyses that can instigate further research in this direction in a much shorter time.
The remainder of this paper is structured as follows: First, we report the related work of bibliometric analyses in design. Then, we outline the theoretical underpinning for our study. In Section 4, we describe our methodology for creating and analyzing our sample of design research papers. In Section 5, we present the results of our bibliometric analyses, followed by a critical discussion and an outlook on future work.

2. Related work

Bibliometric analyses of publications in a particular field, in selected publication outlets, or in a particular timeframe play an important role in understanding and reflecting a discipline's research interest and development. Cash (2018, p. 98) claims that "design research lacks the formalized approaches to the theoretical framing and reporting of research necessary to support systematic self-reflection and critique". In recent years, this kind of meta-analysis gained increasing interest also in the design discipline and was addressed in several publications. For example, Chai and Xiao (2012) analyzed 15 years of the top design journal *Design Studies* from 1996 to 2010 with regard to the observed citation and co-citation behavior. Cash et al. (2013) build on their work and compare the results with the publications presented at the 2012 DESIGN conference. The results of both papers provided insights into citation behaviors of the design community, such as the most-cited sources from within the design field, as well as from other disciplines. Later, Burns et al. (2016) investigated the developments of publications in *Design Studies* over 36 years. Their study yielded insights on the most popular topics over time. A more recent paper (Perry & Pereira, 2023) analyzed 10,981 papers from the 14 most relevant design journals, as suggested by Gemser et al. (2012), covering the period from 2005 to February 2022. Their bibliometric analyses focused, for example, on the geographical compositions of authors and editorial boards, along with related citation behavior.

3. Theoretical underpinning

A theory is a model of some aspect of the world that explains some real-world phenomenon (Weber, 2012, Dubin, 1969). Gregor (2006) distinguishes five types of theory: (1) theory for analysis, (2) theory for explanation, (3) theory for prediction, (4) theory for explanation and prediction (i.e. causal theory), and (5) theory for design and action. For designers, the type 5 theory is particularly relevant as it addresses the question of "how to design something" (Gregor & Jones, 2007). But the other types of theory also provide useful insight for the act of designing: type 1 represents a taxonomy of a relevant design context; type 2 represents an interpretative understanding of, for example, users' needs; type 3 provides predictions of future developments, based, for example, on heuristics, simulations, or machine learning models; and type 4 provides causal explanations of potential influences of designed artifacts on the world. In the design field, such a theoretical understanding of the world is particularly relevant for understanding in how far a specific design artifact or its features have an effect on people and the environment or if the artifact would be able to solve a particular problem. For this purpose, it is irrelevant whether the theory comes from design or other disciplines. Cash (2018) criticizes the fact that the design discipline references a lot of theory from other disciplines, while vice versa, this is not the case. We argue that since design is an interdisciplinary discipline by nature, this fact is not to be seen negatively. Designers need to reference theory from other fields. For example, human-centered design needs to look into theories from the social sciences, maybe even into biological theories. Physical or digital design artifacts need to consider theories from engineering, physics, or computer science. When designing medical artifacts, one needs to investigate medical theories and so on. Designers need interdisciplinary theory knowledge, and hence, it is crucial to understand how theories from different fields relate to each other. With this paper, we aim to explore the state of theory use in design.

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4. Methodology

Our approach is divided into the following three steps: (1) creation of the corpus of papers to be analyzed, (2) development of an ontology of named theories for later comparison with the theories mentioned in our sample of papers, and (3) automated analyzes and generation of visualization with the help of natural language processing (NLP) and dimension reduction methods using Python. These three steps are described in more detail in the following sub-sections.

4.1. Corpus

We limited the papers to be included in our sample to the conference papers published in the proceedings of the ICED and DESIGN conferences from 2010 to 2023. We downloaded the papers manually from the proceedings of these 14 conferences, which are available as open-access publications. We checked manually for duplicates. This procedure resulted in a total of 4,451 papers (see Figure 1).

