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Journal of Engineering Design

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/cjen20

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**To cite this article:** Boris Eisenbart, Lucienne T.M. Blessing & Marco Canatamessa (05 Apr 2024): Two decades apart and looking forward – exploring rigour in reporting on research in the engineering design research community, Journal of Engineering Design, DOI: 10.1080/09544828.2024.2327912

**To link to this article:** https://doi.org/10.1080/09544828.2024.2327912



Published online: 05 Apr 2024.

JOURNAL OF ENGINEERING DESIGN
https://doi.org/10.1080/09544828.2024.2327912

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# Two decades apart and looking forward – exploring rigour in reporting on research in the engineering design research community

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**ABSTRACT**

The engineering design research community is engaged in a long-standing and lively debate about what defines design as a unique field of research. This includes a discourse on a rigorous way of conducting research through various academic outlets germane to the community. This paper explores the current state of rigour in reporting engineering design research by analysing the proceedings of two recent ICED conferences and comparing the results with those of an identical analysis of an equivalent set of ICED proceedings published exactly 20 years earlier. A lack of such rigour ultimately permits lower quality work to prevail as it sets poor examples for young researchers and affects credibility and trustworthiness of the field. The data shows the significant improvements made and identifies potential areas to address. By establishing the current state of rigour in reporting considered acceptable in the community for one of its main conferences and how this has evolved, the paper allows us to infer trajectory and formulate concrete recommendations for further improvement.

**ARTICLE HISTORY**
Received 22 October 2023
Accepted 5 March 2024

**KEYWORDS**
Rigour; design research; research documentation

## 1. Introduction

### 1.1. Motivation

The engineering design research community has long been involved in a lively debate on what defines it as a distinct field of scientific research, as this very series of Research Notes and Special Issues illustrates well. The concept of 'design science' (Samuel and Lewis 2001; Simon 1969) raises pertinent questions around what delimitates it as a separate discipline, what are its paradigms, and ultimately also what defines 'good' scientific conduct in relation to the research carried out within this field (Blessing 2002; Cash, Daalhuizen, and Hay 2022a; 2022b). Such debate stems from the desire to identify it as a distinct field of scientific research, given the huge body of work that has been created over the years that is germane to the engineering design research community. Yet, the multi-facetted nature

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of design also challenges the community to give a minimal set of generally applicable – and commonly agreed – standards to the field, so to ensure a methodical and enduring progress. Design research as a discipline has roots in both the social and the natural sciences (Diekmann 2001), spreading from arts, humanities and economics to engineering and manufacturing. It is observed how these backgrounds lead researchers to draw specific research questions, approaches and standards from the respective technical, societal and environmental domains they were educated in (Birkhofer and Kloberdanz 2005; Blessing 2002; Cantamessa 2003; Cash 2020; Horváth 2001; Höger 2008). Consequently, research into design and the methods and theories that comprise it are multi-facetted in terms of involved tools, people, approaches, and terminology (Blessing, Chakrabarti, and Wallace 1998; Hales 1987), some unique, yet often borrowed from other fields (Cash, Daalhuizen, and Hay 2022a; Cross 2001; Simon 1969).

This inadvertently propels inconsistency, limited comparability of studies and, ultimately, hampers agreement among design researchers on what rigorous, high-quality research conduct into engineering design will – or in fact should – entail (Blessing 2002). There is agreement, however, that any such general standard must not be the smallest denominator, but in fact propel high levels of rigour in research conduct (Cash, Daalhuizen, and Hay 2022a; *this series*). This article adds to this discourse by studying the way engineering design research is reported in the community, focusing on one of its main and oldest conferences, the International Conference on Engineering Design. More importantly, we seek to establish the state of the art in terms of rigorous reporting of research in the community, as no formal such standard exists as of now. This follows the argument of distinction by having a commonly shared, rigorous way of presenting the engineering design research, which, as we will show, is not the case. Importantly, scholars, such as Cross (1984), Reich (1995), Blessing, Chakrabarti, and Wallace (1998), Dorst (2008), Curedale (2013), Faste and Faste (2012) and Cash et al. (2022b), formulate a consensus that the lack of agreed rules around rigour of reporting in design research ultimately:

- permits lower quality work to prevail as it sets poor examples for young researchers, and
- affects the credibility and trustworthiness of the underlying research, which negatively affects the recognition of the field as scientific.

### 1.2. Research Aim and Scope

Journals and conferences have formulated requirements around the minimum quality of research articles to be published. And either by design, or by naturally emerging common practice, a certain way of conducting and presenting research has formed in the different research communities. Although there are slight differences between disciplines, their requirements tend to be well-established and adhered to. Yet, in the engineering design research community, despite the requirements formulated by its academic outlets, the discussion continues unboundedly, showing that there still is a need to formalise what the community considers appropriate standards. This is evidenced by the very series of research notes this article is part of, as well as by comments from reviewers and an array of articles recurring again and again over the last 20 years, including textbooks and other scholarly works that provide guidance on rigorous, scientific research, including reporting, into engineering design. The multi-facetted nature of engineering design, and hence of its research,

may be an explanation of the continued discussion, but does not explain the perceived lack of rigour in reporting. This paper pursues the following two central aims:

(1) Rather than looking at guidelines put forward by editors and conference organisers establishing what *acceptable* reporting *ought to* display, this paper takes the approach of studying already published work to establish the *actual* situation of what is *accepted reporting of* research in the engineering design community;
(2) Given the enduring discussions about rigour in reporting, we seek to establish whether and in what way adherence to rigour has changed over time, in order to infer where the community might be, or ought to be headed.

Seminal work by Cantamessa (2003, 2001) analysed the suite of research articles published at the 1997 and 1999 International Conference on Engineering Design (ICED), widely considered one of the flagship design-focused conferences of the engineering design community[1]. His work showed that inconsistencies, such as omissions of relevant information pertaining to how research was conducted (and with whom) and what relevant theories were used, were commonplace in reporting research work at the time, setting poor examples and affecting credibility by suggesting poor conduct of the research, even though this not necessarily has to be the case. This and similar work (e.g. Blessing 2002; Cross 1984; Reich 1995) not only started a discourse in the community, but also directly motivated the proposition of prescriptive approaches for (engineering) design research specifically, ever since (e.g. Blessing 2002; Blessing and Chakrabarti 2009; Cash 2018; Cash et al. 2022b; Curedale 2013; Faste and Faste 2012; Goldschmidt and Matthews 2022; Gray 2022; Höger 2008; Koskinen et al. 2011; Krippendorff 2006; Laurel 2003). These approaches aimed at creating a baseline, if nothing else, for what makes 'good' research conduct and by extension how it would have to be documented and reported on. At the same time, adjacent disciplines that are increasingly doing research into design have well-established and traditionally very rigorous research and reporting standards, which they continue to apply when studying design. Examples are management/economics (e.g. Brown 2009; Dong, Garbuio, and Lovallo 2016; Garbuio et al. 2015; Martin 2009), specifically with its links to innovation (e.g. Assink 2006; Bonnardel and Zenasni 2010; Kwon, Moonkyu, and Kim 2015), and psychology, to which there is a long-standing link (Cross 1982). Training workshops, summer schools and Special Interest Groups on design research methods and methodologies and on publishing have been established, some of which have been running for several decades within, or promoted by, the Design Society or the Design Research Society. We posit that all these developments should have created a shift and increased awareness of rigour in research and its reporting within the community. And it would therefore have spawned a noticeable increase in the quality of how research is conducted and reported. The latter is the focus of this paper.

### 1.3. Approach

As one of the first comprehensive works on the state of engineering design research, in this article we use the aforementioned analysis of the ICED proceedings from 1997 and 1999 by Cantamessa as baseline for our analysis. To identify the current state of reporting and determine whether it has become more rigorous, we selected the ICED conference

proceedings from 2017 and 2019, exactly 20 years from Cantamessa's original study, and also the last two ICED events held in-person prior to the global Covid-19 pandemic[2]. The choice of ICED proceedings remains relevant as ICED is the largest and longest-running conference series in the engineering design research community, with an acknowledged review process involving a minimum of two and up to four reviewers in a double-blind process, and a high consistency in researchers and institutions that represent the community (see McMahon 2012; Birkhofer 2011 and our own parity analysis between 1997/99 and 2017/19 below). Two of the authors have been involved in the ICED conferences over the entire time frame under discussion. Whilst there has been a change in templates and detail to the instructions (both author and reviewer), and each ICED iteration features a unique overarching theme related to design, the scope of research being called for by the conferences has remained fairly stable, mainly adapting to new topics as and when they arise. In fact, for citation and indexing purposes (SCOPUS), the list of research topics and themes must not be changed too much between different iterations of the conference. We also consider the ICED proceedings suitable, since they cover a uniquely broad range of research topics, by and large reflecting all central design-related interests fundamental to the engineering design research community. Equally, they present both advanced and nascent research studies, discussion papers form only a small minority (Cantamessa 2003). Conversely, journals tend to be more focused on specific research topics/areas, prefer fully matured work and are proactive in curating a certain style and format. Furthermore, ICED reviewers are typically recruited from within the community, whereas journal reviewers may not. Finally, the relatively short length (low page limit) compared to journal articles forces authors to select content, thus – in terms of rigour in reporting – inadvertently revealing what authors consider most relevant to report. As such, the conference series offers a singular window to explore and compare the state of reporting on conducted research and what the community effectively considers acceptable for authors to attend and present their work in this forum. Nevertheless, extending the analysis we present in this paper to include other conferences and journals would be a worthwhile endeavour to deepen our understanding and verify our assumptions and findings.

