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A Metaresearch on Engineering Design Research

The Case of Empirical Studies

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INTRODUCTION

The design research is distinguished by a number of features when compared to other areas of engineering. Some of these include its relatively youth, the diversity of different approaches used, the contribution of researchers from different professional disciplinary backgrounds, together with the absence of a specific area of the natural sciences that it can be considered a natural descendant of and where research methods and tools have been adopted from. As a result, it is challenging to precisely define the scope, type of research approach, or the community which stands behind engineering design research. Being aware of such issues is essential for proper research leadership in general, along with associated activities like organizing events, peer reviewing, or mentoring the work of graduate researchers.

A study conducted by Cantamessa (2003) had the objective of making a first effort in this regard by presenting a quantitative analysis of the contributions to the 1997 and 1999 editions of the International Conference on Engineering Design (ICED). However, it seems that such a study was not repeated for the publications in the ICED conferences of the following 20 years. With this study, it is intended to repeat the analysis done 20 years ago for ICED17 and ICED19 in order to provide an up-to-date overview of engineering design research and to compare it with the study conducted 20 years ago. In addition to analyzing all types of research papers published at ICED17 and ICED19, another objective of this study is to specifically focus on the empirical studies conducted at these conferences and examine each unique feature of those in-depth.

As Cantamessa (2003), this study is designed to contribute to the discussion on the foundations of design research by providing a preliminary empirical "cross-section" of the work of the research community. To this end, it examines the papers presented at the 2017 and 2019 International Conference on Engineering Design (ICED). The decision to analyze the information provided at ICED was made because it is one of the largest and most comprehensive conferences in the field of design research.

One of the reasons why the papers from this conference were selected is because of the diversity and prestige that are at the core of this conference. At ICEDs, design research from a variety of fields is presented by early career scholars, researchers, students, and industry.

This should help to understand the gaps that have existed in this field, which is still quite young but rich in data and information. The selection of a single conference may lead to biases, such as an over-representation of the work of European researchers and, consequently, their chosen topics of investigation. In terms of the generality of the results presented in this paper, the likelihood of such bias should be considered a limiting factor.

In line with Kuhn, this paper explores the scope of design research as an identifiable research paradigm (Cantamessa, 2003). According to Kuhn (1962), a paradigm is a combination of research questions, underlying theories, and research methods generally accepted among a scientific community in the intervals between scientific revolutions. The value of the paradigm is when researchers who adhere to the paradigm do not have to go "back to basics" each time but can build on the work of others and advance the topic of study in a rapid series of gradual advances. This process continues until the paradigm's theory and procedures reach their limits and they are no longer able to meet new challenges. At this stage, the old paradigm is pitted against new, competing, and "revolutionary" paradigms, each based on a different theory and approach. From this point of view, design research can be considered as a relatively new subject that has emerged from innovative ideas and proposals. The extent to which it has developed into a clear paradigm or whether it is still in a pre-paradigmatic stage should be examined.

This study consists of four chapters. The first chapter presents the history, key terms and definitions of engineering design research. The second chapter details the methodology used when conducting this study. The third and fourth chapters consist of a descriptive analysis of the ICED17 and ICED19 papers as well as a comparison with the study conducted by Cantamessa (2003). While the third chapter discusses general characteristics of all the research papers, the fourth chapter focuses on the in-depth analysis of the particular characteristics of the empirical studies. The study is closed with “Conclusion” section.

CHAPTER 1

1. ENGINEERING DESIGN RESEARCH, HISTORY and DEFINITIONS

This chapter provides general knowledge about engineering design research that should be known before analyzing research papers. First, the history and evolution of engineering design research is explained. Then, the main differences between science and engineering are reviewed. In the third part, the engineering design process is explained in detail. The fourth part dedicated to International Conference on Engineering Design and the last part mentions various design approaches used for different kind of research.

1.1. History and Evolution

As a research tool, engineering design is used for discovering, describing, organizing, rationalizing, and applying design information (Pugh 1990). Design research seeks to improve the existing state of design by expanding our comprehension of the phenomena of design in their full complexity and by generating and validating information, methods, and tools (Blessing 2002).

Design could be characterized as a stand-alone field, independent of the various sectors in which it is used, on the basis of the advancements made to date. (Andersen 2001). Instead of a rigorous description of empirical principles, the purpose of design research is to create new systems of knowledge. Design knowledge is intrinsically complex, and its origins span from formal scientific information to tacit human understanding. Design research has developed very rapidly over the past decades and as a result presents a cluttered, if not chaotic, picture (Arciszewski 1990). The underlying reason is that with the increase of information, the order of knowledge does not develop by default. Nonetheless, science entails a quest for order that manifests itself not only in the organization of information, but also in the techniques of examination. The dominating theoretical/methodological paradigms of thought imply that research in the natural and formal sciences is often organized in opposition to the field of engineering design.

Both engineers interested in design, Bruce Archer and John Chris Jones were two of the most influential figures in the British design techniques movement. They had been among the planners of the very first conference on design approaches, which was held in London at Imperial College in 1962. First published in 1970, Jones' seminal book, Design Methodologies: Roots of Human Futures, presented a series of methods that designers could use, most of which were derived from other fields. Two elements in his choice of approach are particularly noteworthy. First, he wanted to enable designers to work at a higher level of systems and community design, which included the level of commodities and components. Second, he wanted to make the designer's approach explicit, moving away from the dominant perception that design comes from a black box of inspiration and arriving at the realization that a well-articulated methodology can greatly aid the design process. Jones is also known for his critique of the design methodology movement in 1977, when he stated that design approaches had become too inflexible (Bayazit, 2004). His leaving was a decisive factor in the demise of the "first generation design approaches" as Horst Rittel had earlier characterized them (Bayazit, 2004).

Describing design as a process that falls between science and art, Bruce Archer was far more flexible than some of his contemporaries. Tomás Maldonado convinced him to join the faculty of the Hochschule für Gestaltung in Ulm, Germany, in 1960, where he hoped Archer would serve as a mediator between numerous groups of faculties who had strong views about the nature of design. Archer returned to England in 1962 to head a research project on medical device design at the Royal College of Art. The establishment of the Industrial Design Research Unit at the RCA in the early 1960s under Archer's leadership was a significant step forward for design research. As the Design Research Unit was renamed the Department of Design Research, it joined the other graduate programs at the institution. Archer included an appendix of a large number of research papers conducted by students in the Department of Design Research in a seminal paper published in the proceedings of the 1980 conference, Design: Science: Method (Archer, 1981). The studies were distinctive in their focus on items for specific users as opposed to consumer goods, and they seldom addressed values, methodology, or other relevant issues. Most studies concentrated on specific goods, such as medical devices, products for physically disabled children, or government command and control consoles, though a few were more abstract, such as the development of analytical modeling tools for use in design. A second appendix to Archer's essay is equally noteworthy,

as it contains work on art and design history, design education, and graphic design done by related departments (Archer, 1981). Although Archer did not elaborate on why he thought cultural studies was an important part of design research, he identified a connection between the two fields.

Design methodology and the question of how to describe design were major issues when the Design Research Society (DRS) was established in 1976, of which Archer was a founding member. Was it a science or was it something else that used principles of science? How was design knowledge different from other kinds of knowledge? At DRS conferences, the questions of what made up design knowledge, how to define design as a field, and what precisely were designers' ways of knowing were repeatedly posed and continued in the DRS journal Design Studies, founded in 1979.

Nowadays, design research is a field of global endeavor. One can select different starting points to trace its origins, yet the design methods movement in the United Kingdom is a good beginning because there is a clear path from there to where many researchers find themselves today. Then again, the field of design research is far broader than most researchers are aware of, and it encompasses a multitude of actors, many with little or no knowledge of what the rest are working on. In fact, the field is made up of a set of distinct discourse societies or networks, each pursuing their own objectives based on their own best practices and measurable deliverables. Those groups have a variety of goals and are of diverse nature. While for some, the goal of research is to develop new goods, for others learning more about design as a cultural phenomenon is interesting. Consequently, we must recognize that the word "design research" has different connotations depending on the person using it. It should not appear, however, that the discourse groups are isolated from one another. Rather, they regularly overlap and, in some cases, intersect. Researchers often belong to many groups and commute between them.

Journals, websites, and conferences might originate within a particular community, yet they often attract scholars from outside that group. Cross-fertilization is the very reason that a cross-community study grows and leads to discoveries that go far beyond the limited sphere of interest of any particular group.

1.2. Science and Engineering

Science is commonly referred to as the study of the natural world through observation and experimentation. Physics, chemistry, biology, and earth, space, and environmental sciences are examples of "natural sciences." Scientists, like engineers, use a thinking process called scientific inquiry to solve problems.

The use of brainstorming, analogy, mental models, and visual representations is common in scientific research and engineering design. Scientists use these tools to pose questions about the surrounding world and to attempt to derive principles that explain the patterns they observe. Engineers use them to modify the world to meet people's needs and aspirations.