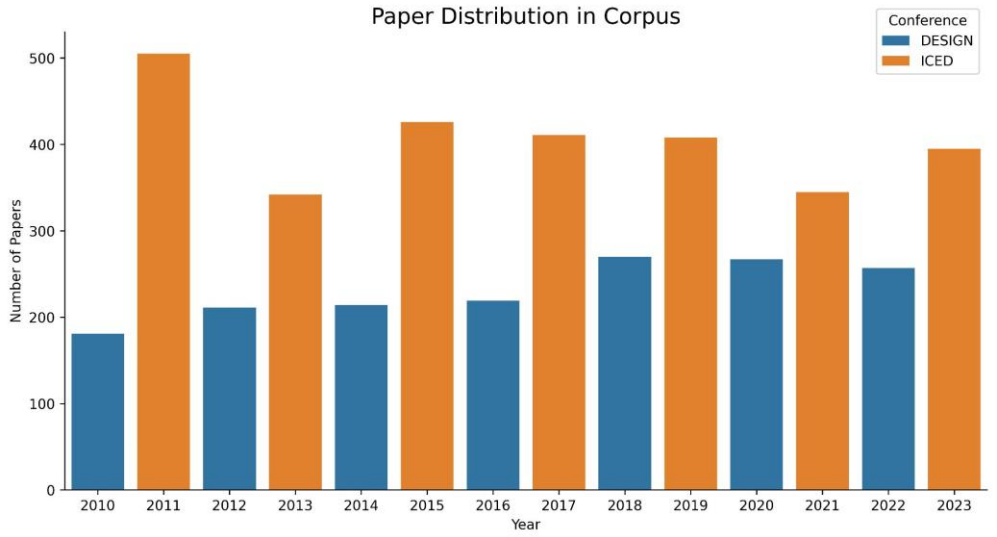

Figure 1. Number of papers published in design and ICED conferences between 2010 and 2023 (n=4,451)

We decided to include only papers from these 14 conferences in our corpus for the following reasons: With this paper, we are aiming to present a first overview of theory-use in the design field and to test our new approach for ontology-based bibliometric analyses (as described in the next subsections). We argue that the ICED and DESIGN conferences provide a good sample of the latest work in the discipline and hence allow us to derive insights into the role of theory for the design discipline in the past 13 years. We acknowledge that this sample must be extended by including papers from the relevant design journals, which will be addressed in future work.

4.2. Theory ontology development

We followed the ontology development process of Arp et al. (2015). The theory ontology used as the foundation for our bibliometric analyses is based on three existing repositories of theories relevant to the design discipline: (1) The "Theories Used in IS Research Wiki" by Larsen and Eargle (2015) contains a total of 148 named theories, mainly from the social sciences, management, psychology, and computer science disciplines. These theories were also considered relevant to the design discipline. (2) Cash and colleagues (Cash, 2020; Cash et al., 2019) presented a collection of 101 design-related theories. In a more systematic approach, Mueller and colleagues developed a theory ontology for the information systems (IS) discipline (Mueller et al., 2022). This ontology contained 321 theoretical entities. An ontology is a taxonomy that groups entities in a hierarchical and semantically meaningful manner and defines additional attributes and relationships between them (Mueller et al., 2022). That means, unlike an unstructured list of theories, as presented, for example, by Cash et al. (2019), an ontology provides additional semantic