We aim to answer three central research questions (RQ):

**RQ1:** What is the current state of rigour in reporting of research at the 2017 and 2019 ICED conferences?

**RQ2:** What pertinent differences and commonalities in terms of rigour in reporting on research can be found between the 2017/19 ICED proceedings and Cantamessa's analysis of the 1997/99 ICED proceedings?

**RQ3:** What conclusions can be drawn about rigour in reporting on engineering design research over the past decades and into the future?

Through this comparative analysis, we expect to make several contributions:

- Firstly, we advance insight into the state of rigour of reporting research in the community in recent years;
- Secondly, we point towards concrete developments over the last decades and further highlight areas that require the community's continued attention to improve the quality of the way in which research is reported and, possibly, of how research is conducted;

- Extending from these insights, we thirdly advance suggestions as to what could be appropriate strategies to further raise rigour in reporting engineering design research.

## 2. Framing rigour in reporting on design research

Within this series of Research Notes, we position our work within Theme 4 of the nine emerging themes of studying research conduct, which deals with the sub-themes of 'standards, reporting and replicability' (Cash, Daalhuizen, and Hay 2022a). Key aspects covered in this theme are credible reporting, citing of related work, replicability (which in turn requires rule-based, standardised conduct) and transfer/translation of work to the wider context of engineering design research and practice[3]. The way research is conducted and how it relates to extant theory and practice must be reported in a transparent manner. To establish measures of rigour in reporting on conducted research we sample two relevant bodies of literature: one focusing on formulating requirements around data acquisition and processing, and one on prescribing ways to carry out research in a rigorous manner (though there are cross-links between them).

At this point, it must be acknowledged that engineering design research is considered fundamentally different in its objective from the established sciences, including engineering. Simon (1969) contrasts scientific study of the *natural* versus the *designed*, a distinction that is resounds in engineering design theory and methodology fundamental to the community (e.g. Hubka 1980; Hubka and Eder 1996). Accordingly, the 'natural sciences are concerned with how things are' whereas design research 'is concerned with how things ought to be' (Simon 1969, 114; see also Cross 1982, 2001). We posit that both co-exist in design research and influence how such research ought to be carried out and be reported on. Design research borrows from other sciences (as discussed above), e.g. while investigating 'how things are' in design, but then innately seeks to translate this into ways to improve design to create better artefacts, have a better process or similar (Blessing 2002; Blessing and Chakrabarti 2009; Dorst 2008), i.e. including a design component into their research work.

Several scholars, such as Wacker (2008), have systematically developed guidelines to assist empirical researchers to assure that their studies fulfill the requirements of established sciences for rigorous theory-building. They tend to emphasise the importance of 'good' formal conceptual definitions, for researchers to follow a logical plan in their work and show sufficient contextualisation in theories of the relevant academic field. For our purposes, such guidelines often only partly apply to engineering design research with its objectives to create knowledge about how things are and recommendations of how things ought to be, if not actual solutions to improve the current situation. As Cantamessa (2001; 2003) found, ICED articles tended not report engagement in theory-building as such (see Section 3.1). Most publications in the community provided little guidance as to how to do design research, leaving it to the individual to find an efficient, effective and rigorous approach. The most relevant for our purpose is Prochner and Godin (2022)'s work, which stand outs in examining possible standards for quality in design research (with a focus on research *through* design), providing guidance to improve planning, reporting, assessment, and discussions on quality. They distinguish five categories of quality indicators:

(1) **Traceability**, comprising *replicability*, *recoverability and transparency*: this pertains to reporting the way the research was conducted to a degree that would permit others to verify and reproduce the work;
(2) **Interconnectivity**, comprising *internal validity*, *credibility* and *contextualisation*: this addresses the need to clear and valid reasoning as to why research has been set up in a particular manner, how each part coheres from one step to the next;
(3) **Applicability**, including *external validity*, *transferability* and *impact*: here, the link is established to extant theory in the context of the research carried out as a measure of validity of the inherent framing of the research, but also the contextualisation of findings in relation to extant theory which would allow application in other situations;
(4) **Impartiality**, encompassing *objectivity*, *confirmability* and *contextualisation in theory and research*: advancing from Point 3, this pertains to measures taken to reduce researcher or subject bias and also grounding of the study design in extent theory in terms of valid choices made by the researcher;
(5) **Reasonableness**, containing *reliability*, *dependability* and *soundness of research methods and research norms*: here aspects of repeatability are discussed in terms of measures taken to ascertain findings by means of following dependable and well theoretically supported process.

In formulating these criteria, the authors extend from Gibbert, Ruigrok, and Wicki (2008), who, building on thoroughly established work discussing empirical and experimental research conduct, including Cook and Campbell (1976, 1979), Yin (1994), Eisenhardt and Graebner (2007), Wacker (2008) and others, formulated similar criteria, such as *internal*, *construct* and *external validity* as well as *reliability*.

In the second body of literature, prescribing ways of carrying out rigorous research, the work of Yin (2014), Blessing and Chakrabarti (2009); Blessing 2002), Patton (2005), Crowther and Lancaster (2012), Dresch, Lacerda, and Antunes (2015) and Creswell and Creswell (2017) are examples that aim to give concrete guidance to researchers on adequate setup of relevant studies, i.e. conjecture of relevant stages and selection/application of research methods for carrying out individual steps in a rigorous manner. Commonly, they (most prominently Blessing and Chakrabarti 2009 and Blessing 2002; Yin 2014) articulate the need of guidance with respect to the following aspects to ensure rigor in research:

(a) the application of an (overall) guiding or underlying research methodology;
(b) the selection and application of research methods for (every) relevant step(s) carried out within a research study;
(c) the grounding of work in relevant theory and/or related work;
(d) the interpretation of the findings with respect to the wider context of investigation;
(e) the assessment of the validity of the study and its results and their alignment to extent theory;
(f) their reliable, replicable and well-reasoned documentation.

As mentioned, they share the notion that design research is more than the study of 'how things are' (Simon 1969, 114) but 'must (ultimately) be useful from a [practical] point of view'

(Blessing 2002, 4). For this reason, design research should not only involve the formulation and validation of theories about the phenomenon of design, but also aims at developing knowledge, founded on an understanding of the present, to intervene so as to change the present in a predetermined way into a more desirable situation (Blessing 2002). In addition to the above, guidance is needed with respect to the following aspects:

(g) derivation of implications for practice (as the industrial or educational reality);
(h) the application of a systematic approach to the development and evaluation of ways to improve practice based on the knowledge gained;
(i) the discussion of the implementation and application of developed knowledge, insights, models or methods/tools.

All of these aspects are considered an essential part of research in engineering design, although aspects (h) may not be part of each study.

Compared to the criteria for rigour put forward by Prochner and Godin (2022) and Gibbert, Ruigrok, and Wicki (2008), guidelines directly aide scholars to set up their studies in a way that allows demands for scientific rigour to be met. That is, rigour in each of the listed aspects should increase the quality of the research, here defined as the fulfillment of Prochner & Godin's criteria. As such, we see a relationship where, for example, rigour in the application of an *overall research methodology*, rigour in the *application of research methods for relevant steps carried out* and *their reliable, replicable and well-reasoned documentation* are pre-requisites for satisfaction of Prochner & Godin's criteria, such as *traceability*, *interconnectivity*, *reasonableness*. However, for the community to determine the credibility and trustworthiness of research results, the research must be reported in a manner that allows verification of these criteria. Based on the aforementioned relationship between the criteria and the aspects of rigorous research, it is the reporting on these aspects that allows the verification of the criteria. In other words, rigor in research requires rigor in reporting (see aspect (f) above).

