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DoCS4Design

Doctoral Courses System for Design

DoCS4Design Keywords Analysis: First Iteration (O3/4)

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Erasmus+ project DoCS4Design (Doctoral Courses System for Design).

A paper based on part of this report has been as Mattioli, Figoli, & Stappers (2023), Connecting the PhD in Design: How PhDs Label Their Thesis Research. LearnXDesign Conference 2023. Design Research Society.

The analysis of keywords also formed the basis for the descriptor fields and word clouds in the Vignette tool.

The dataset of PhD theses and keywords has been published as open data on Zenodo: www.doi.org/10.5281/zenodo.10548837.

Citation:

Stappers, P.J., Figoli, F.A., & Mattioli, F. (2023). D4D Keywords Analysis: First Iteration. Project Report. DoCS4Design project. Available at http://DoCS4Design.eu

8 Dec 2023

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Introduction

In the DoCS4Design project, we collected PhD theses from the past ten years at the six partner schools. The purpose of the collection was to seed the WunderLibrary, an inspirational database for the PhD in Design. A promising benefit is that the collection can shed light on the themes of PhD research at our institutes and how its authors described it through keywords. Next to the listed keywords, titles and abstracts were also available for the 352 theses. In this document, we review the collection toward the following themes:

1. about the research themes at the partner schools:
    a. *which themes are prominent?*
    b. *which are particular to only one school?*
    c. *which link between two different schools?*
    d. *(how) did the keywords develop over the years?*

2. about the thesis authors' interests as expressed in their choice of keywords:
    a. *besides the content topic, which aspects are mentioned (e.g., method, types of design, societal impact)?*

3. about the value of listed keywords versus analysing free text (titles and abstract):
    a. *can automated scraping of the theses provide more meaningful links between works?*

4. about the relationship between keywords:
    a. *which combinations of curated keywords are listed multiple times?*

Question(s) 1 is connected to the data we collected about the partner's research themes. That exercise provided a great variety of ways in which the research themes at the partners' institutes are described (e.g., from the expertise of chairs, research agendas, and funding constraints); the promise of the analysis is to find a common language that connects across the schools, highlighting complementary strengths and opportunities for cross-fertilisation (for future PhD).

Question 2 may express the size of a niche or pool in which certain projects fit but especially indicate the aspects for which PhD students might want to engage with peers (for instance because they work in a similar societal sector or with the same methods, or with methods that a student is considering).

Question 3 is related to the WunderLibrary. Access to the current collection of theses is curated (which requires considerable effort), e.g., to harmonise the ways in which keywords are chosen, and spelt (American versus English spelling, singular versus plural), but also it appears that the listed keywords are usually 'invented on the spot' by the author, not guided by a system. If automated analysis of the (lead) texts can show connections, that would enable the WunderLibrary to suggest connections between new works automatically.

Question 4 was done for the WunderLibrary keyword network.

Method

Basic data of PhD theses from the schools in the years 2012-2022 were compiled. For each thesis, location data (school, author, year of publication), library data (DOI reference, URL), and content data (listed keywords, title, abstract) were gathered. Note that the numbers vary substantially from half a dozen at IIT and CMU to well over a hundred at Polimi and Delft. The latter schools are likely to appear more in quantitative analysis.

Tab.1: Number of 352 theses collected from the six schools

Number	Color	Institution
48		Aalto University
7		Carnegie Mellon University
6		Illinois Institute of Technology
20		Imperial College London
129		Politecnico di Milano
142		TU Delft
352		All institutions

Patching

Several patches were needed to fix omissions in the dataset. It was noted that keyword information was not complete and that different school libraries used different ways to gather keywords (probably keywords were optional and left to the discretion of the author, not following a system). For example, where listed keywords were missing, a representative from the school was asked to suggest a set of keywords (usually from the title and abstract or inspection of the content). Also, although all schools offer their PhD theses through online repositories, the way they are structured differs from place to place, e.g., in a university-wide repository where the word 'design' yields results from many disciplines. All keywords supplied were in English.

Curating

Starting from this initial dataset, the authors started a qualitative keyword curation process consisting of three main steps of check:

1. **spelling check** comprises correcting typos and spelling mistakes, deleting not-English words, deleting punctuation, writing the acronyms in their extended form;
2. **representativeness check** comprises deleting or modifying too specific keywords and unrepresentative ones for design (e.g., name of cities, Countries, companies), deleting too generic keywords (i.e., designers, designing, design);
3. **consistency check** comprises splitting too long keywords into representative ones, checking the consistency of keywords, and ensuring that the variations of the keyword were included (i.e., plural-singular, acronyms-extended, synonyms, UK-US spelling).

Then, two of the researchers grouped the provided keywords into a first clustering, which reduced the number of keywords from 1432 to 774 clusters represented by a 'curated keyword' (named level-3 below because two merged cluster levels were constructed). The reduced number of keywords is considered the basic description level for further analysis. Examples of level-3 clusters (highlighted celeste bolded font) of level-4 raw keywords can be found in Tab.2, where they are also counted based on how many times authors have used each keyword for labelling the thesis in the repositories of their institution. Note that some level-4 keywords (e.g. accelerometers,

accessories, action tendency) score a counting equal to zero: this is because they were added during the curation process (e.g., plural or singular version of a keyword).

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Tab.2: examples of level-3 clusters (highlighted in celeste) of level-4 raw keywords; the numbers indicate how often authors have used each keyword for labelling the thesis in the repositories of their institution

Keywords	Nr.
3d compression	**1**
3d compression	1
accelerometer	**1**
accelerometer	1
accelerometers	0
accessibility	**9**
accessibility	4
design for all	2
design for disability	1
inclusive design	1
universal design	1
accessories	**1**
accessories	0
accessory	1
accomodation	**3**
temporary accommodation	1
temporary living	2
action research	**3**
action research	3
action tendencies	**1**
action tendencies	1
action tendency	0
active packaging	**1**
active packaging	1
activity theory	**1**
activity theory	1
actor-network theory	**1**
actor-network theory	1
adaptation	**1**
adaptation	1
adaptive mediations	**1**
adaptive mediation	1
adaptive mediations	0
advanced design	**1**
advanced design	1
aesthetics	**6**
aesthetics	3
beauty	2
digital aesthetic	1
affecting attitudes	**1**
affecting attitude	0
affecting attitudes	1

Keywords	Nr.
digital modeling and fabrication	**30**
3d modeling	0
3d modelling	1
3d printing	5
3d scanning	1
additive manufacture	1
additive manufacturing	6
advanced fabrication	1
cnc	0
cnc technology	1
computational modeling	0
computational modelling	1
digital fabrication	3
digital manufacturing	1
direct digital manufacturing	1
distributed manufacturing	1
distributed production	1
electrochemical additive manufacturing	1
generative modeling	1
generative modelling	0
laser cutting	1
numerical control technology	0
reverse modeling	1
reverse modelling	0
selective laser melting	1
slm	1
digital storytelling	**1**
digital storytelling	1
digital surrogates	**1**
digital surrogate	0
digital surrogates	1
digital technologies	**4**
digital technologies	4
digital technology	0
digital transformation	**4**
digital transition	1
digitalisation	1
digitalization	1
digitised collection	1
digitised collections	0

Analysis

One other researcher further grouped the clusters into superclusters (level-2) and hyperclusters (level-1). This action was only performed for keywords that were used more than once and at more than one school.

Tab.3: overview of the number of different keywords per level and the median size of each keyword group

Level	Number	Keyword level	Made by	Purpose/source
1	14	hyperclusters	interpreted by Stappers	for this analysis
2	50	superclusters	interpreted by Stappers	for this analysis
3	774	curated clusters	curated by Mattioli and Figoli	for WunderLibrary
4	1432	raw keywords	patched by Mattioli, Figoli, Stappers school contacts, thesis authors	from thesis repositories

Tab.4 illustrates the clustering and analysis for the topic of 'fashion'. Twenty times an author listed one of the 16 level-4 keywords; these 16 were grouped into three level-3 keywords 'fashion', 'fashion design, and 'fashion system'. These in turn were clustered into two level-1 and level-2 clusters as 'types of design - by outcome' and 'object - results'. Three schools contributed to the topic. The keyword 'fashion design' was also found 7 times in the text and titles of the theses, and the word 'design' 18 times more. On the right-hand columns, it can be which authors, e.g., author 4, listed what keywords (4) or had the word in the text (-4).

Caveat: limitations of the data and analysis

It should be noted that the analysis is exploratory and tentative. The quality of the data is uneven for many reasons.

1. The 'original' level-4 listed keywords may have been awkwardly chosen by the authors, without a particular system, often with little or no (library) guidance.

2. The higher level clusters (level-1 and level-2) were a 'rough' guess by a single researcher on the basis of a guess to the meaning of the level-3 keywords. No after-checks to the content were made, but the curating researchers indicated that they saw more links between the clusters instead of a single, hierarchical grouping at level-1 and level-2. For the WunderLibrary, this strengthens the assumption that the information structure should be a network. For the questions listed in the introduction, we should take the level-1 and level-2 keywords with a pinch of salt.

In the current formulation, the 'labels' at level-1 and level-2 should not be taken per definition, they are shorthands for the clusters below them as on a wall with post-its, and as short words may be misunderstood, e.g. level-1 'quality' is a label that covers 'perceptual qualities' such as sound, vision, but also cognition and emotion (see Tab.5).