While science is a field of knowledge that encompasses the study of the physical and natural world, engineering is the utilization of such knowledge to develop, produce, and manage a product or process that addresses a problem or fills a need (i.e., a technology). The goals of engineers and scientists are distinct. Natural scientists attempt to both explain and describe the natural world. Engineers have consideration of a variety of criteria and constraints in developing solutions to problems, needs, and wants that benefit people, animals, and/or the environment. In the contemporary world, engineering and science are inseparable. The design of engineers is based on scientific understanding, and many scientific breakthroughs would be infeasible without the tools of engineering.

Some scientists have come up with the following definitions of science:

“Scientists try to identify the components of existing structures, designers try to shape the components of new structures.” (Alexander, 1964)

“The scientific method is a pattern of problem-solving behavior employed in finding out the nature of what exists, whereas the design method is a pattern of behavior employed in inventing things ... which do not yet exist. Science is analytic; design is constructive.” (Gregory, 1966)

'The natural sciences are concerned with how things are ... design on the other hand is concerned with how things ought to be.” (Simon, 1969).

With the help of scientific research, knowledge moves towards well-tested ideas that originate in the physical world, are built from the bottom up, and then translated into generalized, abstract ideas about how the world works. The resulting construction can be divided into three levels, each connected by two bridges.

The first level consists of physical objects of scientific interest, such as grasses and grazing herds in the African savannah, stars and hot gases visible across cosmic time, and organized electronic phases evolving within one-thousandth of absolute zero.

At the bridge to the next higher level, the physical objects become objects of study by means of human perception, aided by instruments such as radio telescopes, magnetometers, and binoculars, yielding results that can be recorded and transmitted, broadening the limits of human comprehension.

The means by which information is transferred from the realm of physical objects to the realm of symbols and ideas is observation. On the next level of information flow, scientists provide specific descriptions of what they observe.

Concrete descriptions act as a bridge to the top level of in this image of science by advancing the development of theories, first by producing ideas of how the universe operates, and then by permitting the testing of those ideas through an intellectual sort of natural selection. The compelling features of theories that compete for attention and application include their simplicity, their scope and precision, and the scope and precision of observational tests-and, certainly, the extent to which theory and data match.

A model for this type of analysis is Newtonian mechanics. Its scope includes all matter, force, and motion, and its precision is mathematically flawless in its computations. Both its efficacy in practice and its inadequacy as a definitive theory are due to the breadth and accuracy of its scope and precision. While Newton's laws provide accurate predictions for motion of any velocity, careful observations can reveal the shortcomings of their forecasts. Knowledge therefore proceeds from bottom to top in scientific research: physical systems constitute concrete descriptions as a consequence of observation and investigation. Concrete descriptions help form scientific hypotheses by providing proposals and then testing said proposals.

In scientific investigation, data is transferred from matter to mind, whereas in engineering design, information is transferred from mind to matter. With investigation, information is gained with the help of instruments, while with design, information gained with the aid of instruments is used. In designing, inquiry matches its descriptions to the physical world, while designing develops its propositions to fit the physical world.

The differences here are as concrete as the difference between an academic laboratory microscope and a milling machine on a production floor, to give just a couple of examples. At the higher, more abstract levels of engineering and science, the changes are

also less tangible, but they are at least just as significant. The differences in this case relate to designs and theories, both of which are intangible but very different productions of the mind.

Scientific theories must be novel and precise; when multiple theories seem persuasive, only one must be correct; engineering theories must be proactive and innovative; when multiple design solutions are successful, then success is assured.

While scientists look for theories that are applicable in as wide a range as possible, engineers look for ideas that are well matched to specific domains. Scientists' goal is to formulate hypotheses that make precise and therefore fragile predictions (like Newton's), while engineers' goal is to design systems that have a wide safety margin. What distinguishes science from engineering is that in engineering, a single failed prediction can invalidate a theory regardless of how many previous attempts it has passed, whereas in science, a single design solution can validate an idea regardless of the number of previous iterations that have failed.

1.3. Engineering Design Process

Engineering research is the process that engineers follow to recognize and solve problems. It has been characterized and mapped in a variety of ways, but there are specific similar characteristics in all of them. This effectively problem-solving approach is adaptable enough to work in practically any kind of system. At each stage of the process, engineers gain valuable insight into the problem and alternative solutions.

Design research is the creative process of identifying requirements and then designing a solution to meet those requirements. This solution may be a product, a strategy, a structure, a project, a method, or something else, depending on the situation.

The engineering method of creative problem solving is the general technique for successful engineering design. The process of selecting the best feasible action in a given scenario is called problem solving. The challenges engineers face vary across and within engineering domains. Because of the variety of difficulties, there is no general set of techniques that is appropriate for every situation. However, not every engineer goes through the same stages in their design process.

The engineering design process is a series of steps that engineers follow to find a solution to a problem. While these steps are not strictly predetermined, some generic steps are defined as follows (Haik et. al., 2015).

The first step consists of identifying the problem. Here, the issue to be resolved, to whom the design product is intended, constraints and prerequisites are determined.

In the second step, brainstorming is done to find potential solution candidates. At the beginning of the design process, good designers brainstorm about different solutions and compile a list with as many of them as possible. It is better not to criticize the designs and instead let the ideas flow as freely as can be.

“Research” is the third step. In this step, studying past initiatives can help avoid the pitfalls that others have encountered. Talking to people from different walks of life, such as users or consumers, can provide different perspectives.

What is the fourth step is to establish criteria and constraints. Once a list of possible solutions has been compiled and the requirements of the project have been defined based on the research, the next step is to identify any constraints on the project. It can be done by going through the criteria again and combining the findings and considerations from the earlier steps of the process.

The next step is to investigate other options. One may choose to explore other options to evaluate different outcomes and determine the best course of action. For any viable concept, this means repeating some of the previous procedures.

After weighing the alternatives, it should be possible to choose the technique that best suits one' s needs. Those that do not meet the requirements should be discarded. This step is called "designating a strategy".

After deciding on a strategy, the next phase is to refine and improve the solution to create a design proposal. This phase is called the "design proposal" and can last throughout the duration of the project, even after the product has been delivered to the customer.

Prototyping is the final step and consists of making a prototype of the design concept as an indicator of the function of the final product. Prototypes are often built with different materials than the final product and finished at a lower quality level.

1.4. Design Approach

A design approach is a comprehensive concept that may or may not include a methodological guide. Some are used to guide the overall purpose of the design. Other methods are used to guide the designer's inclinations.

The above are only some of the approaches:

Design artifacts are used as an embodied critique or commentary on a culture's current values, beliefs, and behaviors.

Ecological design is a design strategy that considers the impact of a product or service on the environment throughout its life.

Participatory design (originally co-operative design, now commonly referred to as co-design) is a method of using collective creativity in design with the goal of actively involving all stakeholders (e.g., employees, partners, customers, citizens, and end users) in the process to ensure that the final product meets their needs and is usable.

Scientific design is a form of industrial design based on scientific knowledge.

Science can be used to investigate the consequences and requirements of a new or current product in general, and to design goods based on scientific knowledge. For instance, studies of filtration performance, mitigation performance, thermal comfort, bio degradation, and flow resistance can be used to develop a scientific design of face masks for COVID-19 mitigation (Verma & Dhanak, 2020; Kumar & Lee, 2020).

The design or structuring of the experience around a product and the service associated with its use is referred to as service design.

Sociotechnical systems design is a philosophy and set of tools for the collaborative design of workflows and supporting processes with respect to organizational goals, quality, safety, cost effectiveness, and customer needs in core work processes, as well as the quality of people's work experiences and social needs.

Transgenerational design is the process of creating goods and environments that are compatible with the physical and sensory limitations associated with aging that restrict important daily activities. User-centered design focuses on the needs, desires, and limitations of the end users of the developed artifact.

International competition and technological advances, the unrelenting demand for higher-value goods, and the presence of product liability regulations have forced the industry to take the following actions:

- To accelerate the implementation of innovative technologies.

- To shorten the timeframe for design.

- To ensure designs are executed correctly the first time.

- To innovate more regularly and to generate more inventive products.

- To increase product and system reliability.

To answer these questions, industry and academia have focused their research efforts on methods to automate and control the design process, or at least parts of it, while improving the quality and results of the process. It is well known that only when a process can be automated, a thorough understanding of how it works, how it can be improved, and even how it can be optimized is required. Numerous scholars, most notably Marples (1961) and Hales (1987), have studied the engineering design process as it is applied in specific industries and sectors and have provided concise explanations of the engineering design process.

Clearly, this research must continue because the context in which engineering design is practiced is dynamic, to say the least. In addition, it is necessary to research the specific activities involved in the process to provide both depth and breadth of knowledge. Thus, considerable effort has been made in recent years to develop computer-based tools to assist engineers and designers in the conceptual design phase (Ullman & Herling, 1996; Scrivener et. al., 1993). Most of these tools are based on descriptive research rather than prescriptive design concepts (Al-Salka et. al., 1998).

Considering the dynamic nature of the engineering design process and the associated need for more specific information about design activity, a wide range of research methods and procedures have been adopted and developed.

A close examination of the designer's actions should reveal the cognitive processes underlying intellectual functions, including cognition, problem solving, and creative thinking.

