Northeastern University

20 DRS 24

Design Research Society

PROCEEDINGS OF

DRS2024 BOSTON

RESISTANCE · REFLECTION RECOVERY · REIMAGINATION

DESIGN RESEARCH SOCIETY INTERNATIONAL CONFERENCE
NORTHEASTERN UNIVERSITY
BOSTON, MASSACHUSETTS, USA
23 – 28 JUNE 2024

EDITORS

COLIN M. GRAY ESTEFANIA CILIOTTA CHEHADE PAUL HEKKERT
LAURA FORLANO PAOLO CIUCCARELLI PETER LLOYD

ISSN 2398-3132

Proceedings of DRS2024 Boston

RESISTANCE, RECOVERY, REFLECTION, REIMAGINATION
Design Research Society International Conference

Northeastern University
Boston, Massachusetts, USA,
23–28 June 2024

Editors:
Colin M. Gray
Estefania Ciliotta Chehade
Paul Hekkert
Laura Forlano
Paolo Ciuccarelli
Peter Lloyd

Proceedings of DRS2024 Boston
Design Research Society International Conference
23–28 June 2024
Boston, Massachusetts, USA
www.drs2024.org

Cover and conference identity design by Viviane Kim
Proceedings copy edited and compiled by Lenny Martinez Dominguez

Editors: Colin M. Gray, Estefania Ciliotta Chehade, Paul Hekkert, Laura Forlano, Paolo Ciuccarelli, Peter Lloyd

Proceedings of DRS 2024 International Conference

ISSN 2398-3132
ISBN 978-1-912294-62-6

Published by the Design Research Society
85 Great Portland Street
London, W1W 7LT
United Kingdom

Design Research Society
email: admin@designresearchsociety.org
website: www.designresearchsociety.org
digital library: dl.designresearchsociety.org

Founded in 1966 the Design Research Society (DRS) is a learned society committed to promoting and developing design research. It is the longest established, multi-disciplinary worldwide society for the design research community and aims to promote the study of, and research into, the process of designing in all its many fields.

DRS International Biennial Conference Series

DRS2002 London; DRS2004 Melbourne; DRS2006 Lisbon; DRS2008 Sheffield; DRS2010 Montreal; DRS2012 Bangkok; DRS2014 Umeå, DRS2016 Brighton, DRS2018 Limerick, DRS2020 Brisbane, DRS2022 Bilbao.

DRS Special Interest Groups

Design Education (EdSIG)
Design for Health, Wellbeing and Happiness (SIGWELL)
Design for the Pluriverse (PluriSIG)
Design for Policy and Governance (PoGoSIG)
Inclusive Design (Inclusive SIG)

DRS Special Interest Groups (continued)

Global Health SIG (Global Health SIG)
Designing Change (SIG DfC)
Design for Tangible, Embedded and Networked Technologies (TENT SIG)
Objects, Practices, Experiences, Networks (OPENSIG)
Sustainability SIG (SuSSIG)
Experiential Knowledge (EKSIG)
Design Retail & Services Futures (DRSF SIG)
Design Ethics (DE SIG)
Sound-Driven Design (SDD SIG)
Interdisciplinary Textiles (IT SIG)

DRS2024 Committees

Conference Chairs
Paolo Ciuccarelli, Center for Design, Northeastern University, Boston
Paul Hekkert, TU Delft, NL

Program Chair
Colin M. Gray, Indiana University Bloomington

Content Committee Leads
Paolo Ciuccarelli, Center for Design, Northeastern University, Boston *(Committee Chair)*
Estefania Ciliotta Chehade, Center for Design, Northeastern University, Boston
Colin M. Gray, Indiana University Bloomington

Strategy Committee Leads
Paolo Ciuccarelli, Center for Design, Northeastern University, Boston
Paul Hekkert, TU Delft, NL
Estefania Ciliotta Chehade, Center for Design, Northeastern University, Boston
Annabelle Tocco, Northeastern University, Boston

Strategy Committee
Julie Farkas, Center for Design, Northeastern University, Boston
Laura Forlano, Northeastern University, Boston
Aashita Jain, Center for Design, Northeastern University, Boston
Brittani LeBel Rousseau, Northeastern University, Boston
Sara Lenzi, University of Deusto, ES
Peter Lloyd, TU Delft, NL
Nikita Saner, Center for Design, Northeastern University, Boston

Keynote Event Committee
Laura Forlano, Northeastern University, Boston *(Committee Chair)*
Paolo Ciuccarelli, Center for Design, Northeastern University, Boston
Viviane K. Kim, Northeastern University, Boston
Kristian Kloeckl, Center for Design, Northeastern University, Boston
Michael Arnold Mages, Center for Design, Northeastern University, Boston

Papers Committee
Colin M. Gray, Indiana University Bloomington *(Committee Chair)*
Miso Kim, Center for Design, Northeastern University, Boston
Michael Arnold Mages, Center for Design, Northeastern University, Boston

Conversations Committee
Sofía Bosch Gómez, Northeastern University, Boston
Kees Dorst, University of Technology Sydney, AU
Miso Kim, Center for Design, Northeastern University, Boston
Frederick Van Amstel, University of Florida
Federico Vaz, Royal College of Art, UK

Workshops Committee
Estefania Ciliotta Chehade, Center for Design, Northeastern University, Boston *(Co-Chair)*
Catalina Cortes Loyola, Universidad del Desarrollo (UDD), Chile *(Co-Chair)*
Liz Allen, Northeastern University, Boston
Sara Carr, Associate Professor, School of Architecture, Northeastern University, Boston
Paulina Contreras, Universidad del Desarrollo (UDD), Chile
Miso Kim, Center for Design, Northeastern University, Boston
Alejandra Poblete Perez, Universidad Tecnológica Metropolitana, Chile
Mariluz Soto, Universidad del Desarrollo (UDD), Chile
Ignacio Galvarino Toledo Roman, Universidad del Desarrollo (UDD), Chile

Labs Committee
Estefania Ciliotta Chehade, Center for Design, Northeastern University, Boston *(Co-Chair)*
Sara Lenzi, University of Deusto, ES *(Co-Chair)*
Mark Araujo, The Mayor's Office of New Urban Mechanics (MONUM), Boston
Arlene Oak, University of Alberta, Canada

PhD Event Committee
Ryan Bruggeman, Center for Design, Northeastern University, Boston
Laura Forlano, Northeastern University, Boston
Luis Garcia, Carnegie Mellon University, Pittsburgh
Sofía Bosch Gómez, Northeastern University, Boston
Alayt Issak, Northeastern University, Boston
Michael Arnold Mages, Center for Design, Northeastern University, Boston
Jules Rochielle Sievert, Northeastern University Boston

Performance & Exhibition Committee
Kristian Kloeckl, Center for Design, Northeastern University, Boston
Laura Forlano, Northeastern University, Boston