Figure 1 shows the identified relationships between the aspects of research to be reported and their relation to Prochner & Godin's criteria. Two aspects are not included in this figure. The first is '(f) their reliable, replicable and well-reasoned documentation', as our focus is on the research aspects to be reported (documented). Only when the reporting is done in reliable, replicable and well-reasoned manner is it possible to verify whether the research fulfils the criteria. The second is '(h) the application of a systematic approach to the development and evaluation of ways to improve practice based on the knowledge gained', which has not been included in our analysis because of its different, more prescriptive nature. The selected set of criteria may not fully apply to the development of the solutions, although they should apply to the evaluation. What has been included, however, is whether the ICED publications report on the type of the proposed support (tool, method, or both) and whether and how the concrete application is discussed.

With this in mind, to analyse the current (2017/19) state of rigour in reporting of research (RQ1) and to compare this to the state 20 years earlier (1997/99) (RQ2), we defined rigour in reporting as the coverage of the aspects of rigorous research in a manner that would allow verification of the criteria for rigorous research. This will form the basis for our comparative analysis of the selected ICED proceedings.

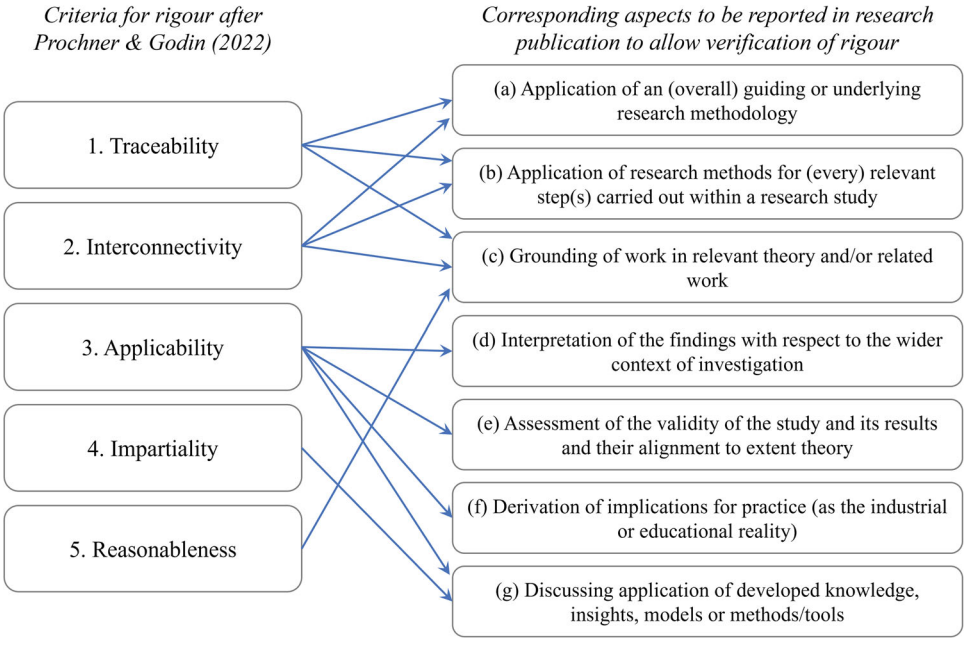


**Figure 1.** Relationships between criteria for rigour in research and aspects of research to be reported in research papers to allow verification of the criteria by the community.

## 3. Methodology

### 3.1. Data analysis and coding procedure

We had access to the original dataset of Cantamessa (2001; 2003), available as detailed excel sheets of codes and categories of the ICED papers of 1997 and 1999, as well as all ICED papers of the years 1997, 1999, 2017 and 2019 totalling 1567 papers, with 820 papers comprising the 2017/19 ICED proceedings and 747 the ICED 1997/99 proceedings. This makes the two data sets of comparable size.

Following the aim of understanding the status of rigour in reporting research in the engineering design community, we employ a quantitative approach in (re)analysing these papers. We limit our inquiry with respect to verification of the criterion 'impartiality' (see Figure 1). It is beyond the scope of this paper to verify the exact measures taken by authors of four different ICEDs to reduce biases, conduct data and/or result triangulation and similar measures. Reporting on employing such strategies was found to be extremely rare in the papers, which is noteworthy in itself.

First, we established the sets of codes with their operational definitions to be used to categorise the content of the papers with respect to the aspects to be reported (see Figure 1), taking into account the different types of research undertaken in the (engineering) design research community (see next section). The coding schemes used in Cantamessa's original work provided the basis for comparison and allowed structured, rather than emergent coding. We made some modifications to the coding schemes to better serve our research questions, drawing on the literature discussed above. The codes were

further substantiated and refined through thematic, inductive analysis (Miles and Huberman 1984; 1994) over repeated workshops with respect to paper categorisations (see Section 3.2).

Next, the established codes were used in an initial round of coding by four design research postgraduate students at [*withheld for review purposes*]. Papers were split up in such a way that each paper was coded by two different coders independently from one another, operating under a two-round Delphi Research procedure for consensus building. This means, when codes aligned between the coders after the initial analysis, they were affirmed. When codes differed between the two coders, they were subject to one round of discussion. If a consensus could not be achieved, one of the authors would act as referee and make the final decision. This procedure does not fully exclude bias, but it gives confidence that it is reasonably reduced. The papers from ICEDs 2017/19 were fully coded with all coding schemes. The coding of the papers of ICEDs 1997/99 was limited to the new and modified coding schemes, for the remainder the original coded data was used.

All codes for all papers were transferred into the same excel sheet expanding on the original one by Cantamessa. The data was analysed using SPSS and R.

### 3.2. Types of research papers

ICED papers feature a wide variety of research topics, objectives, contexts and methodologies and methods. This is the fundamental nature and span of the engineering design scholarship as discussed above. Although the criteria for rigour shown in Figure 1 apply to all types of research, the content of the aspects to be reported may differ, that is, for some aspects, the coding schemes may depend on the type of research. For example, reporting of empirical and experimental studies requires more details on the methods(ologies) used to collect and analyse data, sample sizes, etc. Conversely, for studies involving the development or implementation of new tools and methods, the aspects to be reported include, e.g. how these new tools and methods are expected to impact practice (be it industry or education). Developing a suitable coding scheme for the types of research is thus a prerequisite for the development of the other coding schemes. The coding scheme we used for the types of research reported in the ICED papers is the one developed for the original study by Cantamessa (2001; 2003):

(1) **Empirical research (EMP)**, in which researchers analyse real-world design processes;
(2) **Experimental research (EXP)**, in which researchers purposely set up and study design processes in a controlled environment;
(3) Development of **new tools and methods (NT)** for supporting the design process or elements of it;
(4) **Implementation studies (IMP)**, in which researchers discuss the real-world deployment of innovative methods and tools;
(5) **Other (OTH)**, which includes papers dedicated to theoretical discourse, engineering experimentation, education or opinion/philosophical pieces.

Coding of the type of research was carried out based on the abstracts, introduction and method(ology) sections of the papers or was inferred by consensus of the research team

**Table 1.** Descriptive statistics for the type of research paper.

| ICED | # | EMP | EXP | NT | IMP | OTH |
|---|---|---|---|---|---|---|
| **1997/99** | 747 | 115 | 43 | 341 | 113 | 135 |
| | | 15.4% | 5.8% | 45.7% | 15.1% | 18.1% |
| **2017/19** | 820 | 169 | 105 | 204 | 272 | 64 |
| | | 20.6% | 12.8% | 24.9% | 33.2% | 7.8% |

if not explicitly stated in a paper. Table 1 presents the sample profile based on the type of research reported in the paper, confirming that the originally chosen coding scheme can be considered sufficient, as over 92% of the new and around 82% of the original dataset can be directly matched to the codes.

### *3.3. Coding Schemes*

For each of the research types described in the previous section suitable coding schemes for the aspects to be reported (Figure 1) were derived from the discussed literature and the original codes by Cantamessa (2001, 2003). With reference to aspects (d), (f) and (g), we extend from immediate implications and also code papers as to whether there are references to industrial needs for the research carried out. This would be indicative of reported research linking to concrete practical applications and knowledge gaps in practice which are consistently stated in literature a fundamental raison-d'être of engineering design research. The most prevalent coding schemes for the aspects to be reported for each type of research are presented in Table 2.