Tab.4: example of the keyword structure (columns after 'au5' are not shown)

schools	authors	texthits	level-1	level-2	level-3	level-4	aalto	CMU	IIT	Imperial	Polimi	Delft
3	4	18	types of design	byoutcome	fashion	fashion	1	0	0	0	2	1
2	3	7	types of design	byoutcome	fashion design	fashion design	1	0	0	0	2	0
1	2	2	types of design	byoutcome	fashion design	fashion designer	2	0	0	0	0	0
1	1	1	types of design	byoutcome	fashion design	accessory design	0	0	0	0	1	0
1	1	1	types of design	byoutcome	fashion design	fashiontech	0	0	0	0	1	0
1	1	1	types of design	byoutcome	fashion design	clothing design	1	0	0	0	0	0
1	1	1	types of design	byoutcome	fashion design	dressmaking	1	0	0	0	0	0
1	1	1	types of design	byoutcome	fashion design	fashion design profession	1	0	0	0	0	0
1	1	0	types of design	byoutcome	fashion design	fashion design education	0	0	0	0	1	0
1	1	0	types of design	byoutcome	fashion design	knitwear design	0	0	0	0	1	0
1	1	0	types of design	byoutcome	fashion design	fashion design practice	1	0	0	0	0	0
0	0	4	types of design	byoutcome	fashion design	fashion designers	0	0	0	0	0	0
1	1	3	object	results	fashion system	fashion system	0	0	0	0	1	0
1	1	1	object	results	fashion system	knitwear industry	0	0	0	0	1	0
1	1	0	object	results	fashion system	fashion detail sector	0	0	0	0	1	0
0	0	5	object	results	fashion system	fashion industry	0	0	0	0	0	0
17	20	45	16	16	16	16	8	0	0	0	11	1

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Results

The collection resulted in two main files: a spreadsheet containing, for each of the 532 theses, the author, year, institution, title, abstract, listed keywords, DOI link, and a curated clustering of the 1432 level-4 keywords into 774 level-3 keywords. Many keywords (7XX) were only used by a single author. Of the remaining 7XX, many (2XX) were only used at a single school. Although these keywords can help find the work in a query, their value falls when exposing patterns or connecting authors and schools since it would require deeper interpretation. Therefore, in the level-1 and level-2 clusterings, these keywords were set aside in the 'onlyatoneschool' category (e.g., see Tab.5, first data row); there was also a category 'dunno' where the meaning of the level-3 clustering wasn't immediately obvious. Tab.5 lists the keyword clusters at the final clustering. In each of the clusters, authors from most of the schools can be found.

Tab.5: the level-1 keywords.

schools	authors	Keyword(1)	aalto	CMU	IIT	Imperial	Polimi	Delft	Interpretation of the label
6	232	*onlyatoneschool*	32	6	5	15	101	73	
6	179	types of design	29	4	3	9	82	52	e.g., service design, product design
6	162	method	25	5	4	8	63	57	e.g., research methods used, e.g. interviews, research through design
6	118	values	18	2	1	1	37	59	e.g., sustainability, human-centered
6	83	quality	11	1	3	1	29	38	e.g., human perceptual, emotional, social qualities
6	39	technology	2	1	1	2	15	18	e.g., 3D printing
5	92	object	11	0	1	6	38	36	e.g., chairs, toilets, cars
5	89	context	15	3	0	4	33	34	e.g., hospitals, sectors
5	30	design	8	2	1	0	10	9	e.g., ideation, marketing
5	30	theory	2	0	2	1	14	11	e.g., specific disciplines, e.g., psychology, mathematics
3	24	people	6	0	0	0	8	10	e.g., children, nurses

3	10	activity	0	1	0	0	6	3	e.g., cycling, eating

Appendix A lists the 'most broadly and frequently used keywords' for each of the levels 2 and level-3. There the number of entries is so large that the table is cut off only to show words used in more than one school.

Some of the more populated clusters show a substructure. Two interesting level-1 keywords are shown in Fig.6 and Fig.7 below. These show how the level-1 keyword maps to several level-2 clusters, which in turn map to several level-3 keywords (not shown here). The coloured disks show individual authors, the colour of the disk identifies their school. Some authors use two or three of these level-1 keywords, and for each keyword, several schools are present. Fig. 8 unpacks the level-1 keyword 'quality' into the level-3 curated keywords, showing a range of user experience qualities linked in a network. The lower half shows that many of the level-3 keywords are not connected by shared authors. Fig.9 shows how various 'types of design' are related between the schools.

One quick observation is that at the aggregated level-1 and level-2 we don't see big separations of the schools, and at the curated and raw keyword level-3 and level-4 the numbers of authors per keywords are not very large, so people use different words.

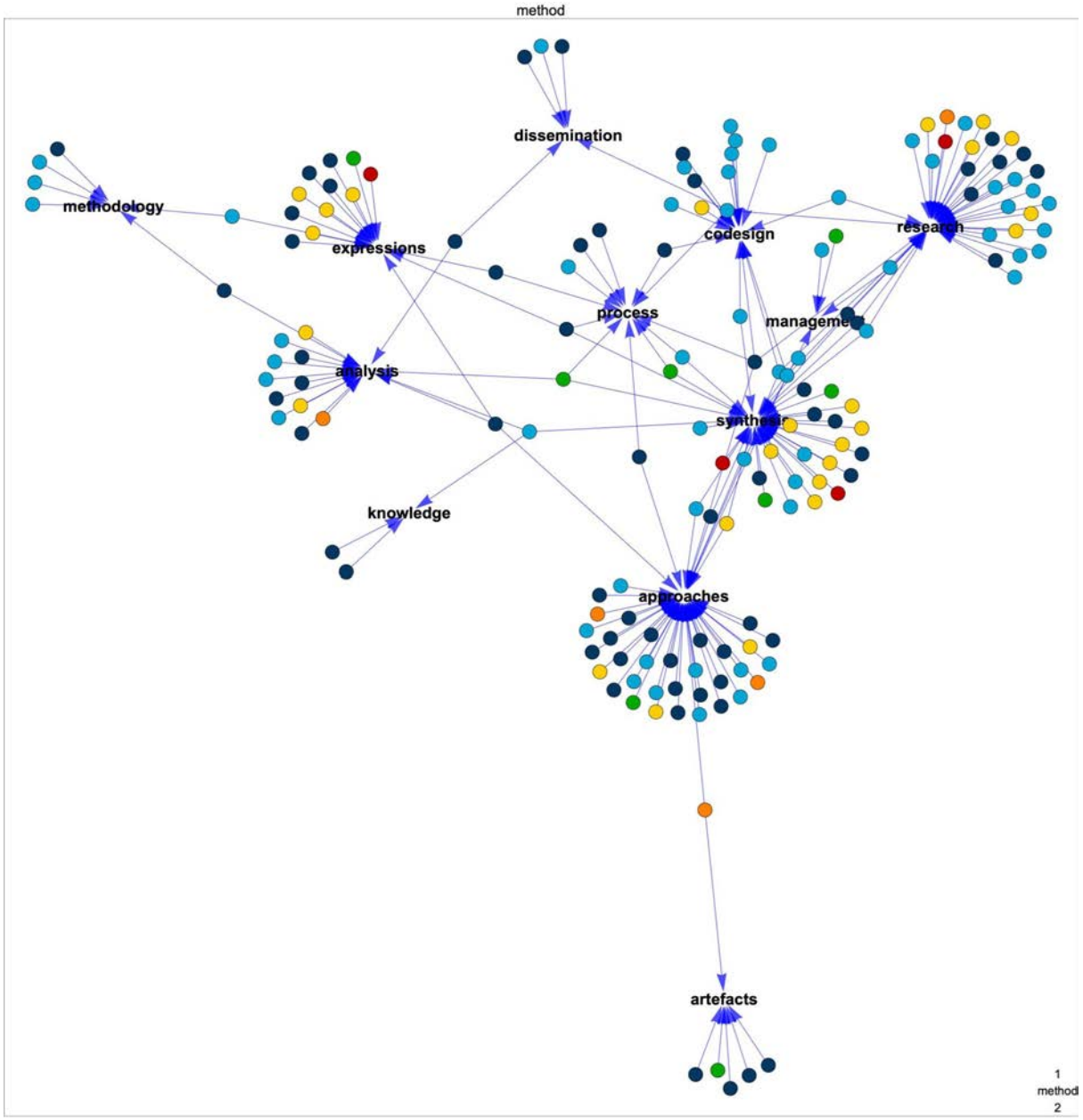

Fig.6: level-1 keyword 'method' contains twelve level-2 keyword clusters.