Fringe Committee
Sofie Hodara, Northeastern University, Boston
Kristian Kloeckl, Center for Design, Northeastern University, Boston
Ann McDonald, Northeastern University, Boston
Anna Nasi, Northeastern University, Boston
Bonnie Parrott, Northeastern University, Boston
Annabelle Tocco, Northeastern University, Boston

Partners
Mark Araujo, The Mayor's Office of New Urban Mechanics (MONUM), Boston
Roi Salgueiro Barrio, Morningside Academy for Design, MIT, Cambridge
Indigo Casais, Museum of Fine Art, Boston
Elizabeth Christoforetti, Graduate School of Design, Harvard, Cambridge
Marion Cunningham, Morningside Academy for Design, MIT, Cambridge
Michelle Fisher, Museum of Fine Art, Boston
Liana Mestas, Design Museum Foundation, Boston
Janessa Mulepati, Master in Design Engineering, Harvard, Cambridge
John A. Ochsendorf, Morningside Academy for Design, MIT, Cambridge
Jennifer Spungin, Morningside Academy for Design, MIT, Cambridge
Maria Villafranca, Design Museum Foundation, Boston

Mapping the evolution of design research: a data-driven analysis of interdisciplinary trends and intellectual landscape

Andrea Vian
Dipartimento Architettura e Design, Università di Genova, Genoa, Italy

Gianluca Carella
Dipartimento di Design, Politecnico di Milano, Milan, Italy

Daniele Pretolesi
AIT - Austrian Institute of Technology, Vienna, Austria

Annalisa Barla
Dipartimento di Informatica, Bioingegneria, Robotica e Ingegneria dei Sistemi, Università di Genova, Genoa, Italy; Machine Learning Genoa Center, Università di Genova, Genoa, Italy

Francesco Zurlo
Dipartimento di Design, Politecnico di Milano, Milan, Italy

Citation

Vian, A., Carella, G., Pretolesi, D., Barla, A., and Zurlo, F. (2024) Mapping the evolution of design research: a data-driven analysis of interdisciplinary trends and intellectual landscape, in Gray, C., Ciliotta Chehade, E., Hekkert, P., Forlano, L., Ciuccarelli, P., Lloyd, P. (eds.), *DRS2024: Boston*, 23–28 June, Boston, USA. https://doi.org/10.21606/drs.2024.1411

Mapping the evolution of design research: A Data-Driven analysis of interdisciplinary trends and intellectual landscape

Andrea Vian[a,*], Gianluca Carella[b,c], Daniele Pretolesi[d], Annalisa Barla[e,f], Francesco Zurlo[b]

[a]Dipartimento Architettura e Design, Università di Genova, Italy
[b]Dipartimento di Design, Politecnico di Milano, Italy
[c]MIT Morningside Academy for Design, Massachusetts Institute of Technology, USA
[d]AIT - Austrian Institute of Technology, Vienna, Austria
[e]Dipartimento di Informatica, Bioingegneria, Robotica e Ingegneria dei Sistemi, Università di Genova, Italy
[f]Machine Learning Genoa Center, Università di Genova, Italy

*Corresponding e-mail: andrea.vian@unige.it

doi.org/10.21606/drs.2024.1411

Abstract: Due to its interdisciplinary nature, research in design, more so than other disciplines, has to develop self-awareness to adapt to the inherent complexity of the contemporary world. This requires the use of big data as comprehensive self-descriptors, along with tools borrowed from the field of Artificial Intelligence (AI) to generate knowledge that researchers in this field can integrate with their own expertise to guide their research activities. We consider a large-scale set of about 170000 design-related scientific publications and leverage natural language processing, machine learning, and data visualization to explore and capture the evolution of the design community. We identify and visualize recurring themes and discussions that helped shape the field. Our findings suggest that research in design is becoming increasingly interdisciplinary and interconnected and that AI-driven approaches can shed light on the future of the discipline and provide valuable insights for researchers and practitioners in the field.

Keywords: Design Evolution; Design Education; Data Visualization; Artificial Intelligence

1. Introduction

Complexity is a growing challenge in our world, from social relations to pandemics to climate change. The most severe and elusive problems that 21st century human society is facing are global problems, characterized by very high rates of complexity and interconnectedness.

This frustrates the efforts of more traditional scientific research, which is still rigidly compartmentalized into monolithic subject areas. In contrast, the most promising contemporary scientific undertakings are characterized not only by substantial interdisciplinarity but also by an imperative multidisciplinary approach that fosters the convergence of diverse expertise and perspectives.

The field of design, which is known for its inherent complexity due to its diverse themes and its connections to various areas of knowledge, is also subject to this phenomenon, especially within the socio-technical realm, even if design can not be defined as an exact science. Cross ("Designerly Ways of Knowing," 2006) argues that design has repeatedly been subjected to attempts at "scientise" design. Many were the contributions to scientize design. Some examples back in history are related to the "design methods movement" of the 1960s, the definition of the "design science revolution" in 1960 (Fuller, 1963) or "the sciences of the artificial" by Herbert Simon (Simon, 2019). However, Cross argues that this transition has never been consolidated, but rather design should be seen as a discipline between science and the humanities.

However, for design to have an impact on complex problems and global challenges, and to contribute more effectively and thoroughly to their resolution, it needs to comprehensively map its scientific collaborations, identify emerging trends, and analyze its operational scope as a whole. In other words, due to its interdisciplinary nature, scientific research in design, more so than other disciplines, must develop self-awareness to make strategic choices for the medium and long term. This requires an approach that relies on the use of big data as comprehensive self-descriptors, along with tools borrowed from the field of Artificial Intelligence to generate knowledge that researchers in this field can integrate with their expertise to guide their research activities.

In this study, we consider a large-scale set of design-related publications drawn from OpenAlex (Priem et al., 2022). OpenAlex is an index of hundreds of millions of interconnected publications across the global research system. Here every publication is linked to one or more keywords that describe the paper's subject matter, according to a predefined and verified hierarchy. Using a set of 67 keywords and the dedicated application programming interface (API), we selected about 169337 unique publications associated with several attributes encompassing the year of publication, authors, type of publication, title, abstract and language. We then leveraged data analysis, natural language processing, machine learning and data visualization to explore the data at hand and capture the evolution of the design community.

Initially, we employ conventional statistical methods to provide an overview of the dataset, encompassing an assessment of the total number of publications produced over the years, the prevalent publication types, and the average number of contributors per publication. Then, we conducted a Semantic Data Exploration, focusing on a temporal-based analysis of recurring keywords or keyphrases. Although this method is straightforward, it allows us to paint a portrait of the field's evolution and the emergence of prominent topics spanning nearly six decades. By creating visual representations of the relationships between these topics, we gain a deeper understanding of how they interconnect and evolve, providing a comprehensive view of the design community's intellectual landscape across different time periods.

To conclude, we applied topic modeling to investigate the interdisciplinary themes within the design community and visualized the progressive increment of interdisciplinarity over time.