## 4. Results

### *4.1. Geographical distribution and parity assessment*

The country of origin of a paper is defined as the country of the affiliation (institution) of the corresponding author. It is acknowledged that there is international exchange between research institutions and scholars; yet, for the purpose of this analysis, we are mainly concerned with the lead author's affiliation as a measure of the consistency in contributions to ICED conferences. Cantamessa (2001, 2003) and McMahon (2012) found these to be predominantly from Europe, which our analysis confirmed to still be the case for ICED 2017/19 (see Table 3), despite the fact that every other ICED conference between 2005 and 2019 has been held in other continents. The core of the ICED community, at least those that attend the ICED series, resides in Europe, with authors from German-speaking countries (DACH) being the most prominent contributors. This is consistent over the 20-year period. Minor shifts are observed in an increase of papers from Europe as a whole and three of the four regions we distinguished; the number of papers from UK and Ireland shrunk from 21.4% to 8.4% in the same time span. Globally, we observe a relative decrease in papers from Asia-Pacific, while Central Asia and Americas are seeing an increase.

We also observe a strong recurrence of affiliations between both data sets. As one example, out of the top contributing institutions (eight papers or more) in 1997/99 (17 institutions) and 2017/19 (19 institutions), there is an overlap of 11 institutions. These findings indicate good consistency over the 20-year timespan and gives confidence that no large

**Table 2.** Coding schemes used for each aspect to be reported and type of research.

| Aspects to be reported | EMP-specific codes | EXP-specific codes | NT-specific codes | IMP-specific codes | OTH specific codes |
|---|---|---|---|---|---|
| (a) Applied (overall) guiding or underlying research methodology | Is a clear description of, or section on the overall used methodology/ approach/ methods reported: 'present' or 'absent'? | | | | |
| | Is the overall objective of the reported research clearly stated: 'yes' or 'no'? | | | | |
| | Is the aim of the concrete study and corresponding method election clearly stated: 'yes' or 'no'? | | | | |
| | Is the data/sample profile clearly described? 'Yes' (either: 'individual', 'project/team' or 'firm/company/organisation') or 'unclear'? | | | | |
| | Is the number of cases/sample size/number of units of analysis studied clearly described? 'Yes' or 'unclear'? | | | | |
| | Is the nature of the study reported clearly stated in a relevant section to permit judgement of the type of category (ES, EX, etc.): 'yes' or 'no'? | | | | |
| (b) Applied research methods for (every) relevant step(s) carried out within a research study | If data was collected, is there a clear description of, or section on research methodology/methods used reported: 'present' or 'absent'? | | | | |
| | If data is analysed is there a clear description of, or section on research methodology/methods used to do so reported: 'present', 'absent'? | | | | |
| (c) the theory and/or related work on which the work is grounded | Are there references to theories present in the conceptualisation of the work reported and, if yes, what is their origin: 'design theories', 'theories from adjacent fields', 'no theories'? | | | | |
| | Are there references to/awareness of results from empirical research related to the topic area: 'yes' or 'no'? | | | | |
| (d) Interpretation of the findings with respect to the wider context of investigation | | | | | |
| (e) Evaluation results as per their consistency and alignment to extent research/theory | | | | | |
| (f) Derived implications for practice (as the industrial or educational reality) | Are concrete conclusions/implications for practice (education or industry) stated clearly: 'yes' or 'no'; | | Is the implementation of method or tool in practice discussed: 'yes' or 'no'; | Is the translation of the tool or method into other context discussed, generalised/inferred: 'yes', 'no', other purposes. | |
| (g) Discussion of application of developed knowledge, insights, models or methods/tools | Are concrete conclusions/implications for theoretical context or body of knowledge stated/discussed: 'yes' or 'no'? | | | | |

**Table 3.** Geographical distribution of ICED papers of 1997/99 (n = 747) and 2017/19 (n = 820).

| | | Europe | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | D, A, CH | Scandinavia | UK & Ireland | Rest of Europe | Americas | Africa | Central Asia | Asia-Pacific |
| ICED97/99 | 80.6% | 26.1% | 9.9% | 21.4% | 23.2% | 12.3% | 0.1% | 0.9% | 6.4% |
| ICED17/19 | 76.0% | 28.7% | 11.1% | 8.4% | 27.9% | 14.9% | 0.2% | 5.1% | 3.8% |

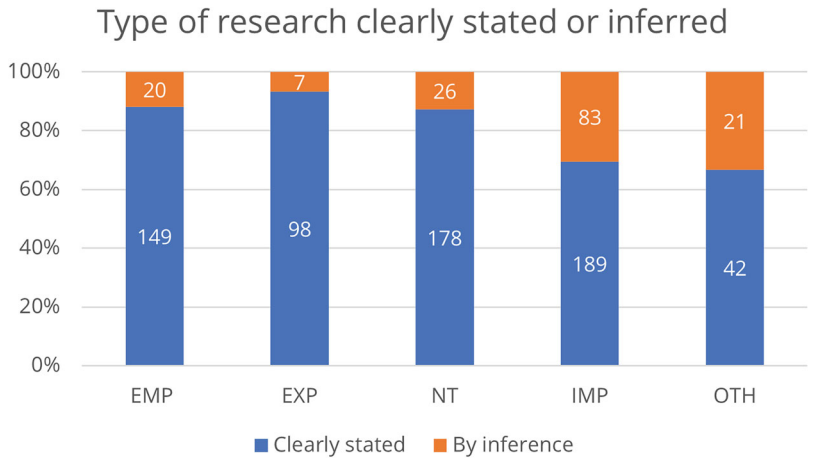


**Figure 2.** Types of research clearly stated in the ICED17/19 papers, versus those that could only be inferred by the team from the paper (n = 820).

shifts have occurred in the demographics of the community that may have caused changes in reporting.

### *4.2. Type of research*

The classification shown in Table 1 is based on the types of research as specified in the papers' abstracts, introduction and/or method(ology) sections; as mentioned, this was inferred from the descriptions, if not clearly stated. Figure 2 shows the percentage of 2017/19 papers clearly stating the type of research versus those that had to be inferred from the descriptions. On average, 19.0% of the 2017/19 papers required inference to code the type of research, or 15.4% if the OTH type of research is ignored. Whether a change in clarity of stating the type of research has occurred from 1997/99 to 2017/19 cannot be established as Cantamessa's original dataset only stated the final outcome of this analysis, i.e. the type of research.

How the types of research reported in the papers have changed over the relevant 20-year period is visualised in Figure 3. In 1997/99 almost half of the 747 papers (46%) were propositions of new tools or methods (NT), whereas empirical (ES) and experimental (EXP) work had the smallest shares (15% and 6% respectively). The second largest group (18%) were 'other' papers (OTH), i.e. those could not be attributed to any of the other types of research. In 2017/19 we see a much different distribution. OTH papers now form the smallest group (8%) and the NT group of papers has nearly halved to 25%. In contrast, the number of EMP and

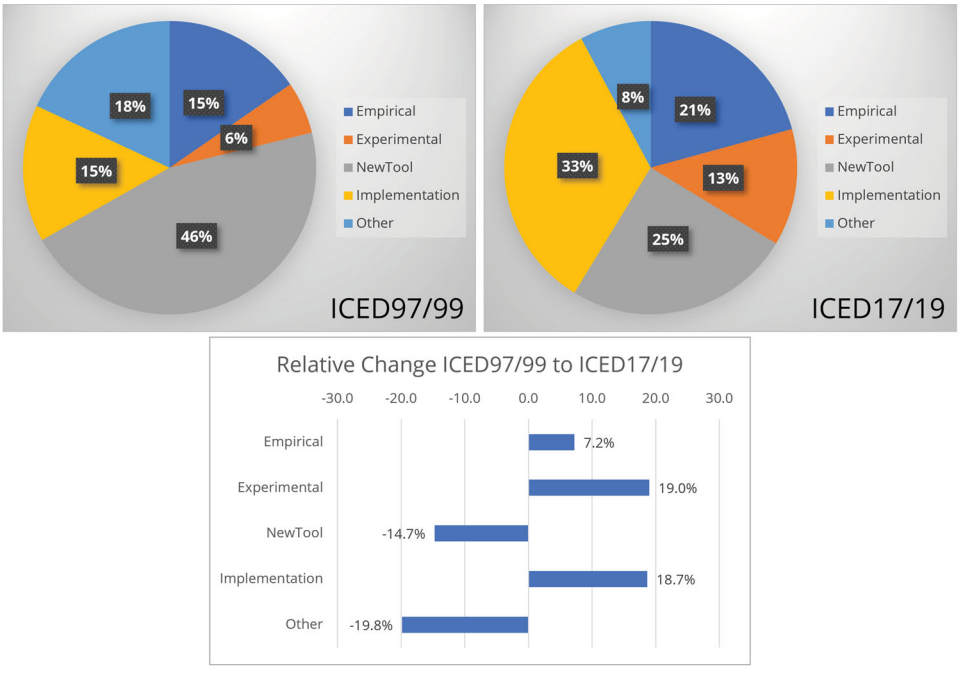


**Figure 3.** Change in research types from ICED97/99 (n = 747) to ICED17/19 (n = 820).

EXP papers have increased substantially to 21% and 13%, respectively, and implementation studies (IMP) have nearly doubled to 33%.