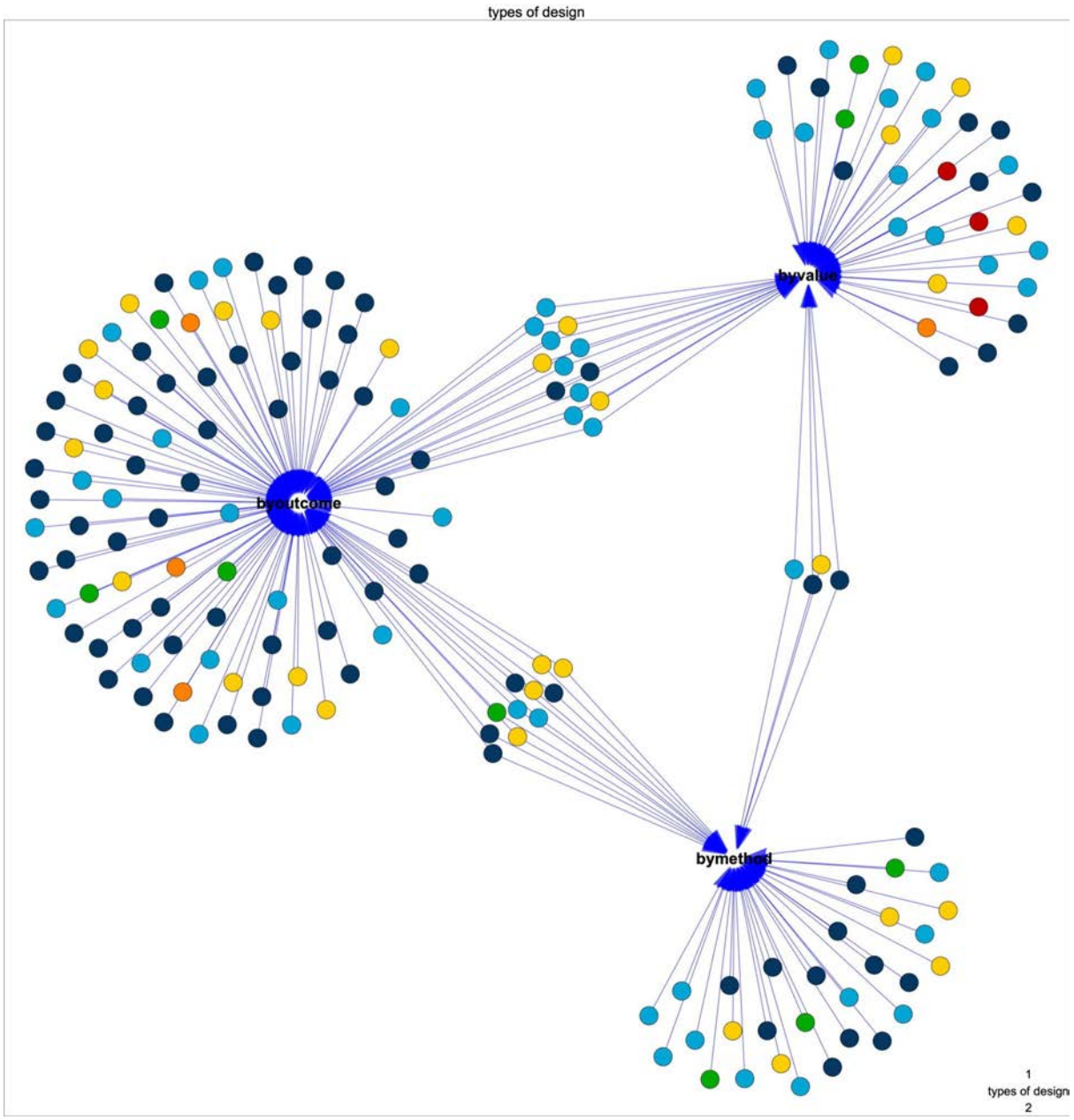

Fig.7: level-1 keyword 'types of design' contains three level-2 keyword clusters 'byoutcome', 'bymethod', 'byvalue'.

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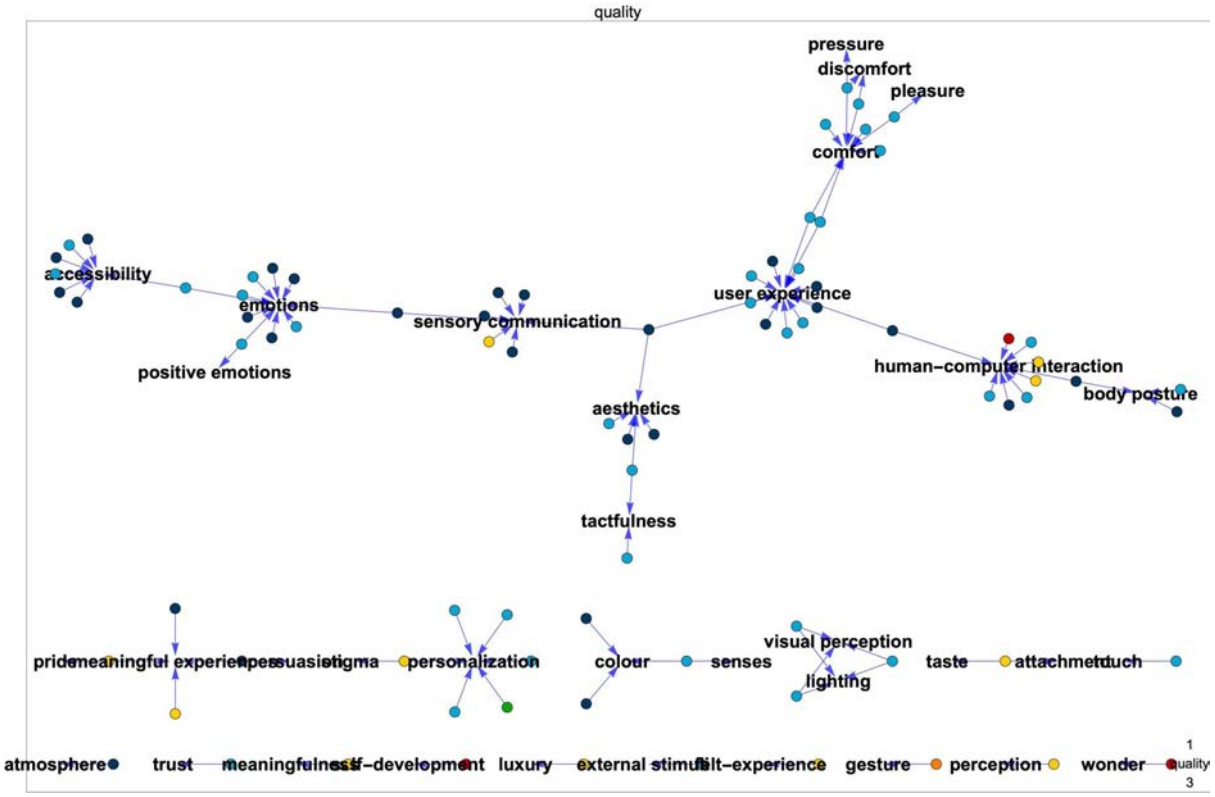


Fig.8: level-1 keyword 'quality' unpacked to level-3 keywords. Note that the overlapping rows of keywords at the bottom of the figure indicate various keywords which one or two authors only use.

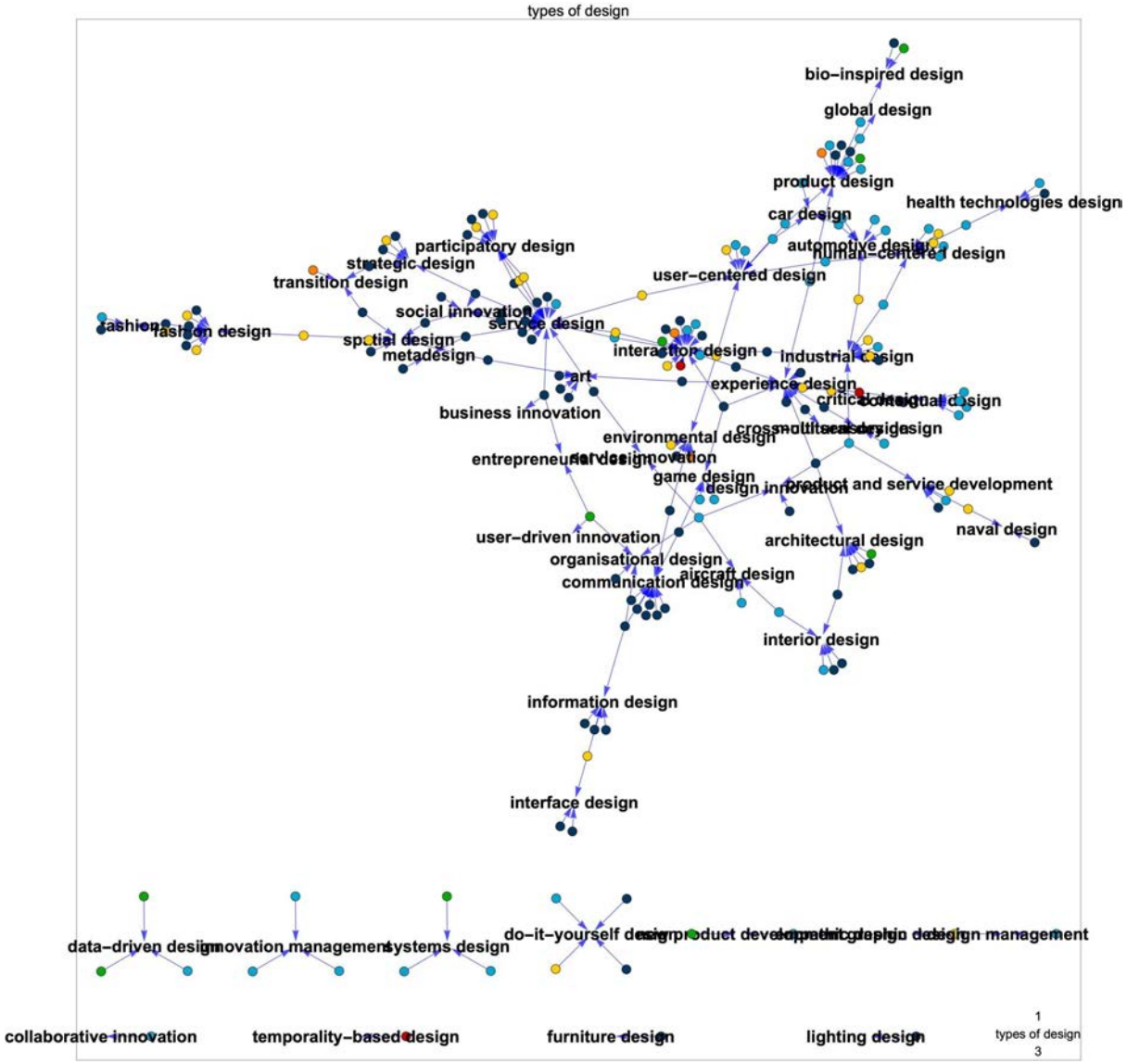


Fig. 9: level-1 keyword 'types of design' unpacked to level-3 keywords.