Because of its scientific basis, the protocol approach has gained broad acceptance as a tool for the analysis of engineering design activity. Advanced field research methods from

the social sciences have been recommended to enhance understanding of how and why design occurs as engineering is progressively recognized as a primarily human activity (Wallace & Hales, 1989).

An example of a social science method that uses ethnography is ethnographic observation. Various ways exist to conduct an ethnographic study, but the goal is to provide a documented account of the tacit norms and customs of the group. The goal is to create a "dense" or "rich" account of the observed group's experiences that interprets their thoughts and feelings (Robson, 2002). It differs from the protocol method by observing rather than participating in the observed action. There is a wide range of options available to the researcher when it is of observation. As a participating observer, you become a member of the community you are studying. It is common for academics to gain access to companies and work as designers or alongside designers to gain insight into their work. Research can become more or less organized as new ideas develop from the data collected (Kennedy 1997). In the field of design research, an ethnographic study was conducted on a company that manufactures photovoltaic cells. (Bucciarelli, 1994). It shows, for example, the impact of time, money, and resource constraints on real-world activity. In addition, the social environment between designers and management affects the way they function.

The study and interpretation of past events based on information obtained from historical documents and narratives is what history is all about. Both primary and secondary sources are used by historians to categorize material. There is a variety of primary sources, such as first-hand accounts from participants or spectators, contemporary documents such as personal notes, memoranda, instruction manuals, and journals. Secondary sources have been written by other historians and scholars to provide summaries and accounts of the events in question.

For the present study, a historical basis or background is crucial. For instance, the advances in design resulting from the emerging of new technologies can be compared with earlier advances.

Some scholars in the area of design have used their personal experiences as designers to explain elements of the discipline. As a result of his own design work, French (1992) introduces a model for the design process. According to Pahl and Beitz (1984), this model is based on identical assumptions. According to Cross et al. (1993), design scholars are concerned about the lack of adoption of their concepts by practicing designers. Involving

designers as equal partners in the study increases the possibility that the research findings will be adopted because of the shared responsibility for the research outcomes.

Through a method similar to participant observation, researchers and designers can work together to gain a shared understanding of their work. The technique of the 'focus group' is also a widely used one. Working as a group of practitioners/researchers, we are in a position to develop theories and tactics based on our shared understanding of the world in which we live.

1.5. International Conference on Engineering Design (ICED)

The International Conference on Engineering Design (ICED) is the hallmark conference of the Design Society, a non-profit organization founded in 2001 on the foundations built by Workshop Design-Konstruktion (WDK) to encourage the advancement of design knowledge in all areas. The ICED conferences were launched in Rome in 1981 and have since been held every two years in fifteen countries, with an additional meeting every two years. Thirteen conferences have been held under the aegis of WDK. The conference follows the same structure as in previous years, including plenary sessions, panel speeches, discussion sessions with focused debates, and workshops led by Design Society Special Interest Groups. The varied program offers scholars and practitioners the opportunity to learn about the latest developments in engineering design and to network.

The objective of the International Conference on Engineering Design is to bring together leading scholars, researchers, and scientists from around the world to discuss and share their experiences and research findings in all areas of engineering design. It also serves as a leading multidisciplinary platform for scholars, practitioners, and educators to present and discuss the latest breakthroughs, trends, and issues in engineering design, as well as real-world difficulties and potential solutions (Lindemann et. al., 2013).

CHAPTER 2

2. METHODOLOGY

In this chapter, methodology used to analyze the ICED17 and ICED19 research papers is explained under three main titles.

2.1. Categorization of The Research Papers

As stated in Introduction part, the examination and classification of ICED17 and ICED19 research papers forms the basis of the study. However, the broad purpose of these ICED research papers and the fact that they were written in different scientific fields make it difficult to compare them. For this reason, a classification method that is easy to understand and can be applied to ICED research papers written in any field has been used. This classification method is the one used by Cantamessa (2003) when comparing ICED97 and ICED99 research papers. Cantamessa (2003) proposed a new classification based on the objectives of research with respect to the process. This classification consists of five categories, and these were used in this study to group ICED17 and ICED19 research papers. These categories are:

1. Empirical research: It consists of empirical research in which researchers analyze real-world design processes.
2. Experimental research: It is experimental research in which researchers consciously establish design processes in a controlled environment.
3. Development of new tools and methods: It consists of studies that involve the development of new tools and methods to support the design process or its elements.
4. Implementation studies: They are the studies in which researchers discuss the real-world deployment and use of innovative design methods and tools.
5. Other studies: They consist of research papers dedicated to theory and education.

This classification has been developed with the underlying speculation that, if the design research community is engaged in distinct kinds of research, this has to be in the view of exploiting their complementary nature. The sorts of exploration exercises have consequently been perceived to prompt a thorough life-sized model of plan research in

which their shared connections ought to be effortlessly made explicit and ultimately considered.

In addition to classification, variables belonging to each category mentioned above were determined. After determining the types of all research papers, the values of these variables were defined. These variables are explained in detail in the next section.

This study was carried out by three graduate students in Management Engineering. As stated before, conference papers from two years were examined in the study. ICED17 consists of 412 and ICED19 408 research papers.

In addition to defining categories, some of the variables belonging to each category detailed below are judgmental and therefore subjective bias is inevitable in such a study. Therefore, each research paper was randomly and equally distributed to two of the three students. When the results of the two people were different from each other, the third person intervened and helped to form a consensus among the students. If no consensus could be reached, the result was determined by a majority of votes. Although this method cannot be expected to completely eliminate subjective bias, it can be said to moderately reduce it.

2.2. Different Variables for Each Research Paper Type

After dividing the research papers into types, various variables belonging to each type were determined. Variables belonging to each type/category are explained below.

2.2.1. Variables for Empirical Studies

Six variables were identified to classify empirical studies among themselves. The first variable is the general purpose of the research paper. Since empirical studies are a method of learning knowledge through observation or experience, the purpose of research may be to observe a design as it is, or to observe the application/use/testing of a particular tool or method in the design. As a result, the values that the variable “general purpose” of empirical studies can take were divided into three classes: the nature of the design, specific tools/methods, and unclear.

In most of the empirical research papers reviewed, empirical studies were conducted with participants, volunteers, students, professors, design professionals, and individuals

involved in the specific field in which the research was conducted. Participants were exposed to controlled environments and empirical studies were conducted through case study/personal interviews, questionnaires, focus groups, one-to-one sessions, and several other methods to record each participant's experience. Therefore, second variable is defined as the “approach” of the empirical study, and three categories of it are identified: case study/interviews (qualitative), survey (quantitative) and not clear.

In addition to research approach, “analysis unit” is another variable defined. It takes four values, depending on which analysis unit the study is performed in.: individual, project/team, firm/company and unclear.

Fourth variable for the empirical studies is number of cases, in other words sample size or number of units of analysis. However, during the analysis, the variable was examined in only two categories: whether the analysis unit was determined in the research paper or not.

Another variable is related to when the study was carried out. While studies that observe an ongoing process are in the “study during the process" category, studies that examine data about a completed process are in the "after/retrospective" category.

The last variable concerns whether the application of findings from empirical studies in both education and industry is mentioned in research articles. Studies that include the effects of the findings, which are assumed to be beneficial for the researchers involved in the development of new design methods and tools, on management or product development practice were examined in the category of "conclusions/implications for practice (education or industry) are present", studies that do not talk about the effects or results on practical applications are in the category of " conclusions/implications for practice (education or industry) are absent".

2.2.2. Variables for Experimental Studies

A study that fully adheres to a scientific research plan is known as experimental research. Experimental research consists of a hypothesis, a variable that the researcher can change, and variables that can be measured, calculated, and compared. Most importantly, experimental research is conducted in a controlled environment. The researcher sets a hypothesis and obtains a result with the data he collects. The result obtained refutes or

supports the determined hypothesis. This research process is known as hypothesis testing or deductive research.

The same classification about objective of the study (nature of design, specific tools/methods and unclear) used for empirical studies is done for experimental studies, as

The second variable relates to the setting of the experimental study. For the relevant research paper, the categories of "individual setting" if the experiment is conducted with individuals, "group" if it is conducted with a group of people, and "with the customer/user of the product" if it is conducted with the customer/user of the product being studied were defined.

Third variable is the same as the last variable of the empirical studies. These are the categories "conclusions/implications for practice (education or industry) are present", and "conclusions/implications for practice (education or industry) are absent".

2.2.3. Variables for Development of New Tools and Methods Studies

Five variables have been identified to classify studies on the development of new tools and methods. The first classification in this type of research papers is whether a software or design method was developed. Accordingly, two categories were determined under the headings of "design method" and "software". If the research paper includes developing both a new method and a new tool, it is in the "both" categories.

Second and third variables are only for the studies about software development. The second variable is used to define whether the research uses an existing software product to carry out a design task or not. The third variable asks whether there is a possibility of implementation of the new software with commercial applications or not.

Fourth variable is about motivation behind the research. Three categories are determined to define the reasons of the study. If a specific industrial need is mentioned in the research paper “specific references to industrial needs”, if only general reasons are given “generic reference to needs” and if no reason or motivation is mentioned “no industrial/educational needs” categories were selected.