2. Evolution and complexity: Design's multifaceted journey through time

Complexity is a qualitative characteristic that permeates many aspects of human life. It is achieved by the organic and structured interaction of different parts, which gives the system unique properties that are not derived from the simple combination of its parts.

According to Donald Norman (Norman, 2016), complexity is the totality of the state of things, the tasks we perform and the tools we use to deal with them. Although complexity may initially seem random and arbitrary, causing frustration in individuals, it is accepted if it is considered necessary because of the phenomena it can activate. That is why it is reasonable to think that complexity in itself is neither good nor bad, but it is the confusion that is problematic. The keys to managing complexity lie in two aspects: the design of things so that they are understandable, and our abilities and skills in managing complexity. Once the structure of complexity is understood, it tends to disappear or become more manageable.

Therefore, it is clear - both on an individual and societal level - that understanding and managing complexity is the challenge of the present and the future. Very often, this complexity confronts us with so-called wicked problems (Buchanan, 1992), defined as problems that are incomplete, multicausal, contradictory, strongly marked by uncertainty and ambiguity, subject to continuous change, highly interconnected and socially intricate. Those are the problems that the exponential evolution of society increasingly presents and that are so difficult to define and solve. They have a multidisciplinary nature that requires the adoption of new means of collecting and systematizing the contributions of various domain experts, which is beneficial to interdisciplinary research (Wilson & Zamberlan, 2015). According to (Dalton et al., 2021), issues that surpass the confines of individual disciplines necessitate collaborative research efforts to address their complexity comprehensively. These challenges, often termed *metaproblems*, demand the integration of diverse expertise and perspectives. By pooling resources and knowledge, these systems strive to create a holistic understanding and effective solutions.

The collaborative approach represents an opportunity to provide scientists, citizens, and stakeholders with the necessary tools to make the positive contribution that our society requires. Moreover, the acceleration of change typical of our time (which brings with it a broadening of the concept of complexity) requires decision-makers and analysts to collect, manage and understand vast amounts of information at an unprecedented pace.

Managing complex phenomena through multidisciplinary collaborations is also something that characterizes scientific research.

Indeed, in the context of research, complexity pushes researchers out of their comfort zones, to seek the expertise of scholars from other fields. This is because multidisciplinary approaches foster greater innovation and a broader view of the scientific questions addressed which, in turn, lead to a significant increase in scientific and interdisciplinary collaboration among researchers (Adams et al., 2005; Huang, 2015; Kuld & O'Hagan, 2018).

These collaborations, on the one hand, bring new ways to tackle complex problems, but on the other hand, create new complexity. They represent an incredibly intricate problem, considering that each discipline has different value systems and sometimes similar but semantically different terms depending on the context (Norman & Stappers, 2015). However, they provide the opportunity to handle new problems and foster the development of new domains.

This is also the case in the discipline of design, which is characterized by an intrinsic complexity in terms of its variety of topics and relations to knowledge domains. Its human-oriented nature requires a profound ability to analyze and master complex phenomena (Norman & Stappers, 2015). Indeed, the contamination between the various design topics is reflected in new relationships and connections between researchers working in different university poles or disciplinary fields. This contamination from the networks of collaborations that are created highlights the concept of diversity and complexity that is increasingly emerging within the design world.

A quote by John Heskett (Heskett, 2005) in his book "Design: A Very Short Introduction", defines the word design as something associated with so many meanings that it becomes almost impossible to disentangle its complexity: "Design [...] as a word is common enough, but it is full of incongruities, has innumerable manifestations, and lacks boundaries that give clarity and definition [....] Design has so many levels of meaning that it is in itself a source of confusion."

It is a relatively new discipline, but its presence is quite old. According to Andrea Branzi's idea (Branzi, 2007) in "Capire il design" ("Understanding Design"), design originated millions of years ago when early hominids began crafting and using stones for hunting or butchering meat. It took extensive talent to make stones sharp enough for hunting weapons. It required the capacity to recognize a need (obtaining food) and transform it into a tool that, after testing, could be utilized by every community member. This story highlights one of the most salient qualities of what we call design today: the ability to turn problems into opportunities through intelligence, which is a key prerogative of human beings (Arquilla, 2022). It started officially as something on par with craftsmanship, then moved on to mass production, and later evolved from mechanical to electrical and electronic products, until it became a driver for constituting new experiences, first physical and then digital. The evolution of design, however, has not only involved new fields of application but also the roles that design has assumed have changed over the years.

Until 2002, design was seen in innovation manuals as a technical task performed by R&D divisions. Nonetheless, it was recognized as a distinct kind of innovation in 2005 by the Oslo Manual (issued by Eurostat and the Organization for Economic Co-operation and Development [OECD]) ("Proposed Guidelines for Collecting and Interpreting Technological Innovation Data," 2005), and it was reclassified as a strategic activity in 2015. If it is true that design has become strategically important and frequently becomes ingrained in an organization's culture, then it's also true that many organizations have addressed design differently, frequently creating custom proprietary methodological frameworks that guide their innovation processes. While many methods have their roots in technology and aim to formalize a design process, they don't always tackle the design challenge from the same angle.

Over time, design has changed and assumed new functions in various situations.Richard Buchanan (Buchanan, 2001) refers to the pluralism of design, which he embodied through four distinct "orders" articulated inside the design history that have synthesized the various historical developments. The four orders show how the design professions have developed throughout time, starting with graphic and industrial design and moving on to interaction design, systems, environments, and organizational design, which is a trademark of the present design movement. Design has undergone several evolutions that have attracted the attention of scholars and practitioners. This attention gave the possibility to study and focus on the different roles and contributions that design can offer (Borja de Mozota, 2006; Brown, 2008; Bruce & Bessant, 2002; Kotler & Alexander Rath, 1984; Verganti, 2008). Design over the years has thus taken on a plurality of functions and viewpoints that make it a complicated discipline even to be defined.

Today, interdisciplinary design is the norm in both academia and industry. Designers are increasingly working on teams with experts from other fields to develop innovative solutions to complex problems. While interdisciplinarity appears as a distinctive trait of design, to our knowledge, no research has been conducted thus far to draw a clear picture of this phenomenon and its influence on scientific production.

This research aims to illuminate the evolutionary trajectory of the design discipline across diverse domains to comprehensively tackle the intricate issues within its purview. In essence, it addresses pivotal queries such as the expanding frontiers of the design realm over time and the focal areas within the design landscape, charting the course of the discipline's interests and focus. To effectively tackle these enquiries, it is imperative to consider a substantial number of design-related publications, in the order of hundreds of thousands. The analysis of such an extensive volume of data can no longer be done manually and instead inevitably requires the use of automated methods and tools, including artificial intelligence (AI) and natural language processing (NLP). The following section elaborates on the methodologies and tools employed to carry out this research study.