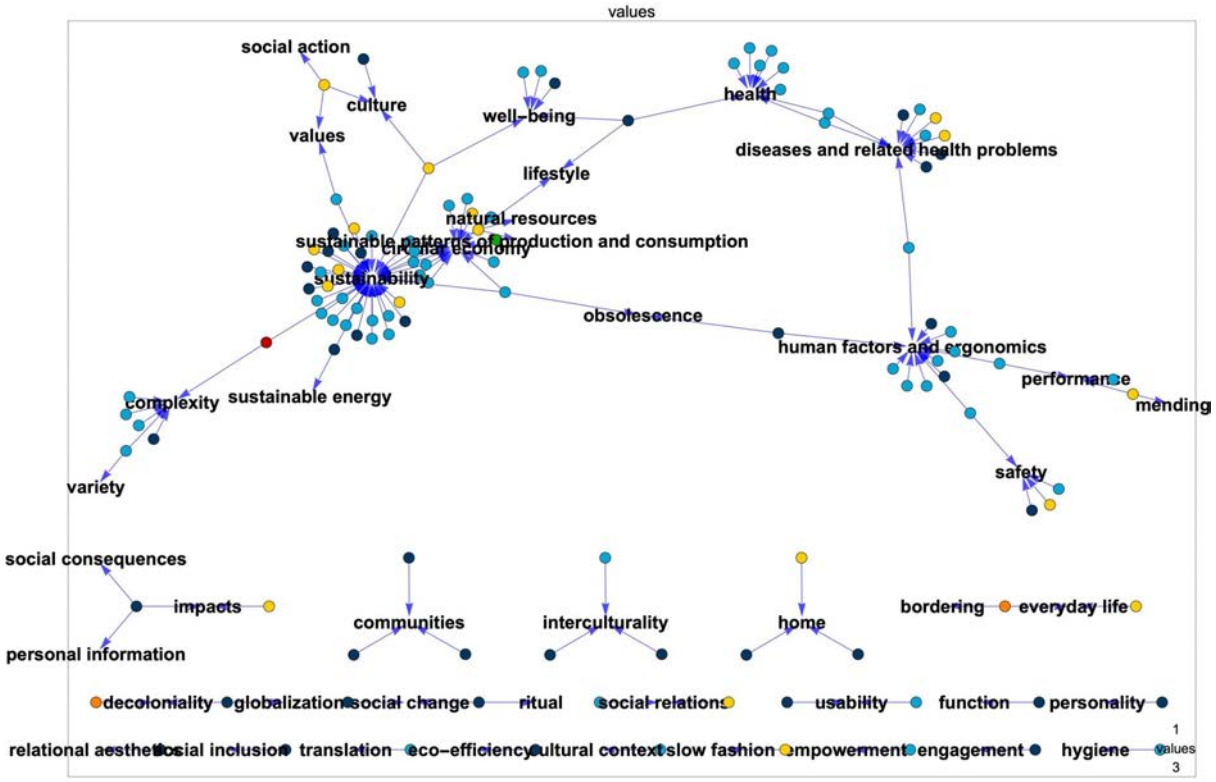


Fig.10: level-1 keyword 'values' unpacked to level-3 keywords.

Shared keywords within each school

Fig.11 shows how authors at each school 'hang together' by having the same keywords at level-3 (that does not mean they chose exactly the same words at level-4). The graphs show clusters of linked activity, especially at Politecnico and Delft; this is partly due to the larger number of authors at those schools but also because authors work closely together. <specific for those thick lines>

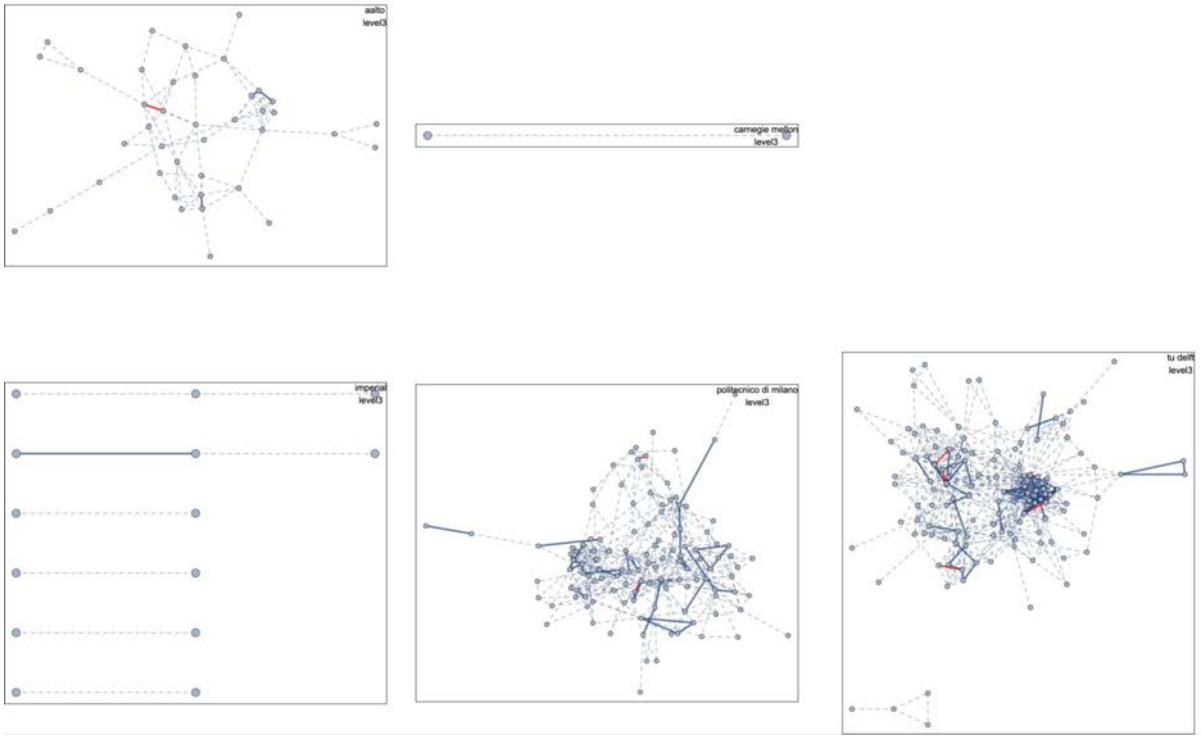


Fig.11: shared keyword structure at each school. The nodes represent authors, the links indicate shared keywords. Authors who do not share a keyword with another author in the school are not shown (hence, only two at CMU, none at IIT). Two authors sharing keywords are shown as thick blue lines. More than 5 shared keywords as thick red lines.

Keywords appearing over time

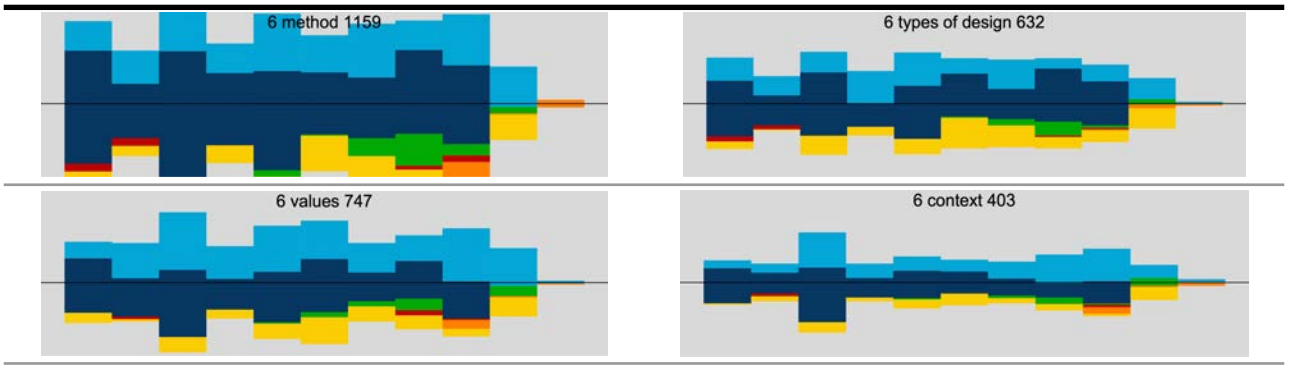
Each thesis came with a year of publication, which allows us to look at how often a keyword is used over the years. The graphs in Tab.12 depict the use of some level-1 and level-3 keywords overtime at the 6 schools.

First observations

The level-1 keywords have many more entries (because they bundle several level-3 keywords) and generally fluctuate between even and odd years. This probably is due to the fluctuating number of students, not to a fluctuation in the topics (see Tab.12). At level-3 we may discern the popularity of topics at some schools, e.g., 'sustainability' and labelling keywords for 'products' may represent both/either a large group of researchers working on the topic, or using a common style for labelling.

Tab.12: examples of level-1 keywords used over the period 2012-2022 (for colours of schools, see table 1). The graph headings 'm' keyword 'n' indicates that keyword cluster was used across 'm' schools in 'n' entries.

Over time 2012-2022



Tab.13: the number of theses per year

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Grand Total
AALTO	4	5	5	3	4	8	5	4	3	7		48
CMU									2	1	4	7
IIT	2	1						1	2			6
IMPERIAL					1	1	4	7	2	5		20
POLIMI	17	10	24	10	16	14	12	14	12			129
TU DEFLT	9	9	16	12	21	12	17	13	19	13	1	142
Grand Total	32	25	45	25	42	35	38	39	40	26	5	352