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connections between entities. Therefore, an ontology enables automated knowledge synthesis and meta-analysis of research findings (Mueller et al., 2022). We expanded the three sources mentioned above with additional design theories and considered possible synonyms. Part-of-speech patterns were used to detect additional named theories in the corpus that were not yet listed in our ontology. These patterns had the form of, e.g., "theory of ADJ? NOUN+" or "NOUN+ theory" where ADJ and NOUN stand for any word that is an adjective or noun, respectively. The wildcard symbol "?" indicates zero or one, and "+" indicates one or more words. The additional found theories were then manually added to the ontology. This procedure resulted in an ontology of 722 theories in a taxonomical structure with 3,289 synonyms. Finally, we enriched the ontology by adding semantic relationships between theories and information about each theory retrieved from (a) Wikipedia and (b) from the paper itself. The theories are organized in a hierarchical (tree-based) taxonomy. The first level of the taxonomical structure includes the following categories: (1) applied sciences theories (including, e.g., design theories and engineering theories), (2) social sciences theories (including, e.g., psychological theories), (3) formal sciences theories (including, e.g., mathematical theories), (4) life sciences theories (including, e.g., biological and medical theories), and (5) natural sciences theories (including, e.g., theories from physics).

4.3. Automated ontology-based analysis of research articles

The analysis of the 4,451 papers was conducted using an automated approach with the help of natural language processing (NLP). First, the structure of the PDFs and different parts of the articles, like the section titles, citations, and sources, were extracted (Mueller et al., 2022; Mueller & Huettemann, 2018). Then, from the extracted full text of the papers, theory entities were recognized and linked to the theory ontology (Mueller et al., 2022). The named theories are recognized anywhere in the paper and are also included if there are no citations to the reference. For each theory in the corpus, a short (2 to 3 sentences) summary was downloaded from Wikipedia. The theory name and summary were concatenated, and a vector embedding was created with a sentence transformer model (Reimers & Gurevych, 2019). Then, we used the dimension reduction method UMAP (Uniform Manifold Approximation and Projection) (McInnes et al., 2020) to project the higher dimensional embedding of the sentence transformer to two dimensions. Hereby, semantically similar theories (embeddings) appear nearer to each other than semantically different theories. Additionally, the theory category was used for color-coding, and the number of papers that use the theory in the corpus was encoded with the bubble size. The resulting visual landscape of design theory use (Figure 6) yielded a variety of analyses, illustrating, for example, the most-used theories, which disciplines these theories stem from, and how often a theory was cited. We ran the analyses in several Python Jupyter notebooks, which allowed us to generate several visual analyses, which are presented in the next section.

5. Results

In the following section, we present selected results from our automated analysis. From the 722 distinct named theories in the ontology, 324 appeared in the corpus. From the 4,451 papers in the corpus, 1,781 papers mention at least one of the named theories (which equals approximately 40%). Figure 2 illustrates the distribution of referenced theories according to the five theory categories.

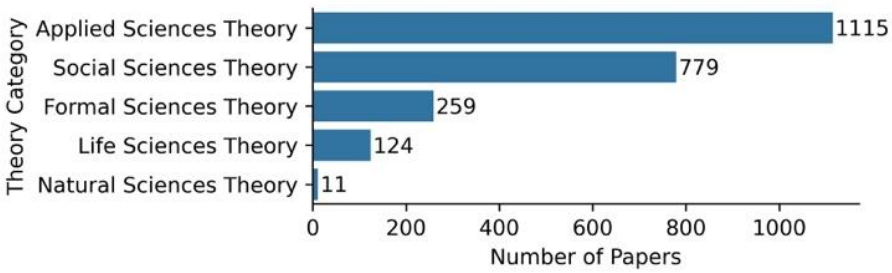

Figure 2. Number of papers with named theories per theory category

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Figure 3 presents a more detailed view of the used theories, according to identified sub-categories. As both figures illustrate, there is a significant majority of papers referencing applied theories or design theories, but not that many from life sciences and natural sciences, such as medicine.