3. Methods

3.1 Data collection

The source of the data used in the study is called OpenAlex[1], an open-source catalog with the ambitious goal of collecting the fruits of global research. Not coincidentally, its name refers to the ancient Library of Alexandria in Egypt, a cultural and literary center of the ancient world. It was created to replace a tool from Microsoft called Microsoft Academic Graph (MAG) (Sinha et al., 2015), a heterogeneous graph containing millions of scientific research publications, which was discontinued on December 31, 2021. The scholars behind OpenAlex decided to inherit the models used by Microsoft up to that point to build a free and easily accessible database that is not bound by market interests. The ultimate goal of OpenAlex is the dissemination of knowledge. OpenAlex makes more than 240 million works accessible, with approximately 50000 new data being added daily. It organizes this immense body of knowledge into a heterogeneous and directed graph using eight different node types:

1. Works: abstracts of articles, books, patents, data sets, and theses
2. Authors: all the individuals who have contributed to the creation of works
3. Sources: all the journals and archives that preserve the works
4. Institutions: the universities, research centers, and organizations to which the authors claim affiliations
5. Concepts: topics assigned to each article
6. Publishers: encompass all the companies and organizations that distribute the works
7. Research funders
8. Geographic areas: the locations where a particular author works or where a work is produced

In this project, the primary focus of interest and data analysis is on works, that are publications, and concepts. Concepts are abstract ideas that various articles deal with. OpenAlex assigns these concepts to each work, and there are approximately 65000 concepts in total. The attribution of these labels follows the model previously implemented by MAG, albeit with some modifications. Each concept is assigned a level ranging from 0 to 5, where at the lowest level, broad concepts such as medicine or engineering are associated, and as the levels increase, there is an increase in granularity, leading to extremely specific topics.

To perform our analysis we collected a corpus of scientific works by querying the OpenAlex catalog. The query was performed by looking at 67 design related concepts: *Art and design, Book design, Co-design, Collaborative design, Communication design, Conceptual design, Critical design, Design and Technology, Design brief, Design cycle, Design education, Design*

[1] https://openalex.org/

elements and principles, Design for All, Design for the Environment, Design for X, Design history, Design knowledge, Design language, Design methods, Design strategy, Design technology, Design thinking, Design tool, Design-based research, Design for manufacturability, Design management, Design process, Design science, Design science research, Ecological design, Environmental design, Environmental design and planning, Environmental graphic design, Evidence-based design, Experience design, Fashion design, Generative Design, Graphic design, Industrial design, Information design, Instructional design, Interaction design, Interactive design, Interface design, Interior design, Iterative design, Integrated design, Material Design, Package design, Parametric design, Participatory design, Philosophy of design, Product design, Product design specification, Rollover (web design), Service design, Spatial design, Strategic design, Sustainable design, Textile design, Universal design, User centred design, User experience design, User interface design, User-centered design, Web design, Website design.

A grand total of 169337 works were initially identified, before proceeding with data cleaning. Firstly, we limited our investigation from 1965 to 2023, with a small exclusion of publications from earlier years due to their scarcity. Subsequently, we excluded all the publications that did not contain authors, titles or abstracts, resulting in a dataset of 162316 works.

Table 1 provides a breakdown of the different types of publications included in the dataset. Each collected publication in the dataset is described by year of publication, authors, type of publication, title, abstract and language.

Table 1 Publication type split.

Publication Type	**Number of publications**
article	134510
book-chapter	22647
report	1594
dissertation	1122
book	1064
other	897
dataset	160
paratext	149
editorial	69
reference-entry	53

peer-review	26
erratum	21
standard	4

3.2 Data handling and manipulation

Before proceeding with textual analysis, we investigated abstract lengths. The statistics revealed important information about how abstract lengths are distributed. Specifically, the 5th percentile of abstract lengths was found to be 61.0 words, indicating a significant portion of concise abstracts in the dataset. Conversely, the 95th percentile of abstract lengths stood at 287.0 words. To prevent biased results, we excluded works linked to abstract lengths that fell outside the specified thresholds, whether shorter or longer. For the remainder of the analysis, a total of 121382 works were considered.

3.3 Natural Language Processing: Text analysis and topic modeling

Word-level n-gram analysis

In Natural Language Processing, an N-gram is a contiguous sequence of n items (or units) from a given sample of text or speech. N-grams play a vital role in text mining and various natural language processing applications. They represent a collection of words that frequently appear together within a specified context. N-grams are widely used in computational linguistics for various tasks, including text analysis, language modeling, and machine learning (Chowdhary, 2020).

Topic Modeling

We used Term Frequency-Inverse Document Frequency (TF-IDF) as an embedding technique to convert textual information into a numerical one. TF-IDF, indeed, is a numerical statistic used in information retrieval and text mining to evaluate the importance of a word within a document relative to a collection of documents (corpus). It is commonly used to rank the significance of words in a document based on their frequency within that document (Term Frequency, TF) and their rarity in the entire corpus (Inverse Document Frequency, IDF).

The transformed dataset was then fed to a Non-Negative Matrix Factorization (NMF) step to identify topics. NMF is an unsupervised learning technique used in data analysis and text mining. It is primarily applied to uncover the underlying structure or patterns within a set of data by exploiting the term frequency matrix of a corpus of documents to extract an additive model of the topic structure (Lee & Seung, 1999; Xu et al., 2003). The result is a list of topics, each represented as a list of terms. We characterized each of them with the top-10 most frequent words and used an LLM (OpenAI, 2023) to define appropriate topic names based on such top-10 words.

4. Results

4.1 Dataset characterization

Using exploratory data analysis and visualization, we characterize the data at hand to develop a deeper understanding of the design publications corpus and shed light on potential relationships among variables.