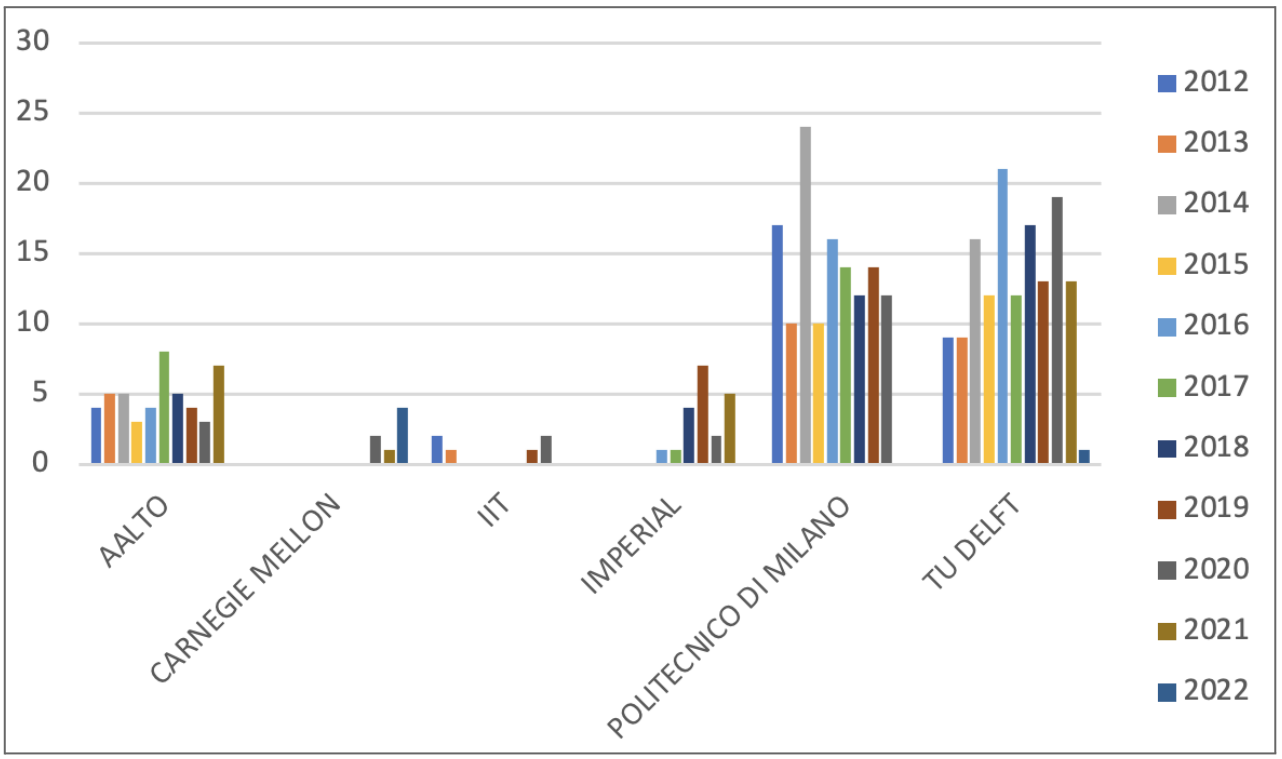
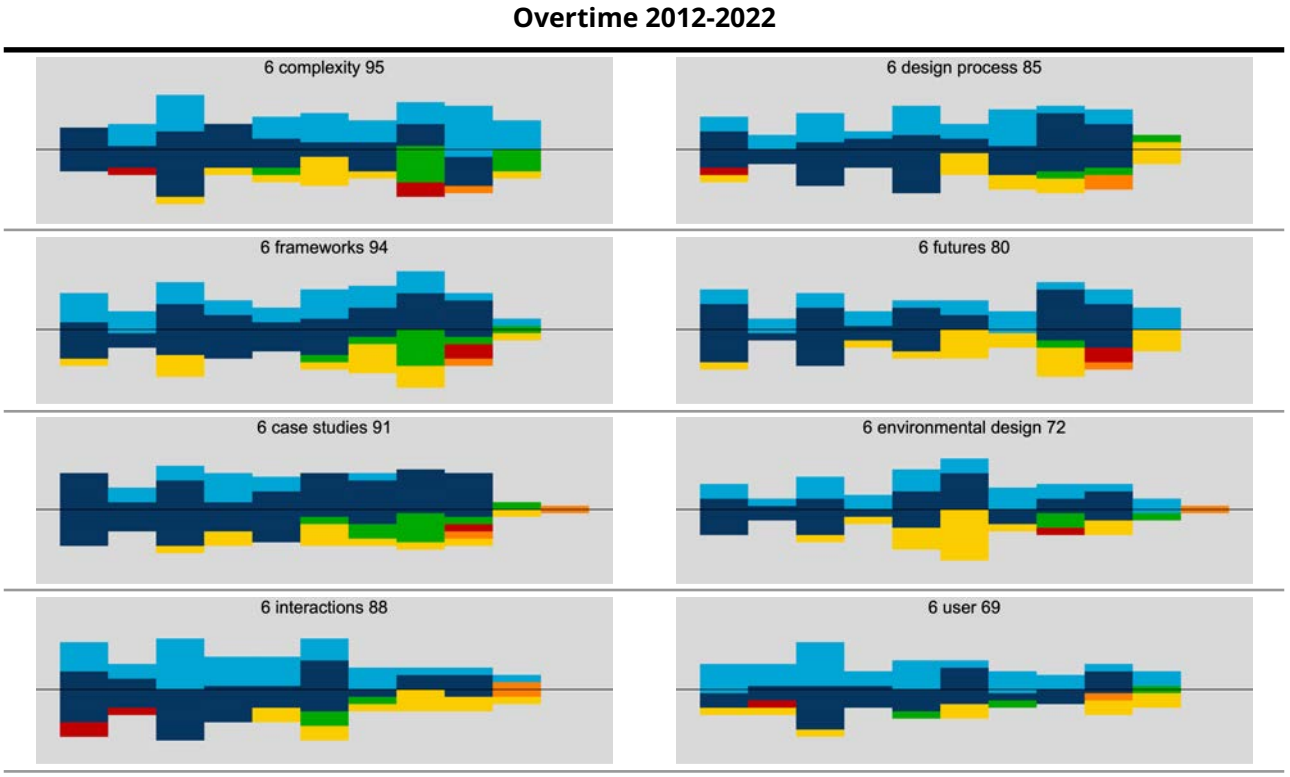


Fig.14: visualisation of the number of theses per year

Tab.15: examples of level-3 keywords used over the period 2012-2022 (for colours of schools, see Tab.1). The graph headings 'm keyword n' indicate that that keyword cluster was used across 'm' schools in 'n' entries.



Discussion

Keywords shared across schools

Popular clusters (level 1)

Tab.5 above had listed how many keywords in each of the level-1 clusters were used at which schools. Most prominent were 'types of design', i.e., 'design labels' such as 'service design', 'design for sustainability', and 'participatory design'. One problem is that these labels do indicate academic design communities but have limited meaning (In 2023 we conducted a small study about the logic

behind these design labels, and published this at dissemination event E2; Stappers, Sleeswijk Visser & van Boeijen, 2023).

Other main clusters refered to research method, context, and implications for design education occur at all schools.

Popular keywords (level-4)

At the lowest level, keywords can still appear in different linguistic level (e.g., the terms 'sustainable' and 'sustainability' appear on separate lines in Tab.17, both under the level-1 cluster of 'sustainability') Most frequently used keywords at level-1. No terms were used at all 6 schools. The most widely used 'interaction design', was mentioned at 5 out of 6 schools, and for a total of 8 times, much less than the runner-up 'sustainability' (Tab.17)). The colours in Fig.16 indicate the number of schools that use each keyword. Clearly words referring to type of design, method, and context, and words referring to outcomes of the project are popular across schools.

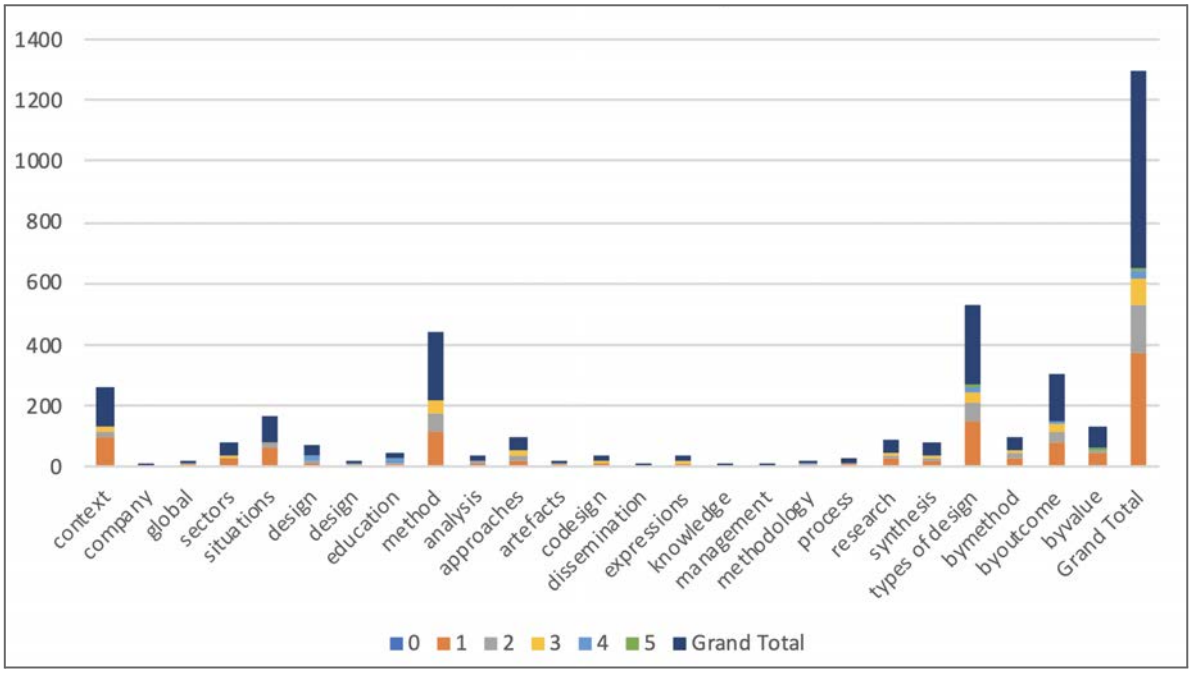


Fig.16: most frequent level-1 clusters and their level-3 terms.

Tab.17: most frequently used level-4 keywords, sorted by the number of schools at which they are used and the number of times they are mentioned

schools	authors	Keyword(1)	Keyword (4)	aalto	CMU	IIT	Imperial	Polimi	Delft
5	8	Interaction design	interaction design	1	1	1	0	4	1
4	25	sustainability	sustainability	4	0	1	0	4	16
4	12	product design	product design	0	1	0	1	3	7
4	12	design education	design education	3	1	0	0	4	4
4	6	creativity	creativity	2	0	0	1	2	1
3	18	service design	service design	4	0	0	0	12	2
3	13	circular economy	circular economy	1	0	0	1	0	11
3	10	innovation	innovation	0	1	0	0	4	5
3	10	sustainability	sustainable	3	0	0	0	3	4
3	9	products	product	0	0	0	1	4	4
3	8	research through design	research through design	1	0	1	0	0	6
3	7	industrial design	industrial design	3	0	0	0	2	2
3	6	design process	design process	0	0	0	1	3	2
3	6	co-design	co-design	1	0	0	0	2	3
3	6	digital modeling and fabrication	additive manufacturing	0	0	0	2	1	3
3	5	architectural design	architecture	1	0	0	1	3	0
3	5	digital modeling and fabrication	3d printing	0	0	0	1	1	3
3	5	human-computer interaction	human-computer interaction	2	0	0	0	1	2
3	4	fashion	fashion	1	0	0	0	2	1
3	4	manufacturing	manufacturing	0	0	0	1	2	1
3	4	machine learning	machine learning	0	1	0	2	0	1
3	3	passengers	passenger	1	0	0	0	1	2
3	3	prototypes	prototyping	1	0	1	0	0	1
3	3	sustainability	sustainable design	1	0	0	0	1	1
3	3	sustainability	design for sustainability	1	0	0	0	1	1
		Design creativity	design creativity	0	0	1	1	0	1

Prominent and unique keywords per school

Appendix B lists the words that are most used per school, and the level-1 clusters in which they belong. The tables 20-25 show that although the schools use different keywords in the main clusters of context, method, design, and types of design, almost all schools address these main clusters. The closing sections of Appendix B list the keywords that were used only at a single school, and whether these words appeared once or more often. Although these lists can be seen to reflect some topics of local interest, further analysis is beyond the scope of this study.