The last variable relates to the implementation of the developed method or tool. If the implementation of the method or tool is included in the research paper, the research paper

is classified as "addressing implementation of method or tool", if not, it is classified as "not addressing implementation of method or tool ".

2.2.4. Variables for Implementation Studies

Three variables were used to classify the implementation studies. The first variable is used to determine whether the work involves the application of methods or tools. If the study mentions the application of both, the option "both" is available as well.

The second variable relates to empirical research on the tools or methods implemented. It asks if the author of the research paper has made reference to empirical research results on the topic.

The third and perhaps the most important variable for the implementation studies is the objective of the research. Implementation studies are divided into four types according to the purpose of the research. If the research focuses on developing a new methodology, the relevant research paper is in the "methodology development" group, if the research paper only talks about the generalization of the existing implementation, it is in the "generalization of the existing" group, if it suggests a viable way of implementation of the relevant method or tool, it is in the "find the way of implementation" category and if it contains a general discussion, it is in the “discussion” group.

2.3. The Variables Common for Each Research Paper Type

In addition to the variables determined separately for each research paper type, there are also variables used for each research paper regardless of the type.

The first group of the variables are the corresponding authors of the research papers and the name of the universities where they work.

The second set of variables is the reference patterns in the research papers. The first reference pattern is for whether or not previous ICEDs are cited, the other is for references to the authors' previous work. The research papers were grouped into three categories according to the types of citations to their authors. The first group is research papers that refer to previous ICED works by one of the authors, the second is those that refer to other publications of the authors, and the third is the research papers that do not refer to the previous work of the authors.

Industrial involvement is another variable classified the research papers. Research papers were divided according to whether they mention industrial involvement or not.

It is seen that references are made to theories in articles written in all branches of science, and that theories are sometimes used for research. As there are theories specific to each discipline, there are also theories specific to the field of design research. For this reason, it is expected that theories should be mentioned in research papers about design research. To measure the proportion of ICED17 and ICED19 papers citing theories, a variable was determined. The variable takes three values: The research paper refers to design theories, the research paper refers to other theories and the research paper doesn't refer to any kind of theories.

Another set of variables concerns whether the methodology/approach/methods used in research papers are clearly defined. First of all, for each research paper, it is determined whether the methods/approaches/methodology used in the study are clearly defined. The second variable was defined only for studies that included data collection. It is concerned with whether the methods used in data collection are clearly defined. The last variable examines this situation only in studies with data analysis. These two variables were not examined for research papers that do not include data collection or data analysis.

CHAPTER 3

3. ANALYSIS

As mentioned in the previous sections, ICED17 and ICED19 research papers were reviewed to perform the analysis. Although there were a total of 820 research papers in the two conferences, the analysis was made with 819 research papers since the two papers belonging to ICED19 were identical. In this section descriptive statistics were carried out for both of the conference papers and the results were discussed. In addition, the descriptive statistical results of the research papers published in ICED97 and ICED99, those in the study of Cantamessa (2003), were compared with the results obtained in this analysis. There are 10 main titles in this section.

3.1. Types of Research Papers

As mentioned in "Methodology" part conference papers were analyzed in 5 different categories. The abbreviations used for the categories are EM for empirical studies, EX for experimental ones, NT for the papers written on new methods and tools, IS for implementation studies and OTH for the other papers which are not belonging to any of these categories. While some papers clearly belong to a category, nothing definite can be said about the categories of others, but the type to which they are closest determined. Hence two labels which are "might be" and "definitely" were used while defining the type of each research paper. The distribution of ICED17 and ICED19 papers by their types is shown in Table 1.

	ICED17			**ICED19**		
	Might be	Definitely	Total	Might be	Definitely	Total
EM	11	60	71	9	90	99
EX	4	51	55	3	48	51
NT	17	92	109	9	86	95
IS	37	106	143	47	85	132
OTH	8	26	34	13	17	30

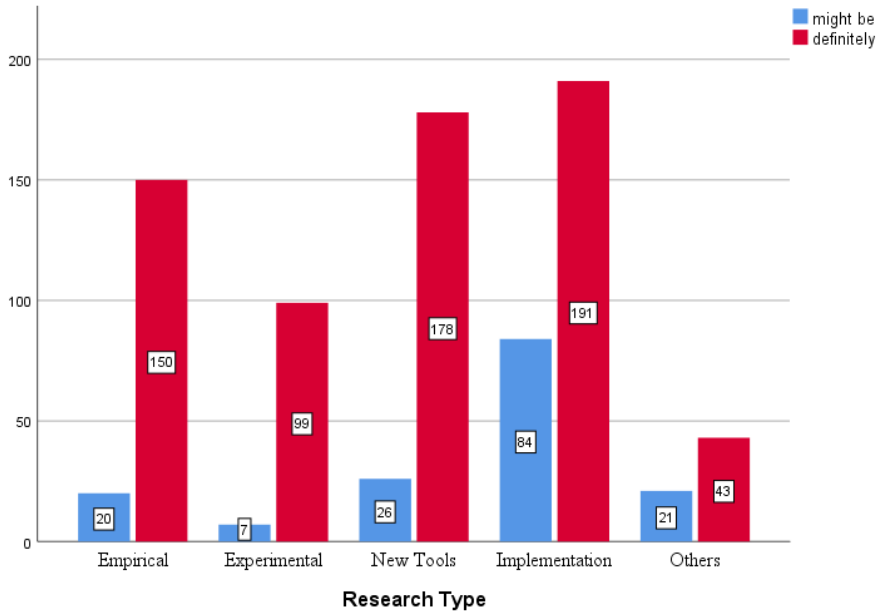
Table 1. Distribution of papers by research type and conference

As it is seen in the results, at both ICED17 and ICED19, implementation studies appeared to be the dominant research type. Development of new methods and tools is the second

dominant research theme for ICED17 papers and the third one for ICED19 papers. Empirical studies are in third place for ICED17 papers while they are in second place for ICED19 papers.

If the number of the papers belong to the "definitely" category is considered, the rankings do not change for ICED17 papers while the result is different for ICED19 papers. Even the dominant research type at ICED19 is changed when only the papers belong to the "definitely" category are counted. The reason is that, at ICED17, the number of the papers belonging to "might be" categories is not very large but for ICED19 papers the number of implementation studies in "might be" category is not negligible. Hence when "definitely" category is considered the ranking is totally changed for ICED19 papers.

At both conferences, when "might be" categories are considered, it is seen that the number of implementation studies is much more than those of other research types. NT and IS papers are difficult to separate from each other in some cases because they have some mutual characteristics. First of all, as Cross (1993) mentions design science is the attempt to make the design process happen in a specific way, using appropriate methods and tools. This both types are related with design science and they both concern real environment rather than an artificial setting. For most of the studies conducted in real environment, both development of a new method or tool and implication of it in a real-world case is involved. Among these studies the ones include only a small case study after explaining a new method or tool was defined as NT studies. However, some studies focus on a real-life implementation besides explaining the new method or tool. In addition, it is not clear whether the method used in some of these studies is new and is included in the relevant paper for the first time, or whether it is an existing method but doing its implementation for the first time in the relevant paper. Such ambiguities cause an increase in the number of implementation studies in "might be" group. To get a clearer conclusion on the dominant research paper type number of each research paper types were analyzed in total for the two conferences.



Graph 1. Distribution of ICED17 and ICED19 papers in total by research type

As it is seen from the graph when both of the conferences concerned together, implementation studies constitute the dominant research type. The second frequent research type is defined as development of new tools and methods, third one is empirical studies, fourth is experimental studies and the last one is other kind of papers. The papers don't have a specific type (others) constitute smaller than 7 percent of the total papers. These papers generally dedicated to theory and education.

As explained in the previous parts Cantamessa (2003) used the same classification for the research papers of ICED97 and ICED99. When the number and ratio of the types of research papers in previous and current conferences are examined, the following results are obtained:

	ICED97	**ICED99**	**ICED17**	**ICED19**
EM	53 (16%)	58 (15%)	71 (17%)	99 (24%)
EX	20 (6.0%)	22 (6.0%)	55 (13%)	51 (13%)
NT	141 (43%)	190 (49%)	109 (27%)	95 (23%)
IS	56 (17%)	51 (13%)	143 (35%)	132 (32%)
OTH	59 (18%)	68 (17%)	34 (8.0%)	30 (8.0%)
TOTAL	**329 (100%)**	**389 (100%)**	**412 (100%)**	**407 (100%)**

Table 2. Comparison of ICED97, ICED99, ICED17 and ICED19 papers

	ICED97 and ICED99	ICED17 and ICED19
EM	111 (15%)	170 (21%)
EX	42 (6.0%)	106 (13%)
NT	331 (46%)	204 (25%)
IS	107 (15%)	275 (33%)
OTH	127 (18%)	64 (8.0%)
TOTAL	**718 (100%)**	**819 (100%)**