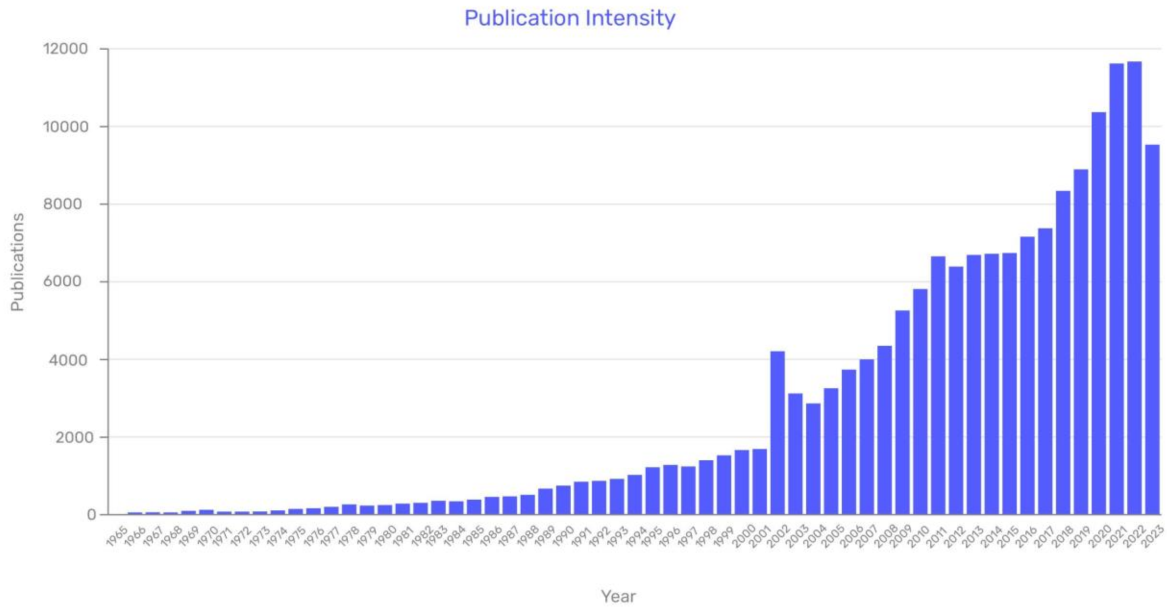

Figure 1 Publication intensity over time. Design research publications from 1965 to 2023 in the Open Alex catalog.

In Figure 1, the number of publications per year is visualized. Starting from 1965, the oldest year of publication in our dataset, publications in the field of design have increased dramatically. Predominantly, the corpus of scholarly works was composed in the English language, with a minority contribution from Italian, Spanish, and French publications. Focusing our analysis on the English subset (constituting 98.4% of the total), we delve deeper into discerning the distinctive attributes that characterize this comprehensive body of scientific literature.

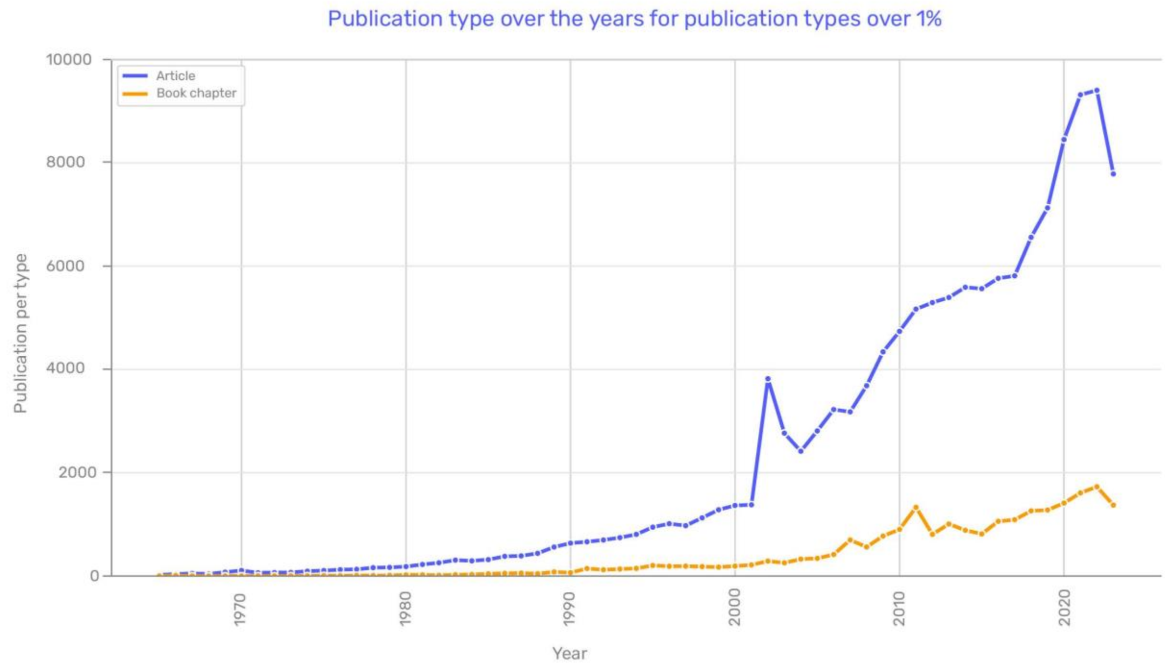

Figure 2 Publication type over time.

In Figure 2, the representation of the annual publication count is selectively curated based on those categories whose total is above 1% of the overall publication corpus: articles and book chapters, see also Table 1. As these two publication types collectively account for over 97% of the entire set of works, we restrain our investigation on this subset.

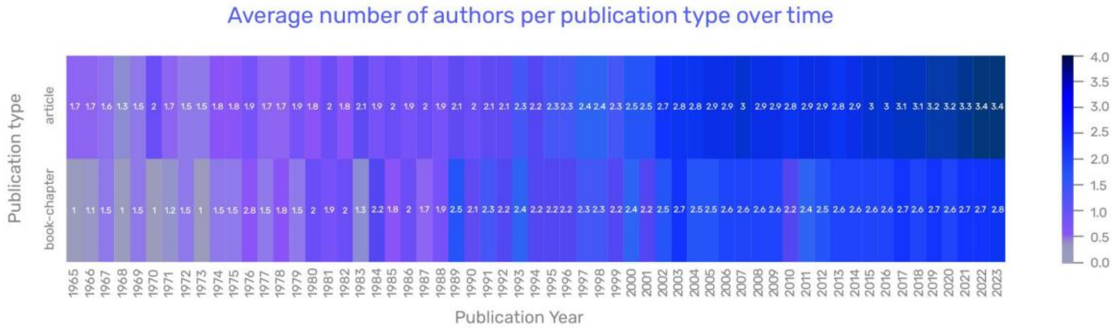

Figure 3 Heatmap visualization showing the average number of authors per publication type over the years

In Figure 3, we present a heatmap illustrating the trend of the average number of authors per paper type: a discernible and consistent rise in the number of authors is observed. This trend signals a significant shift in collaborative research efforts and highlights the evolving nature of scholarly contributions in these domains.

4.2 Tracing design evolution: semantic data exploration and nlp analysis over six decades

Semantic Data Exploration was conducted to extract from titles and abstracts relevant information regarding the evolution of concepts in design. For this analysis, we excluded documents that fell below the 5% (59 words) and exceeded the 95% (289 words) length thresholds, a measure taken to ensure equitable representation of abstracts in the subsequent text analysis. After data cleaning, the total number of considered publications was 124866.

Our experiments' main aim was to trace the transformation and development of design research spanning six decades, from 1965 to the present day. To achieve this, we employed Natural Language Processing techniques, complemented by statistical methodologies and data visualization tools. These analytical tools allowed us to effectively depict the shifts in research interests and trends within the field of design throughout this significant timeframe, providing valuable insights into its evolution over the years. Across a duration of six decades, the analysis encompassed both the computation of the most frequent unigrams (single words) and the examination of bigrams (pairs of consecutive items). The results are displayed in Tables 2 and 3.