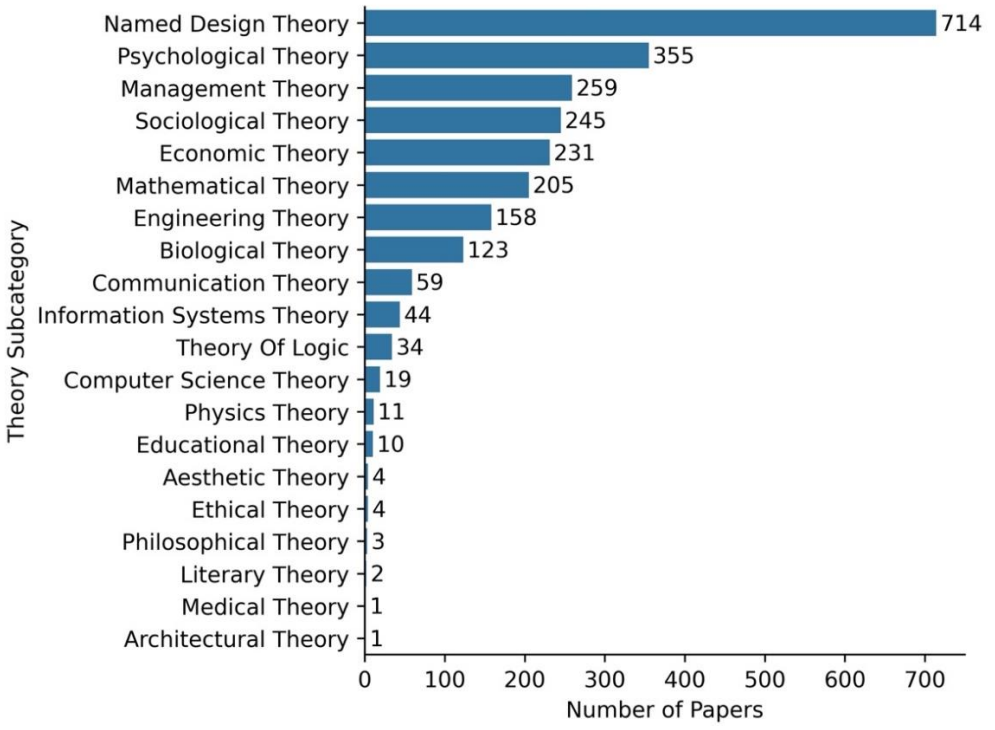

Figure 3. Number of papers with named theories per theory subcategory

Figures 4 and 5 illustrate co-occurrences of theory categories and sub-categories, respectively. Such co-occurrences potentially demonstrate how different theories, stemming from different disciplines, might be used together in a paper.