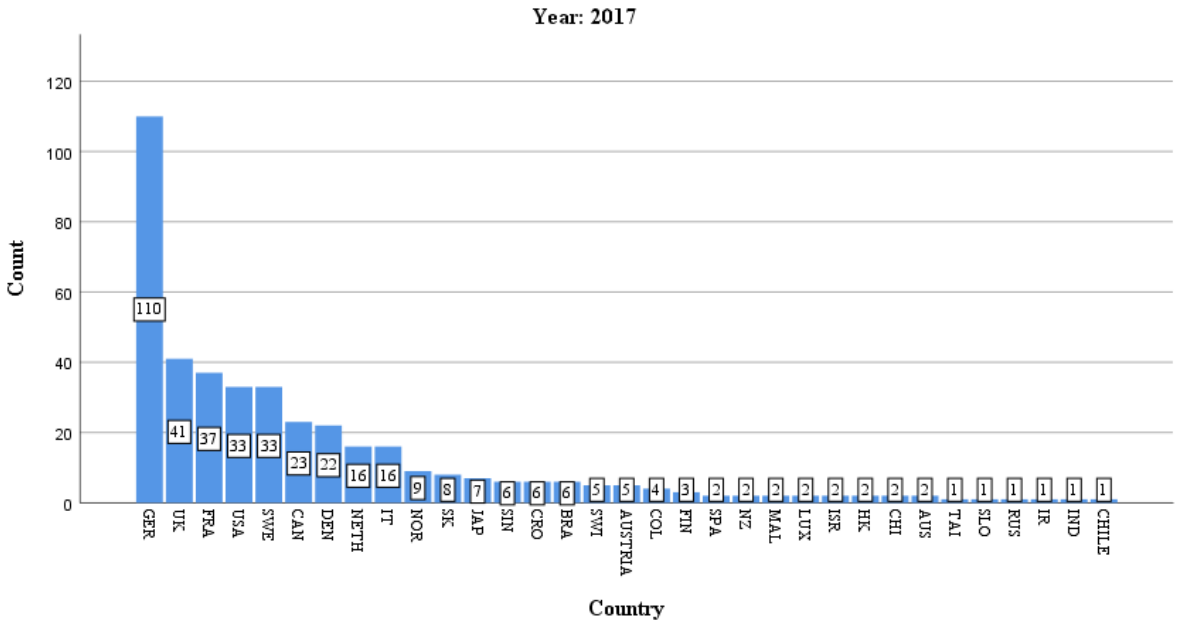
Table 3. Comparison of ICED97 and ICED99 papers with ICED17 and ICED19 papers

As it is seen from the tables, development of new methods and tools is the dominant research paper type at both ICED97 and ICED99 and there is a significant difference in the number of NT papers when it is compared with other kinds in these conferences. Also, for both of the conference papers the percentage of papers which do not belong to any of the four categories has the second highest value. When the total number of the research papers in both conferences are calculated the rankings of NT and OTH studies don't change. Empirical studies are in the third and implementation studies are in the fourth place. Experimental studies rank last and constitutes only 6 percent of the number of total conference papers.

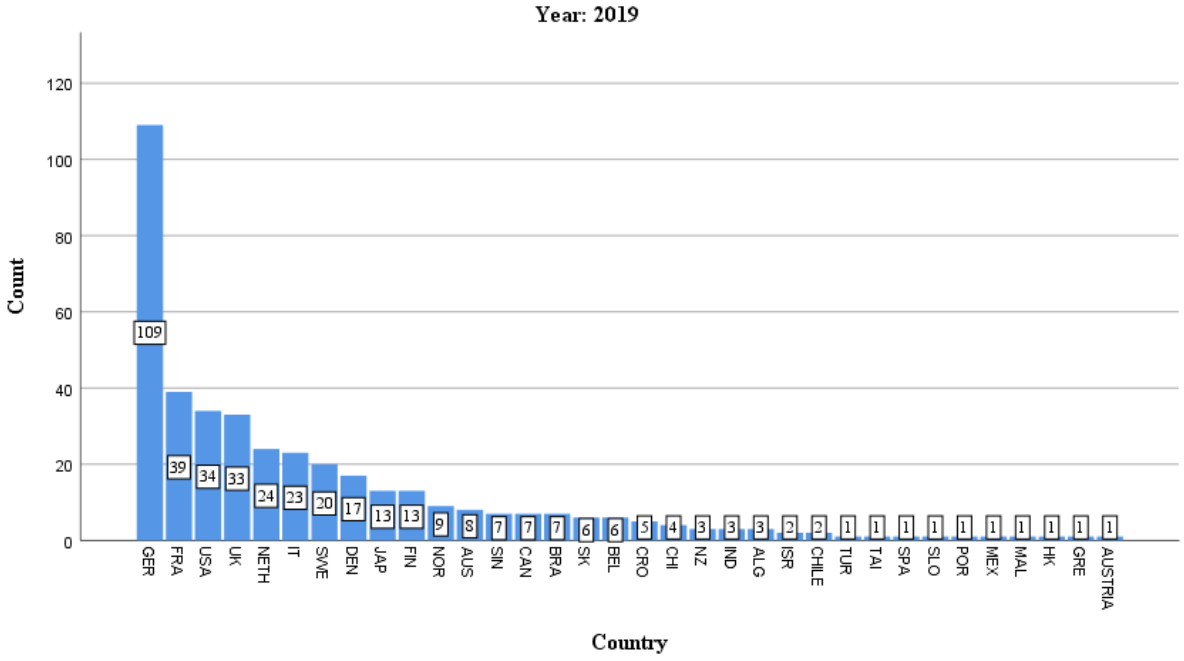
Normality tests were performed in SPSS for ICED17 and ICED19 papers and it was determined that the kurtosis and skewness values were defined between -1.5 and 1.5. According to Tabachnick (2007), it can be said that the types of research papers are normally distributed. Considering the number and ratio of the types of research papers, it is seen that they do not differ excessively from each other. However, it is seen that implementation studies have the majority, and they constitute the 33 percent of the total research papers. Development of new tools and methods is the second dominant category and empirical studies are in the third place. Although experimental studies are in the second place from the last, it is seen that both the number and rate of experimental studies have more than doubled when compared to previous conferences. In addition, the number and rate of studies that do not belong to any specified category have decreased by more than half compared to previous conferences. This could mean that research papers published in ICEDs have started to be more focused on design research rather than focus on only explaining the design theories or education.

3.2. Countries of Universities or Research Centers

Besides type of the research papers, another piece of information collected for each research paper was which university or research center the article was written by. To make a comparison between the different countries involved in the conferences the countries which the universities or research centers located were determined and they are listed for each of the conferences. The abbreviations are used for the graphs and tables and these are alphabetically; ALG: Algeria, AUS: Australia, BEL: Belgium, BRA: Brazil, CAN: Canada, CHI: China, COL: Colombia, CRO: Croatia, DEN: Denmark, FIN: Finland, FRA: France, GER: Germany, GRE: Greece, HK: Hong Kong, IND: India, IR: Ireland, ISR: Israel, IT: Italy, JAP: Japan, LUX: Luxembourg, MAL: Malaysia, MEX: Mexico, NETH: Netherlands, NOR: Norway, NZ: New Zealand, POR: Portugal, RUS: Russia, SIN: Singapore, SK: South Korea, SLO: Slovakia, SPA: Spain, SWE: Sweden, SWI: Switzerland, TAI: Taiwan, TUR: Turkey, UK: United Kingdom and USA: United States. The distribution of the research papers by different countries for each of the conference are listed in Graph 2.

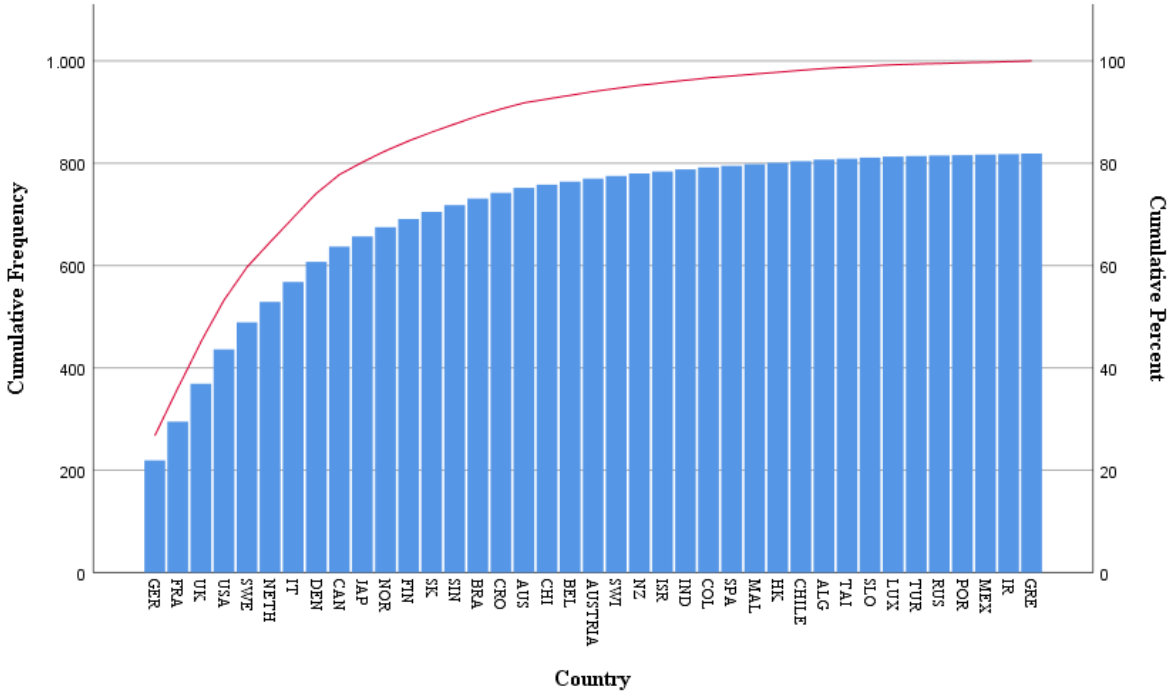


Graph 2. Distribution of ICED17 papers written by universities or research centers in different countries



Graph 3. Distribution of ICED19 papers written by universities or research centers in different countries

As it is seen from the graphs the number of research papers written by German universities for both ICED17 and ICED19 is much higher than that written by other countries. UK, France and USA are the second dominant countries for both of the conferences in terms of research paper numbers.