Conclusions

Question 1 - Research interests at and between schools

The aggregated clusterings at level-1 and level-2 in Tab.17 give an idea about which aspects are mentioned at many schools. There are a few keyword clusters that are used at all schools, but not much remarkable appears. Many keywords are only a few times. Quite some curated keywords appear in different spellings which have been curated, but which could also be matched by a bit advanced software, e.g., 'sustainability', 'sustainable design', and 'design for sustainability'.

Question 2 - Keywords expressing interesting aspects

The aggregated clusterings at level-1 and level-2 give an idea about which aspects are mentioned in keywords, and which aspects the authors deem worth mentioning. A bit of value that is brought here is that when we ask someone about an aspect, we can show a set of 'examples filled in by others before you', which may be a way to trigger a student to describe their own research.

The high-level clusterings (and experience at Delft of using vignettes which informally defined descriptors) suggest that it may be valuable to ask authors to indicate where they stand on the following aspects. One challenge is that PhD work often is on new topics which 'are not yet in the established journals or themes', that the design language is not sharply defined on its idiom, and that PhD students may struggle with finding their position.
The current harvest of 'example answers' from level-2 and level-3 can serve as a way to suggest interesting aspects rather than require a heavy, definition-laden classification scheme. See Tab.19 for these aspects and how they can be suggested through examples.

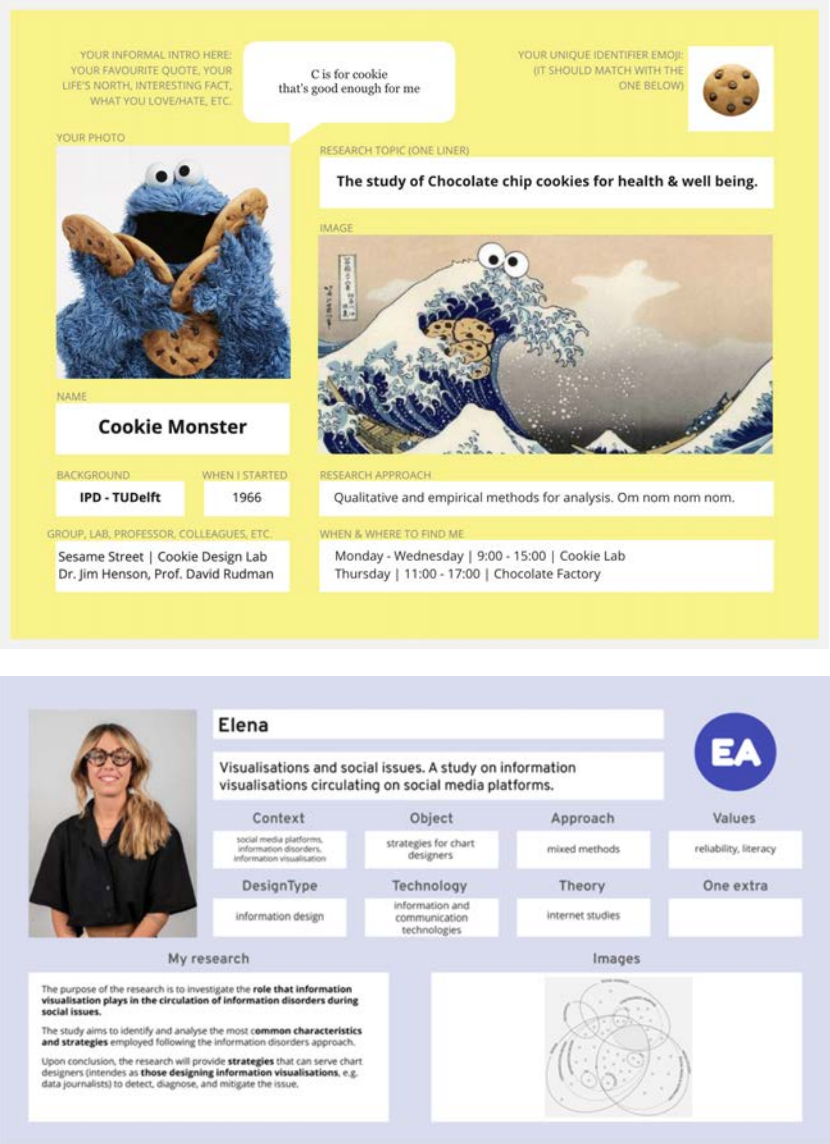
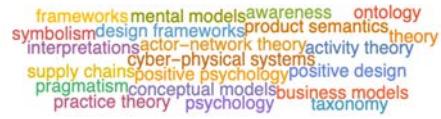


Fig.18: Top: Introduction vignette template (Delft 2021 Research course); bottom: new vignette, using the categories identified in this study (see the DoCS4Design Vignette tool).

Ongoing work: exploring the use of this classification as a means for introducing oneself to peers for current PhD students (not ex post facto as is the case for completed theses).

Tab.19 Descriptors for introductions suggested by keyword themes

Aspect	Suggestive Examples	Why Interesting (to find peers in this aspect)
context, situation, or sector		PhD students working in an application area, often for funded project
research method		PhD students in design (and related fields like architecture) express need for guidance in research methods; design research builds on diverse traditions.
impact, object or effect		Many design research projects often have impact goals, resulting in concrete solution proposals, focused around a product category or a desired impact.
technology		Many design research projects explore or develop emerging technologies or practices.
disciplines or theory besides design		Design research often builds on models and theories from several other disciplines.
related type of design		Many research projects consider particular (emerging) design practices, and participate with or develop methods for those practices.
values, criteria		Some design research often is explicitly human-centered, or technology-oriented.

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Question 3 - Full text versus listed keywords

A preliminary examination reveals an apparent trend. Notably, certain words such as ‘people’, ‘product’, and 'design' frequently appear in the abstracts. Despite their prevalence, these terms seem to lack specificity, often failing to pinpoint distinct qualities or attributes of the theses. Further investigation and a more comprehensive analysis could shed light on the implications of this observation for a more nuanced understanding.

Question 4 - The network of level-3 keywords

Several networks of keywords were created and sent to the WunderLibrary developers to assist in building the platform (Fig.20).

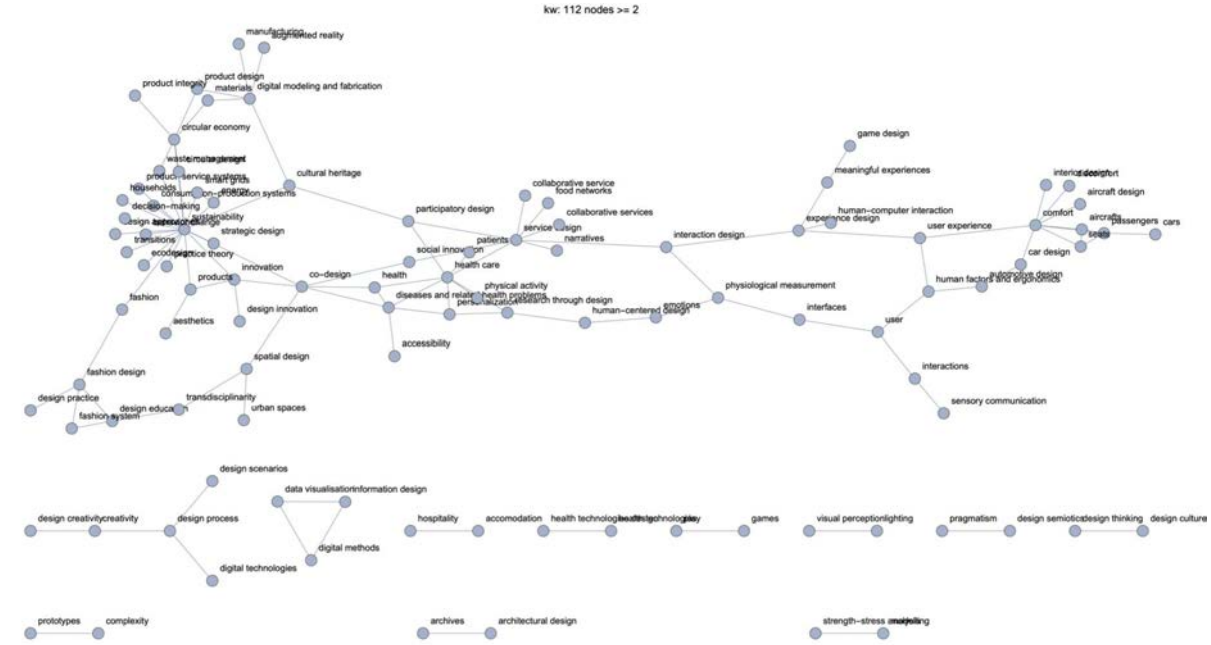

Fig.20: a first glance at the level-3 keyword network

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References

Mattioli, F., Figoli, F.A., & Stappers, P.J. (2023) Connecting the PhD in Design: How PhDs Label Their Thesis Research. *LearnXDesign 2023*. The Design Research Society. 8 pp.

Stappers, P.J., Sleeswijk Visser, F, & van Boeijen, A.G.C. (2023) Design Labels: The words that Divide and Unite Us. 15th International Conference of the European Academy of Design, 19 October, Espoo, Helsinki. P 728-736.

Stappers, P.J. & van Boeijen, A.G.C. (editors, 2022) PhD in Design – A Map & Glossary. Docs4Design project.

Credits

The WunderLibrary's ontology (Keyword analysis) was conducted by Politecnico di Milano and TU Delft.

The report was edited by: Pieter Jan Stappers, Fabio Antonio Figoli and Francesca Mattioli.