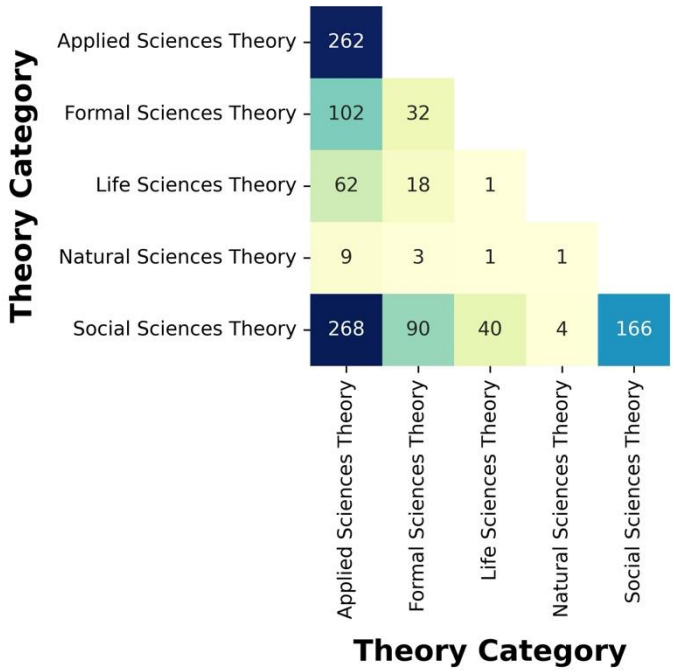

Figure 4. Co-occurrences of theory category

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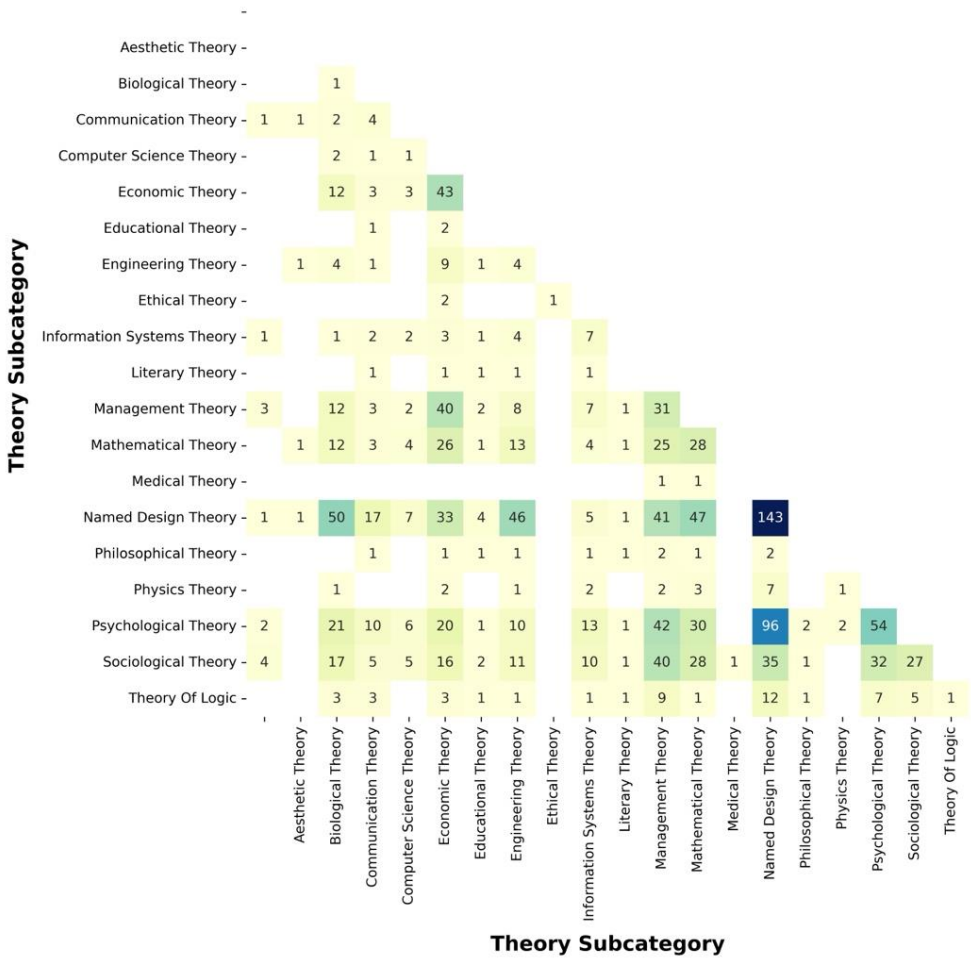

Figure 5. Co-occurrences of theory subcategories

Figure 6 shows a more detailed overview of the semantic proximity of different theories from different disciplines. The colors indicate the different theory categories. Distances between bubbles indicate the semantic similarity, which is automatically extracted from the theory descriptions and titles (through sentence embedding and UMAP, as explained above) in the ontology itself. The size of the bubbles indicates how many papers in our corpus mention a theory (the more usage, the larger the circle). Only the top 200 theories were included, and only the top 70 theories were labeled. Finally, Table 1 presents an overview of the most used theories in the corpus. The table lists not only the number of papers that mentioned a particular theory but also the most-cited reference within the sentence where the theory was mentioned. This reference is not necessarily the author of the original theory but could also be a relevant reference pointing to that theory. The entire table is cut off after the first 24 entries, for reasons of available space in this paper. A full version will be provided after publication as an (online) appendix.