Table 2 Top 20 unigrams over decades

	1965-1974 433 papers	1975-1984 1251 papers	1985-1994 4425 papers	1995-2004 14990 papers	2005-2014 40364 papers	2015-2023 59919 papers
1	design	design	design	design	design	design
2	planning	process	process	product	service	product
3	process	computer	product	process	product	study
4	computer	development	user	service	process	user
5	development	user	interface	model	user	service
6	problem	product	model	user	model	process
7	product	instructional	method	development	study	research
8	method	method	development	method	method	method
9	analysis	planning	service	tool	development	model
10	research	study	computer	information	research	development
11	program	problem	study	interface	technology	technology
12	study	control	information	study	analysis	learning
13	material	conceptual	application	technology	web	result
14	service	analysis	tool	application	application	experience
15	model	model	problem	analysis	information	analysis
16	architecture	service	analysis	web	result	application
17	technique	engineering	knowledge	engineering	interface	student
18	engineering	application	technology	result	tool	tool
19	control	interface	engineering	environment	quality	need
20	industry	material	conceptual	performance	learning	data

Table 3 Top 20 bigrams over decades

	1965-1974 433 papers	1975-1984 1251 papers	1985-1994 4425 papers	1995-2004 14990 papers	2005-2014 40364 papers	2015-2023 59919 papers
1	design process	design process	user interface	design process	design process	design process
2	industry design	conceptual design	design process	user interface	product design	user experience
3	conceptual design	design methodology	conceptual design	product design	user interface	product design
4	design problem	computer aided	interface design	conceptual design	case study	case study
5	computer aided	instructional design	product design	product development	conceptual design	design thinking
6	interior design	design method	computer aided	case study	product development	conceptual design
7	urban planning	user interface	design method	service quality	design method	user interface
8	analysis design	aided design	design methodology	web site	service quality	design method
9	ship design	design procedure	engineering design	design methodology	service provider	product development
10	structural design	design design	process design	design method	user experience	instructional design
11	planning process	product design	product development	interface design	web service	participatory design
12	building design	computer graphic	service quality	life cycle	instructional design	interior design
13	design method	design education	case study	process design	interface design	service quality
14	design philosophy	design development	instructional design	computer aided	web site	service provider
15	design technique	design study	design tool	engineering design	design product	architecture design
16	design procedure	engineering design	human factor	development process	life cycle	design principle
17	architecture historian	fusion reactor	concurrent engineering	service provider	collaborative design	graphic design
18	human factor	human factor	design problem	design manufacturing	design methodology	service design
19	design principle	paper author	design design	design environment	process design	design development
20	society architecture	term condition	aided design	design product	development process	design design

As bigrams provide more context and information, we used the results in Table 3 to draw a bump chart plot, presented in Figure 4. The chart displays the bigrams recurring at least twice among the top fifteen positions over the considered timespan, highlighting how the relative importance varied over time.

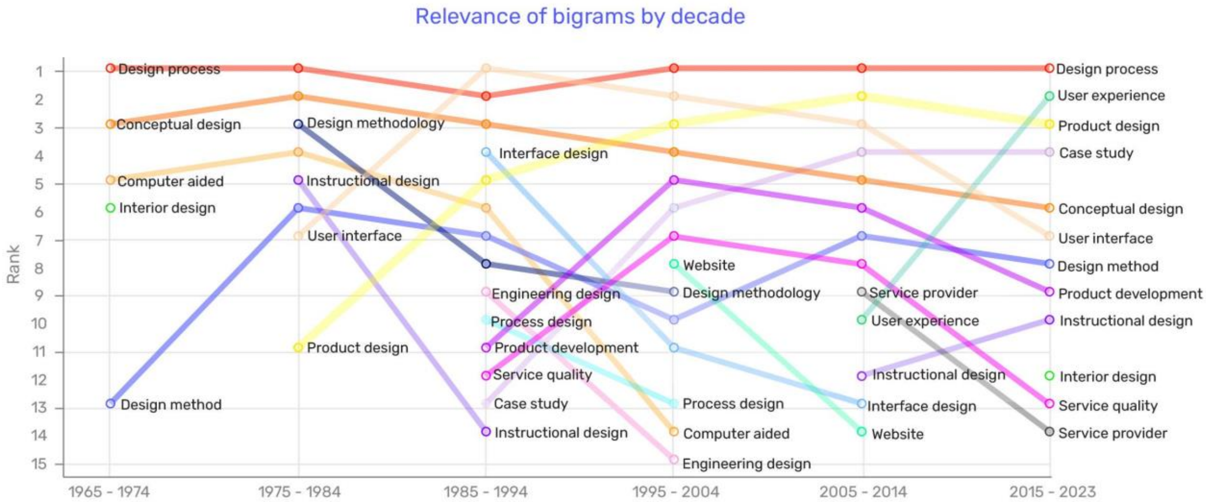

Figure 4 Variation of bigrams relevance over decades.

4.3 Unveiling interdisciplinary themes: Analyzing non-design concepts through topic modeling

Finally, we focused on shedding light on the interdisciplinary trait of design, and its inherent role of *bridging discipline*. We used a state-of-the-art approach for topic modeling to describe the topics of all concepts not related to design that are associated with the publications in the dataset. This experiment is aimed at providing compelling evidence that the field of design has a longstanding tradition of embracing an interdisciplinary approach. A topic modeling analysis based on the TF-IDF and NFM methods on all non-design concepts led us to identify a set of 8 distinct topics. The resulting list is the following:

1. **Engineering and Computer Science**
   engineering mechanical physics systems computer software design science statistics control
2. **Service Quality and Customer-Centric Marketing**
   service business provider marketing delivery framework quality management level customer
3. **Human-Computer Interaction and Interface Design**
   interface bubble user maximum pressure matter method interaction human computer

4. **Product Development and Marketing Mathematics**
product mathematics geometry new development marketing business engineering manufacturing lifecycle
5. **Interdisciplinary Studies in Psychology and Education**
psychology education mathematics computer learning science social multimedia human interaction
6. **Web Development and Internet Standards**
web wide world internet page application usability the computer standards
7. **Engineering Process and System Management**
process management computing engineering operations work in system design operating
8. **Biology, Archaeology, and Visual Arts in Environmental Context**
biology archaeology art arts environmental visual architectural ecology architecture sustainability

As a last step of our data exploration, we present in Figure 5 a heatmap visualization illustrating the temporal dynamics of the average number of concepts not related to design per paper type across multiple years. Notably, the depicted trend exhibits a consistent stable upward trajectory, punctuated by sporadic minor increments within the analyzed time frame. Noteworthy is the discernible ascendant trend within the domain of article categorization, which inherently corroborates the proposed hypothesis that the landscape of design research has progressively integrated an interdisciplinary approach over the examined period.