These results suggest the community to be paying decisively more attention to understanding the phenomenon of design and the use of specific tools and methods within it, and relatively less to proposing new tools and methods to guide the design process or specific steps. As per the reviewed literature (Section 2), it is a fundamental requirement for the development of new tools and methods and similar support for practice or education, to ascertain a sufficient and comprehensive understanding of the phenomena these aim to support. As such, the observed shift would suggest a (more or less conscientious) effort in the community to perform relevant fundamental research before proposing new tools and methods for designers to use. This, by extension, would be indicative of an overall better awareness of the need for rigour in research, in this case, the need to have solid foundations before proposing new tools or methods. A possible driver could have been the increased interest in design in practice and education, which emphasises the importance of understanding the current situation (users, processes, context) before starting the development of concepts. Another possible driver is the increased emphasis in literature, courses and summer schools on the requirements of design research as a scientific endeavour, that is, the need for knowledge production as essential part of doing research, as foundations for the development of theories and models as well as tools and methods.

The reduction of the OTH category could suggest a more targeted selection of papers that are deemed suitable for the ICED conference series in the more recent editions, either by authors (not) submitting work that does not fit the main categories, or through a more directed review process. It must be noted though, just because the OTH papers do not fall

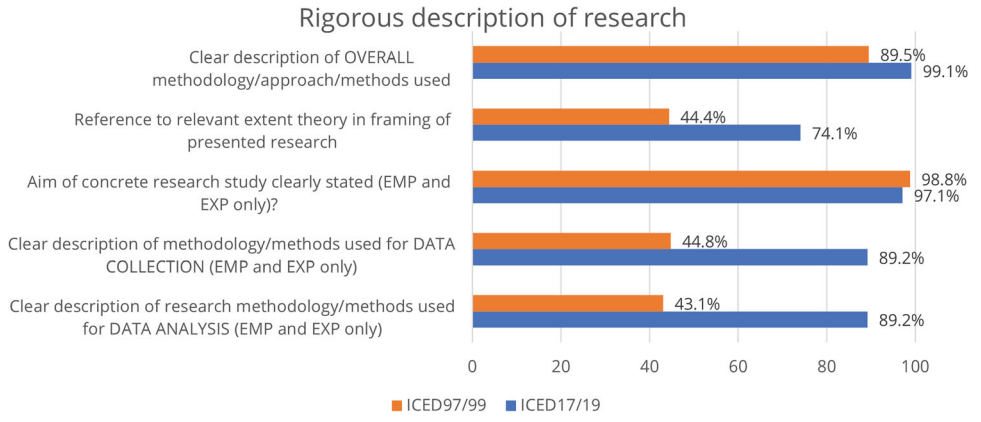


**Figure 4.** Rigour in reporting on aims, methodology/methods, and theoretical/literature foundation. (ICED97/99: n = 612, ICED17/19: n = 756)

within one of the four other categories that they could not be very interesting or important for the development and potential renewal of the field.

### 4.3. Method(ology) used and theoretical framing of research

For any type of research, the application of an (overall) guiding or underlying research methodology and the grounding of the research in relevant theory and/or related work are fundamental (see also Section 2) and therefore need to be reported.

First, we turn our attention to the reporting of these aspects in the two sets of papers. OTH papers are not included in the analysis presented in this section. They are of a different nature and an analysis carried out both including and excluding these papers showed only negligible differences in the descriptive statistics, affecting decimals of percentages only.

In accordance with the relevant coding schemes (see Table 2) this pertains specifically to whether the paper reports on an *overall* systematic (scientific) approach or method(ology) followed in setting up and carrying out the work, and whether *relevant theory* has been used/is referenced in conceptualising and framing the reported research. Specific to those papers that by nature deal with data collection and analysis, mainly EMP and EXP, we also pay attention to whether specific methods(ologies) were followed for *collecting* and the *analysing* any data and if this aligns with a clear statement of *aim(s) for the actual study carried out* and reported on. The results are presented in Figure 4.

We observe that reporting on the overall method(ology) (often referred to as 'approach' by the authors) used is very well covered in both sets of ICED papers, with ICED17/19 falling just short of 100%. We further observe that almost all these papers contain a clearly marked, separate method(ology) section. More noticeable differences are observed, however, in terms of clear articulation of theoretical framing of the reported research. While this is found in less than half of papers in 1997/99, in 2017/19 almost three-quarters of papers feature this.

Turning towards data-related work in EMP and EXP papers, Figure 3 shows that while in both data sets the specific aims for data collection and analysis are reported in almost all

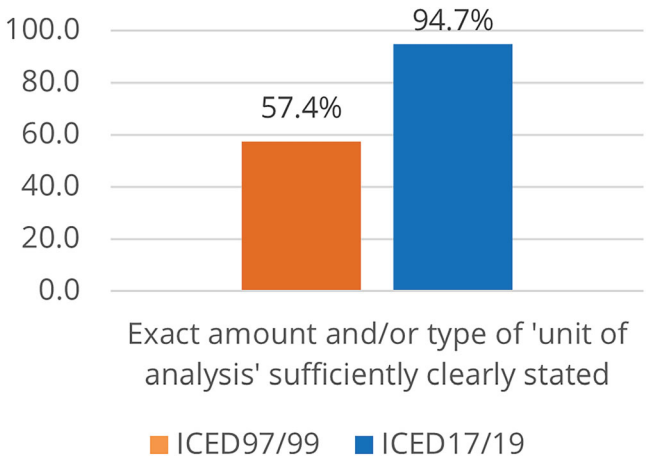


**Figure 5.** Quality of reporting of amount and/or type of data in empirical research (EMP) papers (ICED97/99: n = 115, ICED17/19: n = 169).

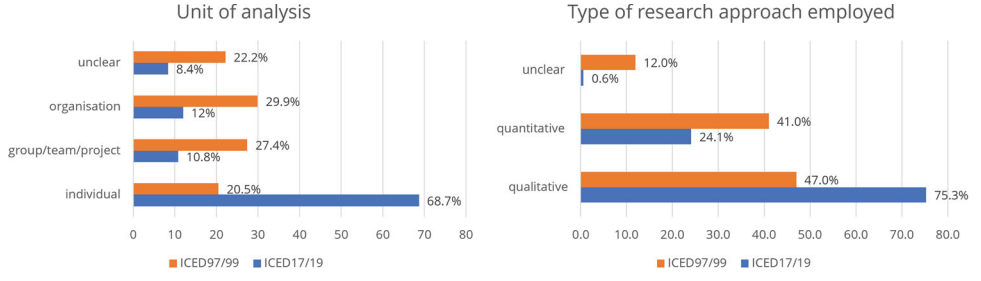


**Figure 6.** Reporting on unit of analysis and research approach employed (EMP papers only) (ICED97/99: n = 115, ICED17/19: n = 169).

papers, starker differences are observed for reporting the method(ology) used for *collecting* and *analysing* data. Whereas in 1997/99 less than half of these papers describe those methods, in 2017/19 nearly 90% have such a description.

These findings on the reporting of methods and methodologies and on the theoretical framing, prompted a more detailed analysis. First, we analysed if the differences in method(ology) sections being reported for data collection and analysis are equally evident in reporting on what *amount* and what *kind of* data was involved in the reported research. Secondly, we analysed the type of specific theories cited or whether related empirical research is cited, respectively (as relevant).

### *4.3.1. Reporting on data collection and analysis in empirical research papers*

First, we analyse – for the relevant papers – whether the *nature of data* involved in the study and/or basic information on *quantity (i.e. sample size)* per the relevant 'units of analysis' are reported sufficiently well that there is no ambiguity as to who or what exactly was studied. Findings for EMP papers are presented in Figure 5.

Next, we review the reporting of the unit of analysis and of the nature of research approach employed (i.e. *qualitative* or *quantitative*), see Figure 6.