Graph 4. Pareto analysis of research paper production by research centers or universities in different countries

Based on the Pareto analysis in Graph 4, it is seen that 80 percent of the research papers are written by approximately 20 percent of the countries where universities are located. These countries are Germany, France, UK, USA, Sweden, Netherlands, Italy, Denmark and Canada. It is also seen that the biggest contribution is made by German universities with more than 20 percent.

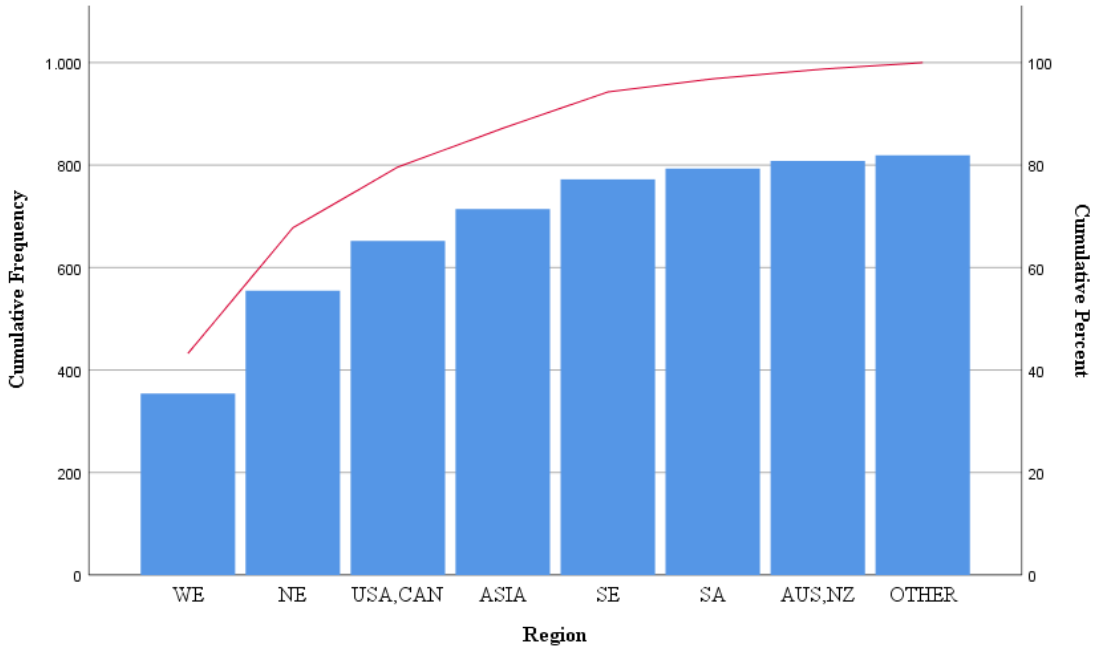
3.3. Geographical Regions of The Universities or Research Centers

Since the above-mentioned countries differ from each other in size and population, they are grouped according to their geographical proximity, and the analysis is repeated on the basis of 8 different regions. These regions are Asia (ASIA), Australia and New Zealand (AUS,NZ), Northern Europe (NE), Western and Central Europe (WE), Southern Europe (SE), South America (SA), USA and Canada (USA,CAN) and other countries (OTHER). The countries in the category of others are Algeria, Israel, Russia, Slovakia and Turkey. The distribution of papers in both ICED17 and ICED19 by the defined regions are in Table 4.

	WE	**NE**	**USA,CAN**	**ASIA**	**SE**	**SA**	**AUS,NZ**	**OTHER**
2017	175	109	56	27	26	11	4	4
2019	179	92	41	35	32	10	11	7
TOTAL	354	201	97	62	58	21	15	11

Table 4. Distribution of papers by geographical regions

From Table 4, it can be said that for both of the conferences (ICED17 and ICED19) the biggest portion of the universities participated are from Western and Central Europe. Considering the country distribution of the research papers given above, it is not difficult to predict this result. Because Germany, France and Netherlands fall into this category, and they make the biggest contribution. Second majority is constituted by the research papers written in Northern Europe. In this study, UK, Sweden and Denmark are analyzed in NE category and as it can be seen from the previous results, the participation of these countries is one of the majorities.



Graph 5. Pareto analysis of research paper production by research centers or universities in different geographical regions

Based on Pareto analysis given in Graph 5, it is seen that the participation of Western and Central Europe constitutes more than 35 percent of all regions. According to the analysis, 80 percent of research papers are written by approximately 35 percent of the regions identified. The Pareto principle cannot be verified here, but if the regions were determined on the basis of the number of universities they contain, a rate of 20 percent could be obtained. However, while creating regions, the aim is to reduce those in the "others" category as much as possible and to show the contribution of fast-developing regions such as Asia and Oceania.

In the study conducted by Cantamessa (2003) the geographical regions of ICED97 and ICED99 papers analyzed in 5 groups: DACH consists of Germany, Austria and Switzerland; UK, IRL (UK and Ireland); S, FIN, N, DK consists of Sweden, Finland, Denmark and Norway; USA, BR (USA and Brazil) and other countries. However, studies on ICED17 and ICED19 papers aimed to analyze the regions more detailly. There are two reasons of it. One of them is decreasing the number of countries in “others” category and try not to underestimate some regions contribution. Second reason is participation from the regions which were specified as “Other” for ICED97 and ICED99 conferences has increased significantly in 20 years. Regardless of all these reasons, the classification made for ICED97 and ICED99 was also made for ICED17 and ICED19 papers. The aim is to

compare the regions participating in ICED17 and ICED19 with those that participated 20 years ago. The results are as in the Table 5.

	DACH	UK, IRL	S, FIN, N, DK	USA, BR	Other
ICED97 and ICED99	27.0%	21.0%	12.0%	12.0%	28.0%
ICED17 and ICED19	28.0%	9.0%	15.0%	10.0%	38.0%

Table 5. Comparison of ICED97 and ICED99 papers with ICED17 and ICED19 papers by 5 geographical regions

As can be seen from the Table 5, despite the intervening 20 years, the largest part of the research papers for all conferences is composed of universities in Germany, Austria and Switzerland. Although the countries of the universities participating in ICED97 and ICED99 are not known exactly, Germany's contribution is the reason why the DACH region is the majority in ICED17 and ICED19.

For ICED97 and ICED99, the contribution of UK and Ireland comes in the second place. However, it is seen that their contribution decreased sharply after 20 years. Although the reason for this decline is unknown, it can be interpreted that the UK may have focused on attending other conferences on engineering design in recent years due to its negative relations with the European Union.

Sweden, Finland, Denmark and Norway constitute the second majority for ICED17 and ICED19 and the third for ICED97 and ICED99. It seems that their contribution in percent is increased in 20 years slightly. On the other hand, the contribution of USA and Brazil dropped by 2 percent.

As mentioned earlier, the share of countries that are not in these 4 categories in ICED17 and ICED19 has increased compared to 20 years ago. In particular, the contributions of France, Netherlands, Italy and Canada cannot be underestimated. Besides the fact that countries make up the majority, one of the aims of this study is to describe the increase in contributions from regions such as Asia and Oceania. Although their contributions were not critical for a research conducted at the end of the 90s, the structure of the world economy has changed today and the contribution of these regions has gained much more importance compared to 20 years ago.

For ICED17 and ICED19, the distribution of the research papers by their research types and geographical regions where the universities are located are analyzed. The results are as in Table 6.