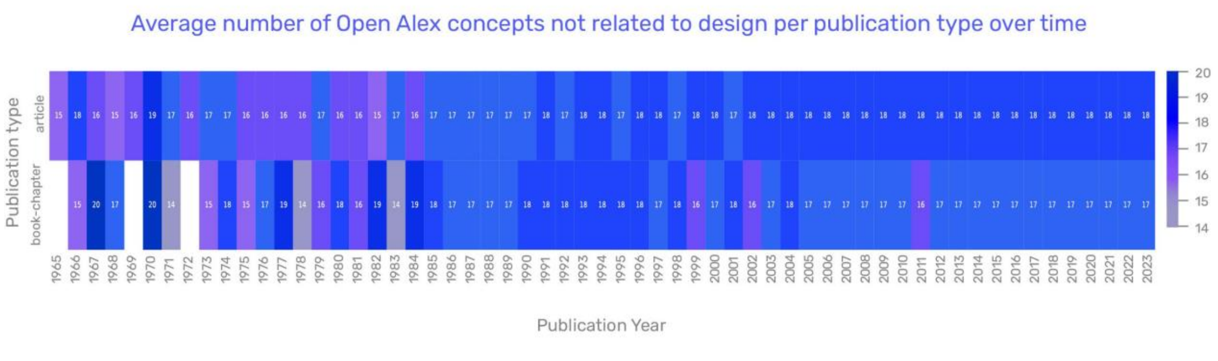

Figure 5 Average number of Open Alex concepts not related to design per publication type over time.

5. Discussion and conclusion

In the decades analyzed, an increase in the number of authors is evident relative to the research products most used as papers in scientific journals and book chapters, as shown in Figure 1. Papers and book chapters highlight collaboration among multiple scholars, even from different disciplinary fields (Figures 3 and 5), aimed at scientific design production in tune with what is happening in other disciplinary fields (such as those, for example, in the hard sciences).

Using linguistic and semantic analysis tools, related themes and topics were highlighted, enabling the identification of thematic areas of interdisciplinary collaboration. The data, obtained with quantitative tools, were reprocessed with qualitative analysis functional to understanding and interpreting the results (see List in Section 4.3).

Quantitative analysis indicates references to concepts proper to other disciplinary fields with a small but constant increment in the decades under observation. This phenomenon makes clear the historical nature of design as a prototype discipline (as well as a practice) of *relating* to other disciplines. The term used by Victor Papanek (Papanek, 1971) is *bridging* discipline, characterized by a robust pragmatic capacity to make operable knowledge from other disciplinary domains. The small increment in the number of references to other disciplinary concepts over time may indicate several phenomena: we could read the powerful thrust of the *Ulmian* experience, particularly with the leadership of Tomàs Maldonado, introducing aspects of technical-scientific knowledge and visual communication, opening toward systems and complexity sciences as well as toward the disciplines of the Humanities.

The first decade could see "crystallized" this capacity for dialogue activated by this experience and capable of influencing design in the coming years. Another reading - which would be worthy of further investigation - should go into the content of *concepts* from other disciplines. While it is true, as documented in the analysis, that the number of references has steadily increased by approximately one-fifth, it may be equally true that other disciplinary references have replaced some significant ones in some decades. Even with the always quite significant number of disciplinary references, there has been a phenomenon of *concept* substitution over time: some disciplines have entered and others have left the design science reference universe (see Figure 4). For example, some references to anthropometry, somewhat related to ergonomics, the basis of a lot of design work in the early 1960s, have been replaced by topics from cognitive ergonomics, mixing contributions derived from general psychology, social psychology and neuroscience. Or, again, the relevant role of design as a functional tool for the competitiveness of firms and organizations emerged strongly (especially in North American circles) in the early 1980s, proposing areas of reference closer to business and management.

Another interpretation key to justifying this small increment of references to disciplinary concepts could be related to phenomena peculiar to the academy for which a discipline in progress at a certain point needs a stable body of reference not subject to specific changes (with this, however, contradicting that prototypical idea of a discipline of contemporaneity capable of implementing a circular process of comparison with disciplines in function of specific objectives).

In the graphic restitution of the recurrences of keyword pairs of Figure 4, we find useful indications, in some cases counter-intuitive to the broader debate on the trajectories of the discipline.

For example: Design Thinking, among the most popular topics of critical reflection and research in recent times, appeared in the last decade as a significant recurring word. Not that there was no reflection on the same in earlier decades but probably not emerging as a topic in its own right or numerically relevant, correlated probably with the topic of Design Process, which presents itself as a linear research topic present in all decades and always in first place in the ranking that measures recurrences. Just as recurring in the decades under analysis are research on conceptual design - which today we would translate as *advanced design* - and *product design*, indicating how much the manufacturing sector, in general, is still as significant an area of placement of designer skills as the research tends to justify. Another area, partly related to the topic of *design processes*, is *design methods*, which saw significant international interest in the 1975-1984 decade and then remained constant over time placing itself in the middle of the international scientific community's interest in the topic. User Interface became a significant and recurring topic of interest from the 1985-'94 decade to become less recurring in subsequent decades and merge into broader themes related to User Experience, growing in the last few decades under observation. Service design, while related to other definitions - e.g. *service quality* - is defined in the 1995-2004 decade and tends to lose relevance as a research topic in subsequent decades, again simultaneously with the growth of interest in user experience design topics.

The cross-reference to other *concepts, themes, and disciplines* has, as mentioned, increased by about one-fifth over time. In contrast, the design objects proper to design practice have significantly increased in number over time. Buchanan's earlier mention of the four orders of design captures this expansion of the discipline: "Today, it seems to be safe to say, the 'existential relevance' of design has been greatly attenuated”. Mario Perniola had titled one of his books *“L'arte espansa”* ("The Expanded Art") (Perniola, 2015). A similar definition could be suggested for design as well. With the third phase of the industrial revolution, the design also expanded," writes design historian Vanni Pasca (Pasca, 2018). The research presented in this essay confirms this expanding dimension towards other disciplines.

The two assumptions are valid, however, and it is the empirical evidence that makes them so. The object of design today may be service, the system of relationships active in the urban sphere, the relationship with *more than human* spheres, and the organization as a whole. As well as areas such as politics (Margolin, Manzini: with the essay *Stand up for Democracy*), the neighborhood city, education, social equity, etc. The disciplinary fields seem to be chosen, in this process of entry and exit of disciplines useful for addressing these issues, according to the purposes of the activities carried out. This aggregation of disciplines according to goals and responses is highly dependent on the contexts and situations of design practice. This confirms design as a bridging discipline between disciplines, where what is relevant is the possibility of putting knowledge from other disciplinary areas into practice as a function of specific *purposes*. In other words, the research unequivocally indicates that design operates in a condition of *meta-cognitio*n. Starting from contexts and understanding them, it has skills able to aggregate knowledge, methods and tools useful for achieving specific purposes, making knowledge from other scientific and disciplinary fields operable. Meta-cognition can be a useful way to explain the numerosity of references to concepts other than those commonly recurring in design. It also indicates a peculiar form of *polyglotism*: design, by training, is confronted with different languages, contents and approaches and can master, at least on a superficial and operational level, these diversities to connect and orient them toward a common purpose.