All partners contributed to the output:

Aalto University	Elise Hodson, Guy Julier, Michel Nader, Sampsa Hyysalo
Carnegie Mellon University	Jonathan Chapman
Illinois Institute of Technology	Carlos Teixeira
Imperial College London	Rafael Calvo, Weston Baxter
Politecnico di Milano	Annalinda De Rosa, Fabio Figoli,Francesca Mattioli, Lucia Rampino, Paola Bertola
TU Delft	Annemiek van Boeijen, Erika Hajdu, Pieter Jan Stappers, Wilfred van der Vegte

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Appendix A: the datafiles

Outcomes of the analysis are consolidated in an excel file 'd4d keyword analysis.xlsx', with several worksheets:

Readme	description and documentation
Clusters	keywords at level-1 and level-4, authors that use the level-4 keywords in listed-keywords and in the text (abstract, title); counts of at how many schools and by how many authors each keyword is listed or appears in the text
Authors	listing of author/thesis codes, with identifier, school, year of theses
RawData	curated excel file containing data about each thesis
…	two pivot files to summarize tables

Appendix B Unique keywords per school

Most popular keywords at each

The tables list, for each school, which level-3 keywords were listed by how many authors at that school, and at how many schools. The boldface keyword is the level-1 hypercluster. So, for example, at Aalto, the keyword 'design education' is listed by 12 authors at Aalto, and by authors at 4-1=3 other schools; it was grouped in hypercluster 'design', together with the keyword 'design practice' (listed 4 times at Aalto, and at 1 other school).

Tab.20: most popular keywords at AAlto.

AALTO

Row labels	Authors	Schools
Context	**4**	**1**
health care	2	1
transitions	2	1
Design	**16**	**3**
design education	12	4
design practice	4	2
Method	**13**	**2**
conceptual design	2	1
creativity	6	4
making	3	2
practice	2	1
Types of design	**43**	**2**
fashion design	2	1
industrial design	7	3
participatory design	7	2
product and service development	4	2
service design	18	3
user-centered design	5	2
Grand Total	**76**	**2**

Tab.21: most popular keywords at CMU.

CMU

Row labels	Authors	Schools
Context	**5**	**1**
Entrepreneurship	2	2
Gardens	1	1
Modernity	1	1
Urban Farms	1	1
Design	**3**	**3**
Design education	12	4
Design pedagogy	1	1
Method	**17**	**2**
Case studies	2	2
Innovation	11	2
Systems thinking	2	2
Tradition	1	1
Visual mapping	1	1
Types of design	**23**	**3**
Environmental design	2	2
Interaction design	8	5
Product design	12	4
Transition design	1	1
Grand Total	**58**	**2**

Tab.22: most popular keywords at IIT.

IIT

Row labels	Authors	Schools
Design	**1**	**1**
design pedagogy	12	4
Method	**16**	**2**
creativity	1	1
design creativity	3	3
futures	1	1
prototypes	3	3
research through design	8	3
Types of design	**11**	**2**
contextual design	1	1
experience design	1	1
interaction design	8	5
temporality-based design	1	1
Grand Total	**28**	**2**

Tab.23: most popular keywords at Imperial.

IMPERIAL

Row labels	Authors	Schools
Context	**17**	**2**
digital modeling and fabrication	12	2
manufacturing	4	3
Startups	1	1
Method	**28**	**2**
complexity management	1	1
creativity	7	3
data visualisation	1	1
design creativity	3	3
design process	7	2
design scenarios	3	2
evaluation framework	1	1
idea generation	1	1
innovation	1	1
optimisation	1	1
sketching	2	2
Types of design	**30**	**2**
architectural design	5	3
bio-inspired design	2	2
data-driven design	3	2
entrepreneurial design	2	2
interaction design	1	1
new product development	2	2
organisational design	1	1
product design	12	4
systems design	1	1
user-driven innovation	1	1
Grand Total	**75**	**2**

Tab.24: most popular keywords at Polimi.

POLIMI

Row labels	Authors	Schools
Context	**19**	**2**
archives	4	1
cities	3	1
cultural heritage	5	2
digital modeling and fabrication	3	2
Design	**19**	**3**
design culture	3	2
design education	12	4
education	4	2
Method	**52**	**2**
action research	3	2
co-design	6	3
creativity	6	4
crowdsourcing	4	2
data visualisation	4	1
design process	6	3
design scenarios	5	2
design thinking	3	2
innovation	10	3
interdisciplinarity	3	2
representation	2	1
Types of design	**109**	**2**
architectural design	7	2
art	3	1
communication design	8	1
environmental design	2	1
experience design	4	2
fashion	4	3
fashion design	3	2
game design	2	1
industrial design	7	3
information design	4	1
interaction design	8	5

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Row labels	Authors	Schools
interface design	3	2
interior design	5	2
participatory design	5	2
product design	12	4
service design	18	3
social innovation	4	1
spatial design	5	2
strategic design	5	2
Grand Total	**199**	**2**

Tab.25: most popular keywords at TU Delft.

TU DELFT

Row labels	Authors	Schools
Context	**27**	**2**
cultural heritage	5	2
digital modeling and fabrication	11	3
health care	3	2
marketing	2	1
physical activity	2	1
trains	2	1
waste management	2	1
Design	**19**	**3**
design culture	3	2
design education	12	4
education	4	2
Method	**54**	**2**
co-design	11	2
crowdsourcing	4	2
design process	6	3
design strategies	3	2
gamification	3	2
innovation	10	3
methodology	4	2
optimization	3	2
research through design	10	2
Types of design	**74**	**2**
automotive design	4	1
car design	3	1
design innovation	3	2
health technologies design	3	2
human-centered design	5	1
industrial design	7	3
innovation management	3	1
interior design	5	2
product and service development	4	2
product design	12	4
service design	18	3
user-centered design	7	2
Grand Total	**171**	**2**

Unique to a school

The keywords listed in this section are at the 'raw data' level (level-4) and seem to have been used at a single school each. For CMU and IIT, where the number of authors is low, the list includes also the keywords that were used only once. For all other schools, we left that out of the list.

Level-4 Keywords used only at Aalto

Legend: ***bold***=twice, *italic*=once

production, culture, participation, transition, narrative, clothes, material agency, fashion designer, peer production, conceptual design, design and craft research, public health, *technologies, perception, experiments, construction, design practices, consumers, history, furniture, patients, housing, narratives, women, measurement, household, automotive, cars, craft, design strategies, transitions, attachment, meaningfulness, materiality, social relations, activity theory, taste, brands, practice-led research, geography, infrastructuring, health care, theatre, natural resources, graphic design, information systems, shipbuilding, pride, stigma, felt-experience, fab labs, urban housing, design studies, energy studies, dwellings, clothing design, dressmaking, physical disability, social action, mending, slow fashion, scp, science fiction prototypes, diy spaces, environmental design, fashion design profession, placemaking, experience goal, human-centered designers, human-material interaction, assistive products, luxury, significant experiences, haptic experiences, briefing, costume design, costume designer, craftology, data-objects, design consulting, design integration, design presentations, material footprint, elderly care, embodied cognition, emerging technology research, experiential knowledge, felting, health agents, injustice, jewelry, job advertisements, nostalgia, possibility-driven design, professional identity, project-specific learning, reverse salients, sociomaterial, systemic change, theatre history, visual attention, work tool, young adults, footwear industry, handicraft, cruise ship, contemporary craft, living labs, short-term future, design and craft practice, distributed production, design heritage, domestic energy use, health services, fashion design practice, tuberculosis, good life, cultural impacts, participatory planning, service development, experience-focused design, symbolism, alternative hedonism, ceramic practice, costume sketch, crafts-consumer, data physicalization, design recruitment, sufficiency, furniture industry, informal design, plant watering, political history, resource-efficiency, slums, stage costume, textile art, textile artists, artisanal production, passenger ships, self-reflection, hobby craft, cultural product, closed-loop recycling, post-consumer textile waste.*

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Level-4 Keywords used only at CMU

Legend: ***bold***=twice, *italic*=once

tradition, motion, bordering, gis, gesture, design pedagogy, modernity, decolonization, disinformation, public service, sacred, somaesthetics, sustainment, systemic understanding, urban commoning, visual mapping, gardens, transition design, ancient wisdom, design for policy, pluriverse design, public sector innovation, worldmaking, worldview, innovation economics, urban farms.

Leve-4 Keywords used only at IIT

Legend: ***bold***=twice, *italic*=once

infrastructure, futures, conceptual model, subjective experience, temporality, actor-network theory, self-development, interactive systems, contextual-scenario framework, wonder, adaptive mediation, discursive topics, ethnomethodology, flows of resources, smart artifacts, social viscosity, fostering creative cognition, architecture and design pedagogy, distributed complexity, community-based participatory research, equity, feminism.

Level-4 Keywords used only at Imperial

Legend: ***bold***=twice, *italic*=once

products, idea generation, polymers, robots, user-driven innovation, supply chains, big data, combinational creativity, evaluation framework, complexity management, design ideation, circular possessions, data-driven text mining, organisational innovation, contaminated interaction, generative adversarial networks, mass individualisation, agile product design, audio augmented reality, audio rendering, binaural audio techniques, computational creativity, computational morphological analysis, computational tools, concurrent specification, construction sector, deep learning methods, human-in-the-loop, design communication, design information retrieval, feedback control, human-object relationships, infill structures, modular construction, modularisation, open platform, physical adaptations, problem structuring, product planning, psychological ownership, requirements analysis, semantic network analysis, shape memory effect, slip resistance, battery pack lifetime, lithium-ion battery, functional consumer products, robotic hoof, robotic systems, innovation toolkit, data visualisation, creative performance, optimal logistics, multi degrees of freedom, electrochemical

additive manufacturing, technological start-ups, systems engineering, design optimisation, industrialised construction.