6. Discussion

6.1. Insights about the role of theory in the design field

Our analysis yielded several insights. From the 4,451 papers in the corpus, 1,781 papers mention at least one of the named theories. This equals a share of only 40%. Consequently, approximately 60% of the papers in our corpus do not refer to any theory. This result aligns with Cash's critique that the design discipline is relatively weak when it comes to underpinning research studies with appropriate theory (Cash, 2018). This finding needs to be cross-checked with articles published in design journals, though. While Figures 4 and 5 illustrate the status quo of theory use in design, Figure 6 shows the semantic proximity of different theories, which illustrates the (missed) potential of interdisciplinary theory use for design.

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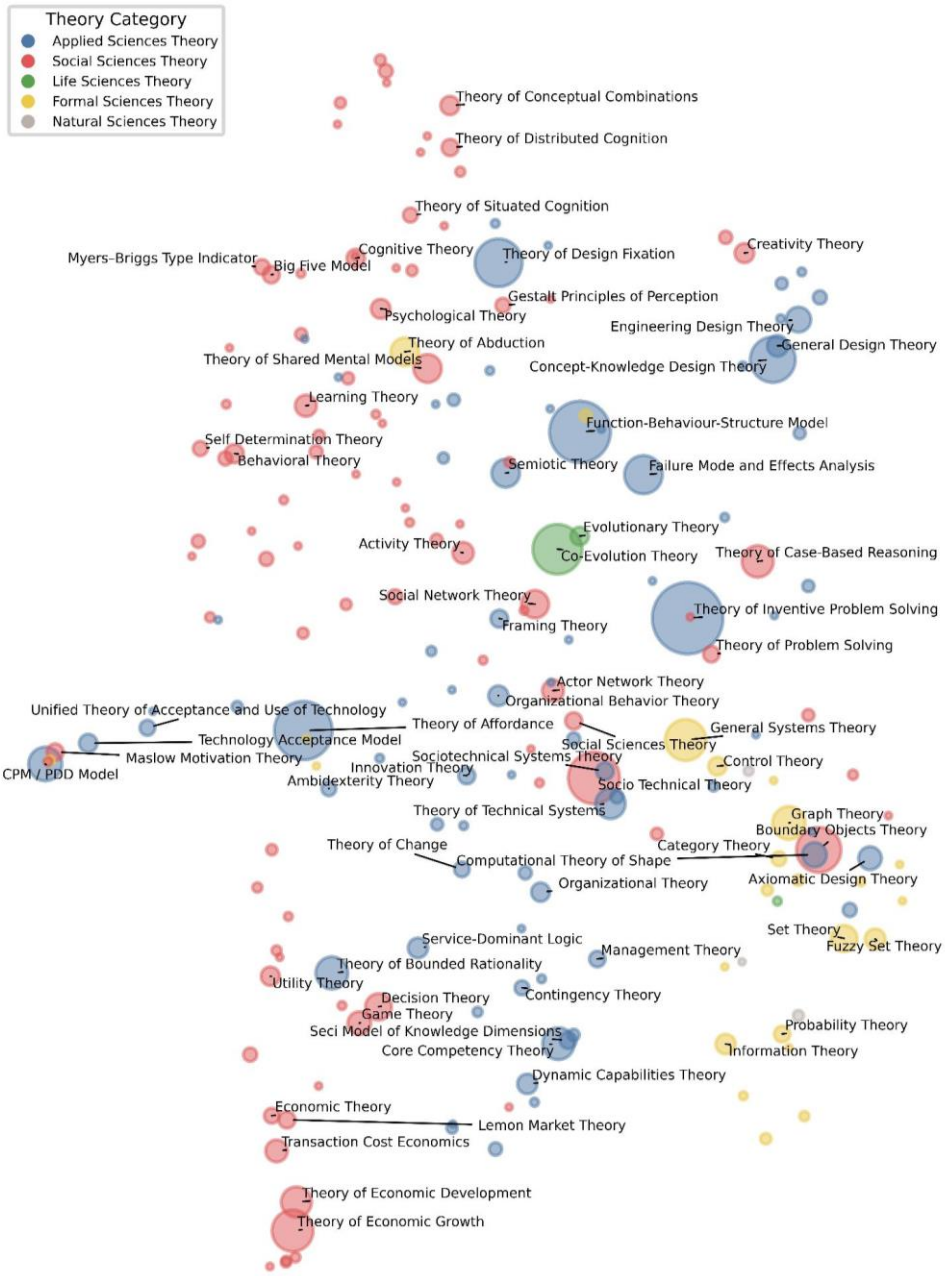