Acknowledgements: This work is partially funded by the European Union - NextGenerationEU and by the Ministry of University and Research (MUR), National Recovery and Resilience Plan (NRRP), Mission 4, Component 2, Investment 1.5, project "RAISE - Robotics and AI for Socio-economic Empowerment" (ECS00000035) as A. Barla is part of the RAISE Innovation Ecosystem. The authors thank M. Cuneo and S. Ravera for computing support.

References

Adams, J. D., Black, G. C., Clemmons, J. R., & Stephan, P. E. (2005). Scientific teams and institutional collaborations: Evidence from US universities, 1981–1999. *Research Policy*, *34*(3), Article 3.

Arquilla, V. (2022). The Value of Design Today. *Transformation by Design. Planning Design Strategies and Services for the Next Generation Digital Challenges.*, 005–029.

Borja de Mozota, B. (2006). *The four powers of design: A value model in design management*.

Branzi, A. (2007). *Capire il design.* (Illustrated edizione). Giunti Editore.

Brown, T. (2008). Design thinking. *Harvard Business Review*, *86*(6), Article 6.

Bruce, M., & Bessant, J. R. (2002). *Design in business: Strategic innovation through design*. Pearson education.

Buchanan, R. (1992). Wicked problems in design thinking. *Design Issues*, *8*(2), Article 2.

Buchanan, R. (2001). Design research and the new learning. *Design Issues*, *17*(4), Article 4.

Chowdhary, K. R. (2020). Natural Language Processing. In K. R. Chowdhary (Ed.), *Fundamentals of Artificial Intelligence* (pp. 603–649). Springer India. https://doi.org/10.1007/978-81-322-3972-7_19

Cross, N. (2006). In Designerly Ways of Knowing (pp. 1–13). Springer-Verlag. https://doi.org/10.1007/1-84628-301-9_1

Dalton, A., Wolff, K., & Bekker, B. (2021). Multidisciplinary Research as a Complex System. International Journal of Qualitative Methods, 20, 16094069211038400. https://doi.org/10.1177/16094069211038400

Fuller, R. B. (1963). Utopia or Oblivion: The Prospects for Humanity. Estate of R. Buckminster Fuller.

Heskett, J. (2005). *Design: A very short introduction* (Vol. 136). Oxford University Press, USA.

Huang, D. (2015). Temporal evolution of multi-author papers in basic sciences from 1960 to 2010. *Scientometrics*, *105*, 2137–2147.

Kotler, P., & Alexander Rath, G. (1984). Design: A powerful but neglected strategic tool. *Journal of Business Strategy*, *5*(2), Article 2.

Kuld, L., & O'Hagan, J. (2018). Rise of multi-authored papers in economics: Demise of the 'lone star'and why? *Scientometrics*, *114*(3), Article 3.

Lee, D. D., & Seung, H. S. (1999). Learning the parts of objects by non-negative matrix factorization. *Nature*, *401*(6755), Article 6755. https://doi.org/10.1038/44565

Norman, D. A. (2016). *Living with complexity*. MIT press.

Norman, D. A., & Stappers, P. J. (2015). DesignX: complex sociotechnical systems. *She Ji: The Journal of Design, Economics, and Innovation*, *1*(2), Article 2.

Papanek, V. (1971). *Design for the real world- Human Ecology and Social Change*. Thames&Hudson.

Pasca, V. (2018). Dopo i discorsi sulla fine. In *Extra 5 (2018)—Eco/Gregotti. Sulla fine del design* (N. Bassoli, M. Garcia Sanchis, G. Piccarolo). Lotus. https://www.editorialelotus.it/web/item.php?id=90017

Perniola, M. (2015). *L'arte espansa* (Einaudi).

Priem, J., Piwowar, H., & Orr, R. (2022). *OpenAlex: A fully-open index of scholarly works, authors, venues, institutions, and concepts* (arXiv:2205.01833). arXiv. https://doi.org/10.48550/arXiv.2205.01833

Proposed guidelines for collecting and interpreting technological innovation data. (2005). *OCDE: Statistical Office of the European Communities*.

Simon, H. A. (2019). The Sciences of the Artificial, reissue of the third edition with a new introduction by John Laird. MIT Press.

Sinha, A., Shen, Z., Song, Y., Ma, H., Eide, D., Hsu, B.-J. (Paul), & Wang, K. (2015). An Overview of Microsoft Academic Service (MAS) and Applications. *Proceedings of the 24th International Conference on World Wide Web*, 243–246. https://doi.org/10.1145/2740908.2742839

Verganti, R. (2008). Design, meanings, and radical innovation: A metamodel and a research agenda. *Journal of Product Innovation Management*, *25*(5), Article 5.

Wilson, S., & Zamberlan, L. (2015). Design for an unknown future: Amplified roles for collaboration, new design knowledge, and creativity. *Design Issues*, *31*(2), Article 2.

Xu, W., Liu, X., & Gong, Y. (2003). *Document Clustering Based On Non-negative Matrix Factorization*.

About the Authors:

Andrea Vian is Professor of Design with the University of Genoa. As digital designer, he investigates user experience, interfaces and accessibility within the human-centered design paradigm. His research focuses on the study and implementation of complex web systems and digital innovation processes.

Gianluca Carella PhD in Design, his research focuses on how to use design inside organizations to create innovation. Also, he is working on projects that deal with design-driven entrepreneurship. His main streams of research are on Strategic Design and Design Management.

Daniele Pretolesi, PhD student at the Austrian Institute of Technology, is a researcher in the field of Human-Computer Interaction. The main focus of his research is in human-AI applications and on data-driven digital systems designed to explain and simplify complex textual data.

Annalisa Barla is Professor of Computer Science with the University of Genoa. Her interests are in the field of machine learning, from the study of robust and reproducible variable selection methods to the understanding and visualization of complex structured network data.

Francesco Zurlo Ph.D., is the Dean of the School of Design of Politecnico di Milano. His research interests are concentrated on strategic, systematic, and creative research through design, focusing on the ecological impact of business innovations and human flourishing.

PROCEEDINGS OF DRS 2024 BOSTON

Design Research Society International Conference
23 – 28 June 2024
Boston, MA, USA

COVER AND CONFERENCE IDENTITY DESIGNED

by Viviane Kim

PROCEEDINGS COMPILED

by Colin M. Gray

EDITORS

Colin M. Gray
Estefania Ciliotta Chehade
Paul Hekkert
Laura Forlano
Paolo Ciuccarelli
Peter Lloyd

ISBN 978-1-912294-62-6

9 781912 294626

WWW.DRS 2024.ORG