Level-4 Keywords used only at Polimi

Legend: ***bold***=twice, *italic*=once

Communication design (8), digital technologies (4), social innovation (4), data visualization (4), art (3), community (3), city (3), environment, play, scenarios, collection, representation, architectural, urban spaces, archives, design framework, temporary living, audience engagement, foresight, hospitality, archive, social change, game design, information visualization, pragmatism, wearable technology, design for all, body posture, collaborative processes, collaborative service, habitat, durability, user experience design, virtual prototyping, information design, community of practice, digital methods, physiological measurement, *framework, future, nature, awareness, engagement, interpretation, design processes, prototypes, behavior, interdisciplinary, interfaces, assessment, interior, function, mapping, impacts, trends, adaptation, university, cultures, interpretations, sensors, textile, exhibitions, collections, mobility, design community, globalization, taxonomy, immersion, questionnaire, stimulus, player, product-service system, storytelling, reuse, navigation, disabilities, new media, haptic, redesign, innovation processes, anticipation, reframing, military, social inclusion, sustainable energy, fiction, meta-design, lighting design, product and service development, interactivity, composite, virtual reality, universal design, atmosphere, makerspaces, advanced design, imagination, accessory design, packaging, urban space, branding, wayfinding, alzheimer's disease, home environment, personal information, personality, relational aesthetics, social consequences, eco-efficiency, communication systems, furniture design, cross-cultural design, human-product interaction, positive psychology, non-pharmacological therapies, design for disability, hci, social network, affective computing, coaching, criticism, cultural learning, gender issues, non-designers, open innovation, social value, textile design, materials, accessory, house, monitoring system, ferry, citizen participation, design challenges, data analysis, living lab, practice-based research, user study, fashion education, digital manufacturing, e-commerce, intangible cultural heritage, intangible heritage, manufacturing processes, public transport, waiting area, healthier, decolonial theory, intercultural city, intercultural studies, ritual, light art, diy-materials, self-production, metadesign framework, participatory tools, business innovation, fashiontech, experimental games, yacht design, organisational design, organizational processes, sd, service value, contemporary living, strategic niche management, spaces of transition, transition management, bid,*

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experience offer, experience prototyping, mobile experience, on-site experience, ontology, theory of practice, wearables, emotional state, persuasion, meaningful experience, digital aesthetic, interactive interfaces, empirical language, sensory language, accelerometer, temporary accommodation, affordance, auction houses, audience-centric, audiovisual storytelling, career counselling service, ccs, history of cartography, co-curation, codified language, communication devices, complementary currency systems, connected objects, controversy mapping, csr, critical pedagogy, cross-disciplinary approach, cultural content aggregator, customer reviews, cyborg, decision aiding, design competitions, design districts, design experience, design milieu, design semiotics, design semiotics research, digital humanities, digital maturity, digital storytelling, divided cities, dynamic products, emotionally durable design, expo village, food crisis, food network, food networks, food supply chain, footwear, form-making qualities, future thinking, home appliances, homing, human performance, illusory space, immersive space, kansei engineering, leadership, media studies, mental workload, mobile technologies, mobile technology, multifunctionality, design museums, narrative process, narrativity, nomadism, non-expert audience, occupation, ornament, process comparison, process visualization, public spaces, quality perception, resilient strategies, service ecosystem perspective, silence, slow motion, smart clothing, smart garment, sociability, social engagement, social enhancement, social media data, limited-edition, tactile display, tactile evaluation, technonature, thermal insulation, third sector organisations, transformation design, transmedia practice, trialectic of spatiality, trust building, urban growth, urban nature, user perception, virtual acoustics, virtual technologies, waiting time, coir fibre, emerging materials experiences, natural resin, abandoned buildings, lapidarium, product characters, smartphones, design analysis, empathic experience, process redesign, trans-disciplinarity, transdisciplinary approach, co-production, alternative narratives, design ethnography, creative design process, load, distributed manufacturing, laser cutting, selective laser melting, slm, digitalisation, digital transition, collaborative housing, cultural geography of travel, digital heritage, sport, urban farming, leftovers, refurbishment, fashion design education, knitwear design, aesthetical obsolescence, contemporary art, decorative and industrial arts, design for participation, communication effectiveness, authorial games, organisational encounter, service prototyping, socially shaped innovation, snm, design for experience, immersive technonatural experience, 3d interaction, multi sensory design, wearable devices, design for emotion, haptics, sensorial perception, sensory communication, sensory perception, fablabs, active packaging, affecting attitudes, affective neuroscience, affective wearables, baby monitoring, behavioural problems, boundary objects, bim, cognitive impairment, collaborative teaching, corpus, coworking, cross-cultural education, crossmodal correspondences, crowdfunding, internationalization of the curriculum, internationalized curriculum, daily rituals, data-activism, design

activism, design awards, design contests, design prize, design trophy, design for therapies, design for transforming, design-oriented heritage activation, design weeks, digital city, digitally enhanced people, digital surrogates, direct visualization, distributed renewable energies, older adults, emotional design, entrepreneurial opportunities, exhibition design process, socio-technical experiment, fundraising, game studies, healthcare design, herbarium bestiaries, hotel design, image analysis, industrial cinema, knowledge design, location based technologies, material culture, media activism, media design, migrations, motion-capture, multi-criteria analysis, nonverbal communication, olympic village, open access, ornaments, perishability, physiological data analysis, play design, political design, politics of knowledge, private and public spaces, radical design, reflective practice, ritual affordance, satisfactory consumption, saving resources, scenario-based design, self-assessment manikin, social density, socially engaged art, social museology, subaltern knowledge, subjective maps, suburbs, tinkering, urban dynamics, experiential qualities of materials, expressive-sensorial characterization of materials, material behaviours, materials selection, fashion system, product's architecture, metallic products, self reflection, indie innovation, problem driven approach, comaking, mobile narratives, front-end of innovation, group decision, human decision making, 3d compression, education in fashion, advanced fabrication, cnc technology, direct digital manufacturing, generative modeling, reverse modeling, digitised collection, cohousing, architecture modern heritage, cultural processes, farmers' markets, transport services and systems, knitwear industry, fashion detail sector.

Level-4 Keywords used only at TU Delft

Legend: ***bold***=twice, *italic*=once

Comfort (8), health (7), codesign (5), behaviour change (5), human-centered design (5), automotive design (4), material perception (3), smart grids (3), ecodesign (3), visual perception (3), lighting (3), innovation management (3), car interior (3), recycling, train, physical activity, marketing, rtd, software, paintings, energy systems, aircraft, stakeholder involvement, product integrity, personalised, discomfort, beauty, mental models, user-centered design, work safety, complex, *young children, workspace design, work context, web-based learning system, indoor fire evacuation application, e-waste, take-back, waste management, weee, virtual learning environments, virtual environments, variety, users, ucd, user centered design, user context research, user characteristics, user identification, trust, translation, touch, toilet, urinal, haste, time pressure, hurry, three-dimensional ultrasound, technological enablers, teamwork, tailoring, tactile, tactfulness, tactful objects, systems-oriented design, systems design approach, systems design, system-level features,*

system-level modeling, system manifestation features, symbolic meaning, sustainability motivation, supplier-customer relationship, strength analysis, stress analysis, software development, socio-cultural dimensions, societal problems, social ties, social networks, social enablers, social design, social connectedness, electronic textiles, smart materials, simulation model, side support, shared understanding, service organisation, sensitive settings, senses, semantics design, semantic inference, self-report emotions, seat, seats, seat design, scalability, sales engineer, robotics, soft robotics, research-through-design, relationship governance, relatedness, rehabilitation, regulated tender environment, refugees, recommender system, rapid ethnography, purchaser, public procurement, psychology, proprioception, product categories, product quality, product lifetime, life cycle assessment, middle-of-life data, product property, product's performance, product appreciation, process research, pressure, pre-embodiment design, practice-oriented design, social practice theory, posture analysis, positive emotions, positive design, pleasure, open-ended play, plants, physical environment, photovoltaics, pipv, pv products, persuasive technology, mass customization, person-centred, personal informatics, task performance, perceptual cues, patient, packaging design, organisational logics, managing obsolescence, observational research, new ventures, multisensory, modeling, non-dimensional modelling, middle class, mental representations, gear design, material properties, critical materials, material integrity, bio-based materials, low-income market, local design and production, lean thinking, intercultural empathy, human interaction, interaction qualities, interactive artefacts, intended users, inspiration process, inspiration sources, innovation champions, innovation ecosystems, innovation networks, innovation systems, industrial work, industrial ecosystems, industrial design engineering, image features, hygiene, human-robot interaction, percentiles, households, white goods designer, heating, tips, total joint arthroplasty, surgery, medical devices and systems, radiotherapy, surgical procedures, surgical simulation, surgical training, orthopaedic surgery, safe vacuum grasping, health psychology, care, ehealth, palpation, e-health, pediatric healthcare, mental health, global design, generation y, gaming, game engine software, design for play, fuzzy front end, future visions, forecasting, finite element analysis, feature technology, fault management, fault diagnosis, failure diagnosis, failure analysis, external stimuli, experience-driven design, energy behavior, energy sector, empowerment, empathic design, emotional granularity, emotion knowledge, emotions in crowds, emotion-driven design, emerging markets, electronics, effectuation, higher education, dynamic context management, dual task, driver monitoring, driver behavior, driver assistance, household energy consumption, diy design, autism, breast disease, deafness, digitalization, 3d modelling, 3d scanning, additive manufacture, computational modelling, digital innovation, didactics, developing countries, design studio, design research methods, design learning, design parameters, design inquiry, design

guidelines, design for development, design for behavior change, design features, design competences, design collaboration, design intervention, design anthropology, design aesthetics, decision-making, decentralized networks, data-enabled design, data analytics, data streams merging, cybernetic design, heritage products, cultural context, crowds, crowd management, crowd experiences, contextual user research, context variation, context information representation, contextual design, consumption-production systems, consumer behavior, consumer evaluations, consumer perception, consumer perceptions, consumer markets, composites, compact gear, collaborative systems, collaborative innovation, cognitive resistance, cognitive enablers, co-located learners, coproduction, clinical breast, circular oriented innovation, circular business, circular business model, circular business models, circular collaboration canvas, circular design, circular product design, childhood cancer, checklist validity, multiple case study, car, bolster, car design, capability approach, business models, business, task related posture, biofidelic, biomimicry, cradle to cradle, nature-inspired design, bending strength, behavioral change, axiomatic theory fusion, automation, augmented reality, augmented prototyping, augmented environments, art history, appearance reproduction, airplane, airline, aircraft interior, airplane design, action tendencies, inclusive design