	WE	NE	USA,CAN	ASIA	SE	SA	AUS,NZ	OTHER
EM	57	59	24	15	10	2	2	1
EX	32	22	19	12	15	2	1	3
NT	107	40	15	15	16	2	6	3
IS	135	63	27	17	16	9	4	4
OTH	23	17	12	3	1	6	2	0
	354	201	97	62	58	21	15	11

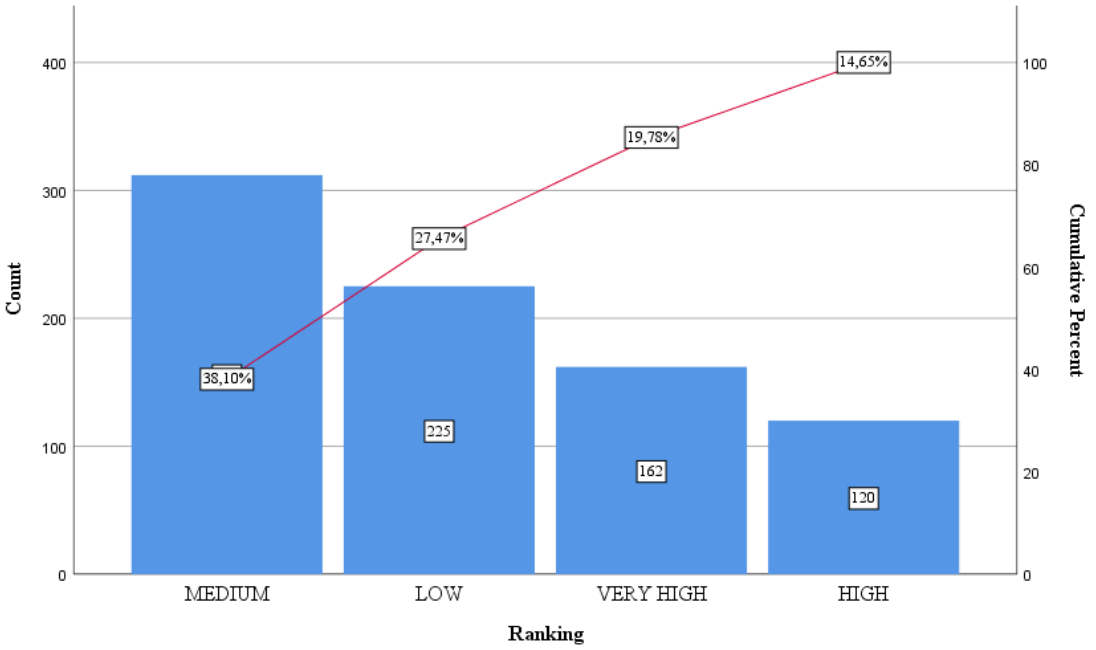
Table 6. Distribution of papers by geographical regions and research types

To determine the association between the geographical regions and research types Chi-square test is conducted. Research type shows significant association with geographical regions where the research papers are written. However, based on Phi and Cramer's V tests the level of association is determined as weak. Therefore, the expected values of the number of the papers if two categorical variables were statistically independent is not mentioned here as in the study of Cantamessa (2003).

As it is seen from the Table 6, since implementation studies are in the majority compared to other types of research papers in ICED17 and ICED19, it is seen that IS papers have the dominancy for research papers written by all regions. In terms of NT research papers, Western and Central Europe again ranks first and Northern Europe ranks second.

3.4. Ranking of The Universities or Research Centers

In addition to the countries and geographical regions of the universities and research centers, their rankings were considered as well. To make an objective classification the "World University Rankings" from Times Higher Education was taken into account. The universities which are ranked in the first 100 universities defined as "Very High" ranking universities. The universities which have a ranking between 100 and 200 were labelled as "High" ranking universities and those located between the rank 200 and 1000 were stated as "Medium" ranked universities. Others defined as "Low" ranking ones. While defining the rankings, negligible errors may have occurred due to the size of the dataset, but this error is expected to be less than 0.01.



Graph 6. Pareto analysis of the research papers by the rankings of research centers or universities

From the Pareto diagram shown in Graph 6, it is seen that medium-ranking universities constitute the majority with 38.10 percent. They are followed by low-ranking universities with 27.47 percent. Although the majority of universities are in the middle and low rankings, the top 100 universities participating in the ICED17 and ICED19 conferences are a non-negligible proportion. The studies carried out by such universities participating in the conferences constitute 19.78 percent of the total studies. High and very top ranked universities, taken together, account for almost 35 percent.

Although the rankings are taken from an objective resource, for the classifications on the rankings subjectivity cannot be excluded. The "very high" classification was limited to the top 100 universities, as the share of universities in the top 100 was sufficient to make an analysis. However, universities in the ranking between 100-200 can also be counted in the "very high" category. The reason why the number of medium ranked universities is so high is that this classification includes all the universities ranked between 200 and 1000. Therefore, it can be said that 85 percent of the participation in ICED17 and ICED19 consists of universities in the top 1000.

RANKING of THE UNIVERSITIES

	TYPE of THE RESEARCH PAPERS					REGIONS of THE UNIVERSITIES			
	EM	**EX**	**NT**	**IS**	**OTH**	**WE**	**NE**	**USA,CAN**	**ASIA**
LOW	42 (18.7%)	31 (13.8%)	55 (24.4%)	86 (38.2%)	11 (4.9%)	106 (47.1%)	39 (17.3%)	30 (13.3%)	18 (8.0%)
MEDIUM	65 (20.8%)	32 (10.3%)	84 (26.9%)	99 (31.7%)	32 (10.3%)	107 (34.5%)	95 (30.4%)	20 (6.4%)	20 (6.4%)
HIGH	28 (23.3%)	16 (13.3%)	32 (26.7%)	40 (33.3%)	4 (3.3%)	69 (57.5%)	35 (29.2%)	2 (1.7%)	11 (9.2%)
VERY HIGH	35 (21.6%)	27 (16.7%)	33 (20.4%)	50 (30.9%)	17 (10.5%)	72 (44.4%)	32 (19.8%)	45 (27.8%)	13 (8.0%)

	SE	SA	AUS,NZ	OTH	TOTAL
	15 (6.7%)	10 (4.4%)	-	7 (3.1%)	**225**
	43 (13.8%)	11 (3.5%)	12 (3.8%)	4 (1.3%)	**312**
	-	-	3 (2.5%)	- -	**120**
	-	-	-	-	**162**

Table 7. Distribution of university rankings according to research types of the research papers and geographical regions where research centers/universities are located

As can be seen from the Table 7, medium ranked universities have the largest share of all types of research. Low ranked universities have the second place and universities with very high rankings are in third place for all research types except for "others". Considering the number of universities in the medium and lower ranks, these results can be expected in advance.

Except for USA, CAN and OTH regions universities with medium rankings constitute the highest percentage for all of the regions. However, it is seen that approximately 28 percent of the Canadian and American universities have very high rankings.

Except for Australia and New Zealand, and other countries, low ranked universities are in the second place. It is seen that from Australia and New Zealand only medium and high ranked universities participated.

3.5. Types of Theory Referenced in Research Papers

Another classification made is about theories that research papers include as mentioned in methodology part. While some of the papers do not mention any kind of theories, some of them mention design theories and some of them give references to theories not related

to design but to other areas of the science. Distribution of the research papers by type of theories they include for ICED17 and ICED19 is given in Table 8.

	No Theories	Other Theories	Design Theories
ICED17	149	213	50
ICED19	74	302	31
TOTAL	223	515	81

Table 8. Distribution of papers by type of theories they include and conferences

As Table 8, shows most of the research papers in both of the conferences refer to theories, but only 14 percent of these research papers include design theories. Most of the articles mention other theories.

In Table 9, the types of research papers are grouped according to the types of theory they mention.

	No Theories	Other Theories	Design Theories
EM	46	112	12
EX	19	68	19
NT	50	126	28
IS	81	179	15
OTH	27	30	7
TOTAL	223	515	81

Table 9. Distribution of papers by type of theories they include and research types

As Table 9 shows for all types of research papers, the majority consists of research papers that refer to other types of theories. For all research paper types, the second dominant group is research papers that do not contain any theory.

3.6. Methodology Description

Research papers were grouped according to whether they contain a clear description of the methodology or approach they are using. The distribution of research papers for each conference according to whether there are methodology explanations or not is given in Table 10.

	Clear Methodology Description	No Clear Methodology Description
ICED17	407	5
ICED19	385	22
TOTAL	792	27

Table 10. Distribution of papers by methodology description

As can be seen in Table 10, almost 97 percent of the research papers include clear methodology description. This ratio is almost 99 percent at ICED17 and almost 95 percent at ICED19. These results show that almost all of the research papers take part in ICED17 and ICED19 were written in a systematic method and method they include was clearly explained.

3.7. Data Collection

In addition to research paper's methodology description, whether data collection was done in the studies is examined. For the papers include data collection part, two groups were determined as the ones clearly describe research methodology they used for data collection and the ones do not describe it clearly. It is shown in Table 11.

	No Data Collection	Data Collection	
		Clear Description of Research Methodology	No Clear Description of Research Methodology
ICED17	34	364	14
ICED19	26	349	32
TOTAL	60	713	46

Table 11. Distribution of papers by data collection methodology

According to the results in Table 11, the number of research papers that do not mention data collection is very low, almost 7 percent of total conference papers. Of the research papers that included data collection, the research methodology for data collection was clearly defined in approximately 96 percent of ICED17 papers and almost 92 percent of ICED19 papers.

3.8. Data Analysis

The same classification was made for data analysis. The research papers were categorized according to whether they included data analysis and, if so, whether the research methodology related to the data analysis was clearly defined.