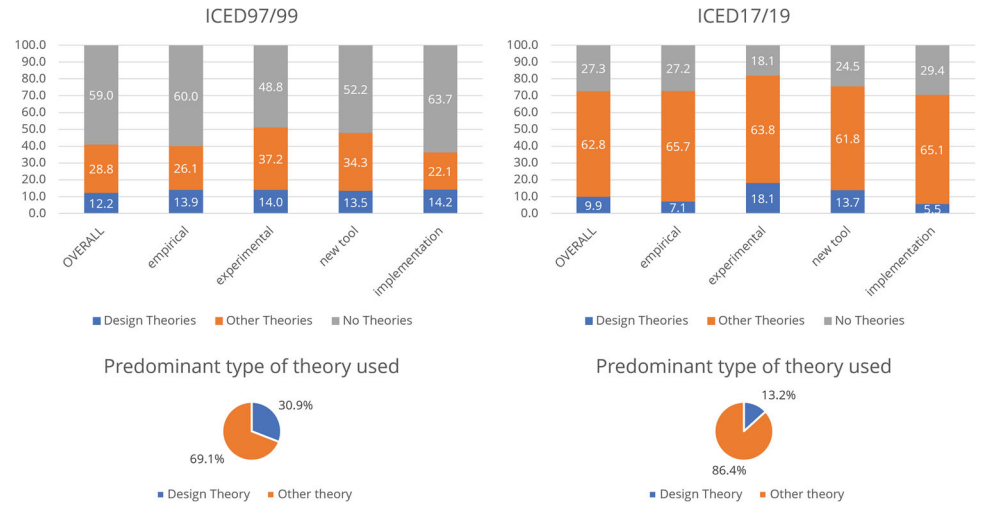


**Figure 7.** Reference to extant theory in framing the reported research (ICED97/99: n = 612, ICED17/19: n = 756).

The findings correlate well with the findings presented in Figure 3: nearly 90% of relevant papers in 2017/19 provide clear articulations of the data collection and analysis methods/methodology. Only 5% of EMP papers in this dataset do not provide sufficient clarity on who/what and how many of the relevant 'unit of analysis' were studied (see Figure 4). Thus, half of those who did not articulate the methodology, still reported details of the unit of analysis. The same is not true for the 1997/99 papers: less than 45% of papers provided sufficiently clear descriptions of the data collection and analysis methods but only 22% of those who did not provide a methodology description, provided details on the unit of analysis (Figure 4), leaving 43% of papers without any reporting on these essential aspects of rigorous research. This is reflected in a substantially higher ratio of papers from 1997/99 where it remains unclear who/what was studied and in what way the data was analysed (Figure 6).

In terms of the *type of unit of analysis* and *nature of research approach employed* Figure 6 shows an about equal distribution across the categories in 1997/99, whereas now we see a substantial change to (1) empirical papers clearly focusing on individuals as unit of analysis – more than two thirds, in fact – rather than at group or organisational level; and (2) over three quarters of relevant papers now employ a predominantly qualitative approach. A further analysis would be interesting but falls out of the scope of our study.

### *4.3.2. Awareness of/reference to relevant theory or other relevant empirical research*

In this section, we take a closer look at whether extant theory is referenced in framing the reported research in the two datasets and whether such theory is *predominantly originating from design research* or *other fields of study*. We acknowledge both types may occur in parallel; in such cases, categorisation was based on the *prevailing* type of theory used in framing the reported research. Findings are presented overall and for each type of research in Figure 7.

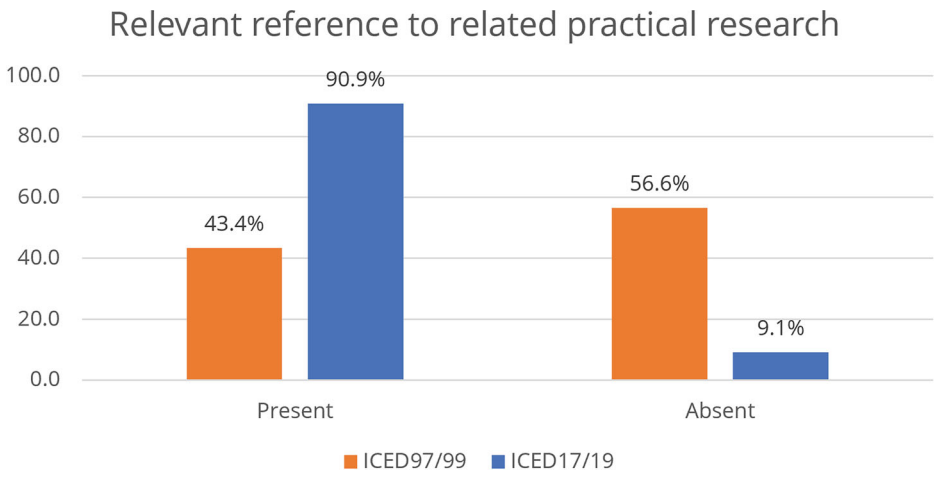


**Figure 8.** Awareness of/reference to related empirical or experimental research for implementation (IMP) studies (ICED97/99: n = 113, ICED17/19: n = 272).

We again observe a stark contrast between the 1997/99 and the 2017/19 ICED papers in terms of whether or not relevant theory is referenced. Numbers seem fairly consistent across types of research in both sets of papers. In both, the largest difference is observed between EXP papers (highest) and IMP work (lowest). More interestingly, we observe that the *relative* utilisation of design theory versus other theory shrunk between 1997/99 and 2017/19, with a calculated percentual difference of −20.03%. However, the total amount of papers explicitly referring to extant theory in their conceptual framing more than doubled at the same time. This means that today, the community builds on a much wider pool of relevant theories, increasingly from outside of the engineering design domain. This is plausible for two reasons. Firstly, as discussed in Section 1, we have seen permeation and increasing exchange between engineering design research and adjacent fields and thus of theories and research methods/methodologies these fields are using. Secondly, referring to Figure 2, EMP, EXP and IMP studies have substantively risen in significance, where it is broadly acknowledged that such work tends to borrow methods/methodologies and theories from fields such as the social sciences (Bender et al. 2002; Diekmann 2001).

We observe the lowest numbers of reference to extant theory for the framing of the reported research within the IMP papers. For this type of research, we further analyse whether authors have referred to related empirical or experimental work which would, alternatively (or in addition) to theoretical framing, allow for positioning of the research and its outcomes. This allows us to draw conclusions on whether authors more generally are aware of related research and draw cross-links between these and their own work. The latter again would indicate adherence to good scientific conduct. Findings are summarised in Figure 8 and highlight a substantial change between 1997/99 and 2017/19: less than half of the 1997/99 papers clearly showed awareness of related practical work (empirical or experimental) compared to over 90% in 2017/19.

The findings summarised in Figures 3–8 paint a clear picture, both with respect to rigorous reporting of research and how this has changed in the period of 20 years. We see a substantial improvement: papers now clearly articulate the aim of the reported work is, how

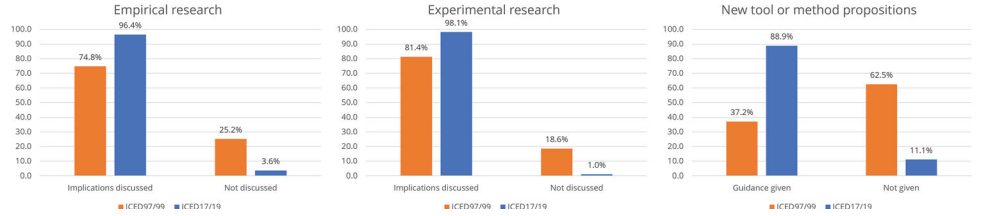


**Figure 9.** The percentage of papers providing clear statements about implications for practice (education or industry) (EMP and EXP, ICED97/99: n = 158, ICED17/19: n = 274) or concrete recommendations and guidance for implementation and application of the research outcome in NT papers (ICED97/99: n = 341, ICED17/19: n = 204).

it was carried out, what specific data was collected, in what way, and how it was analysed. Equally, we see a clearly positive trend in terms of reference to extant theory in framing the reported research.

### *4.4. Reporting on implications for practice and implementation of the research outcome*

The focus of this section is on any reporting on the relevance of the research for practice. The EMP and EXP types of paper were analysed as to whether they contain concrete conclusions and/or implications for practice (education or industry) of the reported research. The NT types of paper were analysed as to whether they provide concrete recommendations or guidance on how to implement and apply the findings or the proposed methods and tools in practice (see Table 2). Results are shown in Figure 9.

The results suggest that across all three categories there is an extremely high ratio (88.9% to 98.1%) of papers of ICED17/19 that explicitly discuss implications for practice of the reported research (EMP and EXP) or provide a concrete set of recommendations or guidelines for how to apply or implement the developed tools and methods (NT papers). Compared to ICED97/99 there is a significant improvement for all three types of paper, specifically though for the NT category. Most ICED97/99 papers (62.5%) did not provide/discuss such information.