Figure 6. Landscape of theory use in the design discipline

Most referenced theories in our corpus stem from the applied sciences and the social sciences, which is little surprising since these are the most closely related to the design field. Only a few theories were referenced from the natural sciences, and the least referenced theories stem from the life sciences. This last point illustrates the potential for the design field to adapt more theories from, e.g., the medical field or the food industry, which are usually of interest to the design field from a practitioner's perspective. Figure 6 illustrates the main contribution of our bibliometric analysis: "the landscape of theory use in the design field". The figure demonstrates that applied theories (the blue bubbles), which also include the design theories, are not only most referenced in our corpus but also how they semantically relate to other disciplines. The figure shows that many applied theories are often closely related to social science theories, which could indicate either redundancy (do design theories re-invent existing theories from the social sciences?) or a valid application and scoping of theory by providing additional perspectives. This question needs to be explored in future research. Other possible semantic relatedness between theories from other fields is not much explored, yet.

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Table 1. (excerpt): Overview of most cited theories in the corpus

		Most Cited Reference for the Theory in the Corpus		
Theory Name	**Count**	**Authors**	**Year**	**Title**
Theory of Inventive Problem Solving	219	Altshuller, G.	1984	Creativity as an Exact Science: The Theory of the Solution of Inventive Problems
Function-Behaviour-Structure Model	162	Gero, J.	1990	Design prototypes: a knowledge representation schema for design
Theory of Affordance	147	Maier, J.; Fadel, G.	2009	Affordance based design: A relational theory for design
Socio Technical Theory	115	Ceschin, F.; Gaziulusoy, I.	2016	Evolution of design for sustainability: from product design to design for system innovations and transitions
Co-Evolution Theory	106	Dorst, K.; Cross, N.	2001	Creativity in the design process: co-evolution of problem-solution
Theory of Design Fixation	98	Jansson, D.; Smith, S.	1991	Design fixation
Concept-Knowledge Design Theory	89	Hatchuel, A.; Weil, B.	2003	A new approach of innovative design: an introduction to CK theory
Boundary Objects Theory	87	Star, S.; Griesemer, J.	1989	Institutional Ecology, `Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology
Theory of Economic Growth	74	Luo, J.; et al.	2012	Technology-based design and sustainable economic growth
General Systems Theory	73	Hubka, V.; Eder, E.	1988	Theory of Technical Systems: A Total Concept Theory for Engineering Design
Failure Mode and Effects Analysis	63	Schneider, L.	1997	VDI-Richtlinie 4008
CPM / PDD Model	49	Weber, C.	2005	CPM/ PDD - An extended theoretical approach to modeling products and product development processes
Graph Theory	47	Milo, R.; et al.	2002	Network motifs: simple building blocks of complex networks
Theory of Bounded Rationality	45	Simon, H.	1956	Rational choice and the structure of the environment
Core Competency Theory	44	Cooper, R.	1998	New Product Development
Theory of Case-Based Reasoning	43	Romli, A.; et al.	2015	Eco-case based reasoning (Eco-CBR) for supporting sustainable product design
Theory of Economic Development	40		2007	The Assessment of Higher Education Learning Outcomes.
Theory of Technical Systems	39	Hubka, V.; Eder, W.	1988	Theory of Technical Systems