As a final point of analysis, we turn to the IMP type of paper. By nature, implementation studies focus on how a method or tool is/could be applied in practice. As can be expected all implementation type papers report explicitly on the application in practice, at least to some degree. As a point of interest, we also analyse differences in the aim/purpose behind the reported IMP studies. Through inductive coding, we identified four main purposes:

(1) *Discussing* how implementation of the relevant method or tool *would* work, without testing this in real-life;
(2) Studying *implementation* of a relevant *existing method or tool* in a real-life context, but no attempt to generalise findings to another situation;
(3) Studying *implementation* of a relevant *existing method or tool* in a real-life context, with the attempt to generalise findings to other situations;
(4) *Developing a (rigorous) methodology* on how to apply the method or tool that is subject of the implementation study in a real-life context.

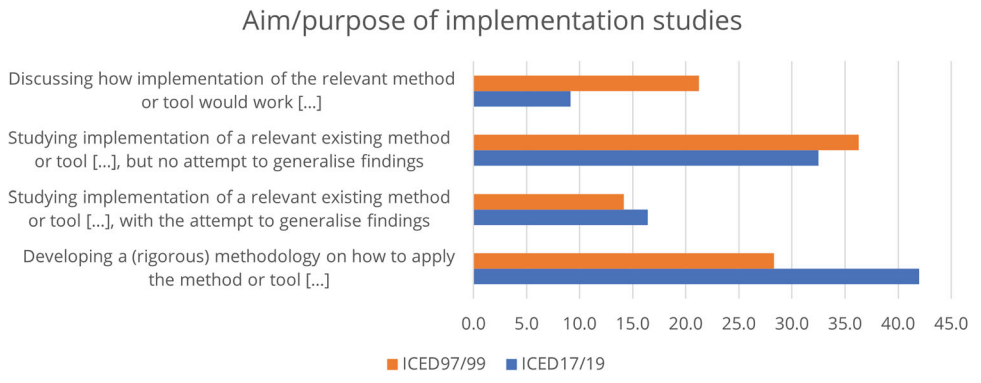


**Figure 10.** Aim of implementation studies (IMP) in relation to practical application of the research finding or proposed methods/tools (ICED97/99: n = 113, ICED17/19: n = 272).

These purposes were used as coding scheme for IMP papers. The results presented in Figure 10 show that, though all papers present some degree of discussion of practical implementation and application (that is, any of the three purposes outside of mere *discussing* how implementation *would* work), in 2017/19 more IMP papers (90.9%) directly address/target application of the studied tools/methods in a real-life context compared to ICED97/99 (78.8%).

## 5. Discussion

### *5.1. Good compliance in recent years and a positive trend*

The findings allow us to give some answers to RQ1 on the current state of rigour in reporting of research at the 2017 and 2019 ICED conferences, and RQ2 on the differences and commonalities in terms of rigour in reporting on research between the 2017/19 ICED proceedings and the 1997/99 ICED proceedings analysed by Cantamessa.

Focusing on RQ1, the current state of rigour in reporting of research at the 2017 and 2019 ICED conferences, we see an overall positive situation. Across all central measures of rigour in reporting of the conducted research (Table 2), the 2017/19 papers score above or close to 90% compliance with the studied criteria for 'good' conduct of carrying out research (see Figures 4–6, and Figure 8). The only exception is the number of papers referring to *extant theory* in the framing of the reported research, which can only be found in 74.1% of the papers (see Figure 4). We will discuss this in more detail shortly. Last but not least, we see an equally high compliance with respect to discussing implications for practice of the research carried out (Figures 9 and 10).

Focusing on RQ2, the differences and commonalities in terms of rigour in reporting on research between the 2017/19 and the 1997/99 ICED proceedings, we observed the following. For all aspects to be reported, we see a substantial improvement, where in many cases the 1997/99 papers scored under or close to 50% in compliance with the studied criteria for 'good' conduct of carrying out research.

The compilation of findings in Table 4 confirms that, compared to the 1997/99 papers, the 2017/19 papers clearly report their overall aims, in what manner it was carried out, following a clearly described overall research method(ology), most often provide a good

**Table 4.** Summary of findings (Types of research: EMP = empirical, EXP = experimental, NT = new tools/methods, IMP = implementation and application, OTH = other, not included for all criteria).

| Aspects of rigour in reporting | Type of research | 1997/99 ICED papers | 2017/19 ICED papers | Diff in % points |
|---|---|---|---|---|
| *Related to criteria of rigour in research* | | | | |
| Clear description of the overall methodology/approach used in the research | All (no OTH) | 89.5% | 99.1% | 9.4% |
| References to extant theory in the framing of the reported research | ALL (no OTH) | 44.4% | 74.1% | 29.7% |
| Clear description of the aim of empirical or experimental studies | EMP, EXP | 98.8% | 97.1% | -1.7% |
| Clear description of the methodology/methods used for data collection | EMP, EXP | 44.8% | 89.2% | 44.4% |
| Clear description of the methodology/methods used for data analysis | EMP, EXP | 43.1% | 89.2% | 46.1% |
| Specification of the unit of analysis | EMP, EXP | 57.4% | 94.7% | 37.3% |
| Specification of type of research approach | EMP, EXP | 88.0% | 99.4% | 11.4% |
| *Related to implications for practice* | | | | |
| References to related empirical or experimental work | IMP | 43.4% | 90.9% | 47.5% |
| Clear statements on implications for practice | EMP | 74.8% | 96.4% | 21.6% |
| Clear statements on implications for practice | EXP | 81.4% | 98.1% | 16.7% |
| Concrete recommendations and guidance for implementation and application of research outcomes | NT | 88.9% | 89.9% | 1.0% |
| Description of the actual implementation of the studied tools/methods in a real-life context | IMP | 78.8% | 90.9% | 12.1% |

theoretical framing and then – if data is collected and/or analysed – proceed to report their step-by-step methodological approach, i.e. how the data was processed and who/what was studied. Finally, they tend to make an effort to describe and discuss concrete implications of their research for practice.

Before addressing RQ3, *reference to extant theory* demands further exploration from two viewpoints. Firstly, at 74.1% it scores lowest for the 2017/19 ICED papers in terms of compliance to the measures of rigorous reporting. While three quarters in compliance is a considerable improvement compared to 1997/99 (44.4%), theoretical framing is essential for scientific research (Prochner and Godin 2022, Wacker 2008). Figure 5 suggests that the type of research does not fully explain the comparatively lower compliance. As an alternative explanation, we look at potential influences from research culture and correlate our measures for rigour with geographical regions of the corresponding authors (see Section 4.1) to test if geographical regions are reliable predictors of deviation from compliance with central measures of rigour (see Table 3). One-tailed Pearson's correlations show only a few such links to be significant. For *reference to extent theory* we find the Asia-Pacific region to be positively correlated ($r(29) = .078$, $p = .01$) suggesting a significantly higher compliance than other geographical regions, whereas DACH is moderately negatively correlated ($r(233) = -.073$, $p = .02$), suggesting a comparatively lower compliance than other geographical regions. Differences between geographical regions could indicate differences in training of early-stage researchers, such as PhD students.

Next, we analyse *references to previous ICED papers*. We find Central Asia and the Americas to be negatively correlated to referencing previous ICED papers (their *own*, *others'* and *overall*). DACH is found to be significantly positively correlated with referencing previous

ICED papers *overall* ($r(233) = .137$, $p = .00$) and their *own* ($r(233) = .087$, $p = .01$), but not of *others* ($r(233) = .049$, $p = .08$). This would suggest that DACH papers tend to report comparatively less on framing around extant theories, but in turn more often use their own (or their own research group's) previously published work for framing reported research.

A further noteworthy finding is shown in Figure 7. As mentioned, the percentage of papers that refer to extant theories has nearly doubled from 1997/99 to 2017/19. However, of the extant theories that are referenced in the 2017/19 papers, the ratio of design theories is rather low (only in 13.2% of papers were design theories the predominant type of theory referenced) and is in fact lower than in the 1997/99 papers (design theories were the dominant type in 30.9% of papers that referenced extant theories). It should be noted that references to theories from outside design were often related to setting up the research or framing the research. For a field that addresses a wide range of aspects (processes, people, organisations, etc.) that, individually, are the focus in other fields, the use of such, often established and fundamental theories is important and indicates a strongly increased awareness of and search for theories that could be relevant for one's research. This also supports the notion of a vitalised exchange and a broader range of theories to enter the engineering design community (Section 1). This raises questions around distinction as scientific field of study. It could be argued that a field should have its own theories to draw upon primarily (at least more regularly) to have a consistent frame of reference. Interest in the development of more fundamental design theory exists and developments have taken place (see e.g. Chakrabarti and Blessing 2014a for philosophical, theoretical and empirical contributions from a variety of researchers). As discussed by (Chakrabarti and Blessing 2014) some extensive attempts to develop theories and models of design took place in the 90s, but the majority never really became established (or even accepted) during that period as a fundamental basis for design research, even for research addressing the very concepts the theories were based upon. This period has been referred to as pre-theoretical, pre-paradigmatic (Cantamessa 2001) or pre-hypothesis (Horváth 2001). Shortly before the turn of the millennium, i.e. the period of our first data set, the situation changed rather quickly. Several new theories of a very different, often more focused, nature were proposed, and some of the earlier work was further developed. As the internet allowed publications to be more easily accessible, the theories became more widely known in a short period of time. They were also accompanied by more fundamental discussions and are richer in nature, using more and different concepts compared to the earlier ones (for a more detailed discussion see Chakrabarti and Blessing 2014). Interestingly, this renewed focus on theory in the 90's took place in parallel to a gradually increasing focus on empirical and experimental studies. The latter, however, did not become an established type of research until in this millennium (as our data shows). These developments may provide a possible explanation for firstly, the observed increase in theorisation and secondly, the reduced percentage of design theories in in the ICED17/19 publications as compared to ICED97/99. The increased theorisation may have been due to a greater awareness caused by the widespread publication of new theories, the many articles highlighting the issues of rigour and the pre-theoretical state of our research (as we discussed earlier), as well as workshops and summer schools emphasising the importance of a theoretical foundation to research. The review criteria for ICED publications are too similar for both datasets to have made a difference in the selection. The reduced percentage of design theories is an interesting finding, which merits further research. We suggest at the moment three possible explanations or