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Theory of Shared Mental Models	34	Mumford, M.; Jack, M.; Feldman, M.; Hein, D.; Nagao	2001	Tradeoffs between Ideas and Structure: Individual versus Group Performance in Creative Problem Solving
Theory of Abduction	34	Dorst, K.	2011	The core of 'design thinking' and its application
Semiotic Theory	34	Stamper, R.	1996	Signs, Norms, and Information Systems
Social Network Theory	33	Gross, J.; Yellen, J.	2005	Graph Theory and its Applications
Set Theory	30	Zadeh, L.	1965	Fuzzy sets
Decision Theory	30	Bell, D.; Raiffa, H.; Tversky, A.	1988	Decision making: Descriptive, normative, and prescriptive interactions

The overview of referenced theories presented in Table 1 is considered a valuable resource for design researchers. We argue that it will help them to identify relevant theories and the respective references for their own papers. In conclusion, the results presented in this paper provide a holistic overview of which theories are relevant to the discipline. The resulting landscape of design theory use is considered a first step towards a better understanding of the role of theory in design.

6.2. Novel approach: Incorporating NLP for bibliometric analyses

As a second contribution of this paper, we present a novel approach for qualitative bibliometric analyses based on ontology engineering and natural language processing (NLP). We argue that this approach can save the researchers a significant amount of time when conducting bibliometric analyses. As reported by Cash (2020), his bibliometric analysis has taken him 30 minutes per paper for reading and coding it manually, limited to 10 papers per day. This procedure would have resulted in approximately 742 hours, spread over 445 days, for manually analyzing the 4,451 papers in our corpus. Instead, the automated analysis took us only a few days. The main effort invested in this paper was dedicated to developing the ontology, which could be used for future analyses on different papers. In future work, we intend to make the ontology available to other researchers. We would like to emphasize, though, that the automated bibliometric analysis does not replace the part of the logical and intellectual interpretation of the results, which still needs to be conducted manually by the researchers.

6.3. Limitations and future work

Further limitations apply to this study: Even if the automated bibliometric analysis can save much time, it might also be less reliable. We cannot guarantee that the ontology contains all theories that exist. Our NLP approach might not have been able to detect theories that were not named as one of our listed theories in the ontology. We were faced with the choice if a central construct should be added as a synonym of the theory or not. If there was a construct that could indicate the use of the theory, we added it as a synonym. If a construct name could be part of multiple theories or is also used without the theoretical meaning, we did not add it as a synonym. There might be cases where the used theory is not explicitly named and was not detected through our part-of-speech pattern. However, as reported by Mueller et al. (2022), the inter-rater reliability of manual and automated entity analysis is relatively robust. Our pipeline does not recognize if a theory is only mentioned but not used in the paper. Future work should include a classification step that detects if a sentence or paragraph is talking about the focal paper or only about related work. Another limitation is our narrow corpus. We included only papers from the two major design conferences in our sample. Future work will have to expand this corpus toward journal publications to investigate differences in theory use between conference and journal publications. Future work will also include (1) further analyses and comparisons with design-related journal publications and (2) creating a digital dashboard in which the entire data set and more detailed analyses are available for interested readers. Moreover, we intend to make the ontology available to other researchers in the future. (3) In this paper, we analyzed the corpus based on text similarities. In future work, we will explore other forms of automated analyses, for example, through inter-theory-networks (Mueller, 2015).

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7. Conclusions

In this paper, we present selected bibliometric analyses conducted on the corpus of 4,451 papers from ICED and DESIGN conferences between 2010 and 2023. The qualitative analyses were facilitated through ontology engineering and natural language processing, which resulted in a significant time saving compared to manual coding. The results yielded some rich insights into the role and usage of theory in the design discipline, specifically in relation to theories from other disciplines. Due to page limitations, we present only selected excerpts from our analyses in this paper. In summary, we argue that the contribution of this paper is twofold: First, we present a rich overview of selected analyses of theory use in the design field, and second, we introduce a novel method for bibliometric analyses. Both contributions might be useful for design researchers interested in exploring the role of theory to advance the design discipline further.

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