a combination thereof: the new theories are not as applicable as they should be for those who were not involved in their development or did not receive training; the new (and old) theories only cover a subset of the concepts that our research endeavours address; established theories in other fields are applicable – at least partially – to our research. Whatever the explanation, one would have expected that the strongly increased number of empirical and experimental studies and the awareness of the need to use theories over the analysed period of 20 years, would have not only led to an increased *use* of theories, but to an increased *development* of more, maybe more specific or refined, design theories and models, and for the percentage of design theories used to be at least the same as in ICED 1997/99. This leads to a final possible explanation: engineering design researchers are less interested in developing theories or models, but more interested in using research results to develop design support. The underlying issue may be that combining scientific and practical goals causes design research to be 'pulled in two opposing directions – towards scientific rigor on one hand, and a greater relevance for professional practice on the other' (Sonalkar et al. 2014). The research community will have to address this dilemma. As a final comment, this effort towards reaching higher standards in research rigour has occurred during a time in which design has been subject to momentous change, both looking at the industrial environment and its needs, and at enabling technology. The need to adapt quickly to a changing environment might be considered as something that runs counter to the effort of developing rigorous standards for research, which requires time and stability. The fact that the research community has been able to cope with change, as demonstrated by the numerous new research streams and topics that have been introduced during these twenty years, at the same time exhibiting growth in research standards, could therefore be pointed out as a positive achievement. At the same time, this achievement contains a warning for the future, to ensure that this balancing act between developing solid foundations and being nimble enough to adapt to a changing environment will still be carried out successfully, thanks to a positive discourse within the academic community and a constant dialogue with industry.

### 5.2. Recommendations for the future

Clearly, the community is on a positive trajectory and proceedings have a high ratio of compliance with the aspects to be reported. From the findings and their further discussion, we posit several recommendations for the future (RQ3) and points of interest for the community to engage with.

#### 5.2.1. Referencing extant theory is essential in any type of research.

While more established sciences, such as psychology, physics, and more recent sciences, such as management, have been trained in and reference the specific, accepted theories they have at their disposal in their field, this is not the case in engineering design research. The number of theories is low, not necessarily generally accepted and, with few exceptions, hardly ever taught and applied in engineering design education. Even if they were, researchers in the community come from a wide range of backgrounds. However, it is vital to explicate the theoretical framing underpinning one's research for the research to be interpreted correctly. The use of theories other than design theories can be very worthwhile but should not be the only possibility to provide a theoretical underpinning because of a

lack of (awareness of) design specific theories. We posit two central demands. Firstly, the community should expend efforts in considering and raising awareness of existing design theories and relevant theories from other fields, and in developing new theories or adapting theories from other fields to cover the many unique phenomena in engineering design where theories are currently lacking. Conferences could emphasise the importance of including the theoretical underpinning of the research for papers to be accepted. While the diversity of backgrounds is acknowledged and appreciated, there must be a foundational set of theories that is shared within the community. Identification and clear communication of which theories the community sees as essential will be needed. This may also be translated into peer review guidelines and more into education/training programs (potentially through the Design Society and Design Research Society) offered to emerging researchers in the community (e.g. PhD students). We identified differences in theoretical framing of reported research between geographical regions, which may be caused by differences in research cultures. Although cultures change over time, providing training through the community – at least at the start – may be most effective.

#### *5.2.2. Rigorous reporting*

Concerning rigour in reporting, the community could mandate that papers must have sections or paragraphs on the aspects to be reported, depending on the type of research, such as the *overall* methodology/approach used, the theoretical underpinning, or the method(s) used for *collecting* and for *analysing* data. Templates and review guidelines mandating such sections will not only help improve the reporting of the research, but also prompt researchers to utilise dedicated methods for data collection and analysis and to document their work accordingly.

#### *5.2.3. Providing source data*

In many disciplines, it is already common practice that survey protocols and essential data must be provided along with research papers. In some cases, the data will be publicly available, in other cases the data is kept by the publisher and only accessible in case of legitimate interest or for use by the reviewers. We noted already that clear descriptions of measures taken to affirm, triangulate and verify the results were extremely scarce. Without such description and without access to the data, it is impossible to verify internal or external integrity, impartiality, or reasonability (see Figure 1) of the research reported. This invites criticism from other research disciplines if the credibility and trustworthiness of the published results cannot be verified. The community together with publishers should discuss how such practice could be introduced, taking heed of the experiences in other disciplines.

Ultimately, these proposals point in the direction of not only improving the reporting of design research with respect to traditional standards, but to bring it closer to current best practice, so that it may stand up against scrutiny at the most rigorous scientific standards and be good examples for young researchers. As stated, the criteria of rigour in research were rarely discussed in the analysed papers, let alone critically discussed.

The data we had to our disposal did not allow us to determine whether the lack of rigour in reporting is only a reflection of the way in which research is reported, or whether this is a reflection of a lack of rigour in the conduct of the research itself. We do believe, however, that the two go hand in hand. As mentioned earlier, reporting is a vital part of research, and both should be conducted with the same high level of rigour.

### 5.3. Limitations and future work

A potential limitation to the study is unconscious bias. Selection of evaluation criteria, training of coders, etc. can carry an inherent experimenter bias. To reduce bias, coders were recruited outside of the team of authors and a two-level Delphi analysis was used during coding to ensure inter-coder consistency. The dataset is extremely rich, with just under 35,000 datapoints. Delta analysis of initial codes showed minimal deviations and findings were consistent in nature between coders, thus propelling our confidence in the results.

Secondly, the analysis of the two sets of ICED proceedings was a time-demanding endeavour and while a huge, combined dataset emerged from this, there are limitations to what could be reviewed. As mentioned, a thorough check of validity of the specific data collected and analysed, reasonability of choices of method(ology) and their contextualisation and framing with theory was beyond our scope. Future research should, however, address this. In-depth analysis of a selection of papers would clearly aide the community to further review and improve practices. One of the first aspects to look for is reasonability of method(ology) selection matching the aims, sample and its theoretical contextualisation, as key aspects of 'good' research conduct following the literature discussed in Section 2.

### 5.4. Conclusions

This paper shows the significant improvements made over the last 20 year in their reporting of research in one of the main conferences of the community. We believe that this is a reflection of the improved rigour of the research itself, but we were not able to confirm this with our data. This paper cannot advance the fundamental discussion in the community of what makes engineering design its own discipline. However, it provides insights into potential areas of further development that can raise the quality in research conduct and rigour in reporting. These, in turn, may help to frame the work we are doing in the community, specifically in relation to theoretical contextualisation and thus to the distinction of the discipline as such.

## Notes

1. The bi-annual ICED series of conferences started in 1981 as an initiative of the WDK (Workshop Design Konstruktion). With the establishment in 2000 of the Design Society (globally the largest research body promoting engineering design research), the organisation of ICED moved to the Design Society as its flagship conference.
2. By not including ICED 2021 and 2023 we forego influences from changes in the way people work, collaborate and travel during the pandemic (see e.g. Holtta-Otto et al. 2023) which arguably could have affected the type of empirical/experimental research studies that were carried out and are thus published in the ICED 2021, and possibly also in ICED 2023.
3. This also aligns with the third issue identified by Blessing (2002, p.4), i.e. 'the observed lack of scientific rigour, in particular with respect to the application of research methods, the interpretation of the findings, the evaluation of the results and their documentation'.

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