		Data Analysis	
	No Data Analysis	Clear Description of Research Methodology	No Clear Description of Research Methodology
ICED17	36	367	9
ICED19	29	343	35
TOTAL	65	710	44

Table 12. Distribution of papers by data analysis methodology

As can be seen in Table 12, similar results were obtained for data analysis as in the data collection part. Because most of the research papers that contain data collection part aim to analyze data collected. Almost 91 percent of ICED17 papers and almost 93 percent of ICED19 papers include data analysis and among these papers research methodology of data analysis was clearly described in almost 98 percent of ICED17 papers and approximately 91 percent of ICED19 papers.

3.9. Industrial Involvement

Research papers were also classified whether they included industrial involvement. In doing so, criteria such as whether an analysis or case study was conducted in a company, whether universities and companies were working in coordination, or whether one of the authors in the study was a company employee were looked at. Results are shown in Table 13.

	Industrial Involvement					
	EM	**EX**	**NT**	**IS**	**OTH**	**TOTAL**
ICED17	52.1%	16.3%	22%	25.2%	23.5%	**27.7%**
ICED19	35.3%	37.3%	28.4%	21.2%	20.0%	**28.3%**
TOTAL	**42.4%**	**26.4%**	**25.0%**	**23.3%**	**21.9%**	

Table 13. Distribution of papers by industrial involvement percentages

From the Table 13, it is seen that the type of research that includes the most industrial participation for ICED17 is empirical studies with a rate of 52.1 percent. This is followed

by implementation studies with 25.2 percent. According to these results, it can be said that more than half of the empirical studies are conducted in a company and the rest are related to educational research. On the other hand, for ICED19 it is seen that industrial involvement rates distributed more equally among the research types. Experimental studies have the highest industrial involvement share with 37.3 percent and empirical studies comes the second place with 35.3 percent.

When industrial involvement is analyzed on the basis of conferences, it is seen that the industrial involvement rates of the two conferences are very close to each other, 27.7 percent for ICED17 and 28.3 percent for ICED19. If analysis is made upon research types, it is seen that 42.4 percent of the empirical studies include industrial involvement. It is observed that other types of research have very similar industrial involvement rates, between 21 and 26 percent.

3.10. Referencing Patterns

In all scientific fields over the years, researchers have advanced based on the results of their colleagues and the researchers have demonstrated this increasing correlation between research findings by referencing to previous studies. Therefore, references can be used as a measure to assess the extent to which researchers are aware of previous literature. In this study, some referencing patterns of ICED17 and ICED19 papers were analyzed. First of all, the proportions of research papers referring previous editions of ICED were examined by geographical regions and shown in Table 14.

References to Previous ICEDs									
	WE	**NE**	**USA, CAN**	**ASIA**	**SE**	**SA**	**AUS, NZ**	**OTHER**	**TOTAL**
ICED17	40.0	34.9	19.6	25.9	50.0	9.1	50.0	50.0	**35.0**
ICED19	43.6	34.8	29.3	20.0	43.8	40	27.3	14.3	**37.1**
TOTAL	**41.8**	**34.8**	**23.7**	**22.6**	**46.6**	**23.8**	**33.3**	**27.3**	

Table 14. Percentage of papers referencing previous ICEDs by geographical regions

According to the results in Table 14, the proportions of research papers referring previous editions of ICED are 35 percent for ICED17 and 37.1 for ICED19. There is a slight increase in this rate in 2 years. On the other hand, the remaining papers do not give any reference to previous ICEDs.

The analysis of the citation percentages at both conferences reveals that more than 41 percent of the research papers written by Southern Europe, Western and Central Europe refer to previous ICEDs. Also more than 33 percent of research papers written by Northern Europe, Australia and New Zealand reference previous ICEDs.

A comparison of the percentages of ICED97 and ICED99 papers and ICED17 and ICED19 papers that refer to previous ICEDs is given in Table 15.

	References to Previous ICEDs	
	ICED97 and ICED99	**ICED17 and ICED19**
References	31.7%	36.0%
No References	68.3%	64.0%

Table 15. Comparison between the papers of ICED97 and ICED99 with papers of ICED17 and ICED19 based on references to previous ICEDs

According to the results of the analysis by Cantamessa (2003) the average rate for ICED97 and ICED99 papers that refer to previous ICEDs has been calculated around 31 percent. It is seen that this rate has increased only slightly to 36 percent in 20 years. At all conferences, the number of research papers citing previous ICEDs is less than half of the total amount of papers. Cantamessa (2003) mentioned that this ratio for ICED97 and ICED99 papers are less than one-third of the papers and it shows a low and disappointing degree of consistency with previous work. Examining the ratios above, it would not be wrong to say that the situation has not changed much after 20 years.

Another reference model examined is the rate at which papers' authors cite their own previous work published in previous editions of ICED. The percentages of research papers that include references to previous ICED work by one of the authors by geographical region are shown in Table 16.

References to Previous Own ICED Works									
	WE	**NE**	**USA, CAN**	**ASIA**	**SE**	**SA**	**AUS, NZ**	**OTHER**	**TOTAL**
ICED17	18.9	17.4	10.7	18.5	26.9	0.00	0.00	25.0	**17.2**
ICED19	20.7	8.7	7.3	5.7	21.9	20.0	18.2	14.3	**15.2**
TOTAL	**19.8**	**13.4**	**9.3**	**11.3**	**24.1**	**9.5**	**13.3**	**18.2**	

Table 16. Percentages of papers that gives references to authors' previous own ICED works by geographical regions

As can be seen from the Table 16, the percentage of research papers containing citations to their own previous ICED studies by their authors is very low, both as the average of both conferences and on the basis of research papers from each region. When compared to results of the previous referencing pattern (references to previous ICEDs) it is seen that the rates are less than half. This can be interpreted as the participation rate of the ICED17 and ICED19 authors to the previous ICEDs was not higher than 17 percent.

The last two classifications of reference models consist of the papers that refer to its authors' publications at other conferences, and research papers that do not refer to any previous work by their authors. The percentages of citations by each defined geographical region are given in Table 17 and Table 18.

References to Own Other Publications									
	WE	**NE**	**USA, CAN**	**ASIA**	**SE**	**SA**	**AUS, NZ**	**OTHER**	**TOTAL**
ICED17	60.0	58.7	60.7	59.3	42.3	45.5	25.0	50.0	**57.8**
ICED19	56.4	63.0	61.0	54.3	71.9	50.0	45.5	57.1	**59.0**
TOTAL	**58.2**	**60.7**	**60.8**	**56.5**	**58.6**	**47.6**	**40.0**	**54.5**	

Table 17. Percentages of papers that gives references to authors' own other publications by geographical regions

	No References to Own Publications								
	WE	**NE**	**USA, CAN**	**ASIA**	**SE**	**SA**	**AUS, NZ**	**OTHER**	**TOTAL**
ICED17	21.1	23.9	28.6	22.7	30.8	54.5	75.0	25.0	**25.0**
ICED19	22.9	28.3	31.7	40.0	6.3	30.0	36.4	28.6	**25.8**
TOTAL	**22.0**	**25.9**	**29.9**	**32.3**	**17.2**	**42.9**	**46.7**	**27.3**	

Table 18. Percentages of papers that does not give references to authors' own publications by geographical regions

As it is seen from the tables 17 and 18, ICED17 and ICED19 mostly consist of the research papers that refer to previous other works of their authors. It is seen that approximately 61 percent of the papers written by the universities in USA, Canada and Northern Europe give reference to their authors' own other publications. In other universities, this rate is over 40 percent.

Research papers whose authors do not refer to their own publications do not constitute the majority, but the proportion is higher than for articles that refer to previous ICED studies of their authors. While the percentage of the papers that do not include references to their authors' previous publications is only 22 percent for Western Europe universities, it is 46.7 percent for the universities in Australia and New Zealand and 42.9 percent for those in South America.

In Table 19, percentages of the research papers that refer to previous publications of the authors are shown both for the averages of ICED97 and ICED99 and those for ICED17 and ICED19.

References to Previous Own ICED Works		
	ICED97 and ICED99	**ICED17 and ICED19**
References to Own ICED Works	17.9%	16.2%
References to Own Other Publications	35.5%	58.4%
No References to Own	46.6%	25.4%

Table 19. Percentages of papers that refer to previous publications of the authors at ICED97 and ICED99 and ICED17 and ICED19

According to the results in Table 19, it is seen that the percentages of papers including references to the authors' own previous works increased from 53.4 percent to 74.6 percent

in 20 years. However, the ratio of the research papers that give reference to the authors' previous ICED works decreased by 1.7 percent.

From the above-mentioned results it can be said that for the percentages of both references to previous ICEDs and references to authors' previous own ICED works are lower than expected. In addition, it is seen that there is no improvement in these rates in 20 years. To compare these referencing patterns with those in other conferences, Cantamessa (2003) conducted an analysis. In this study, three conferences from other engineering fields and one conference with the closest domain to ICED from operations management background were analyzed. The results obtained proved that the referencing patterns for ICED works were no worse than for other conferences. Since it is possible to compare the reference models of the examined conference with those of 20 years ago, comparing the results of this study with other conferences was not included in this study. The scope of the study in reference models is to examine the change in 20 years.

CHAPTER 4

4. EMPIRICAL STUDIES

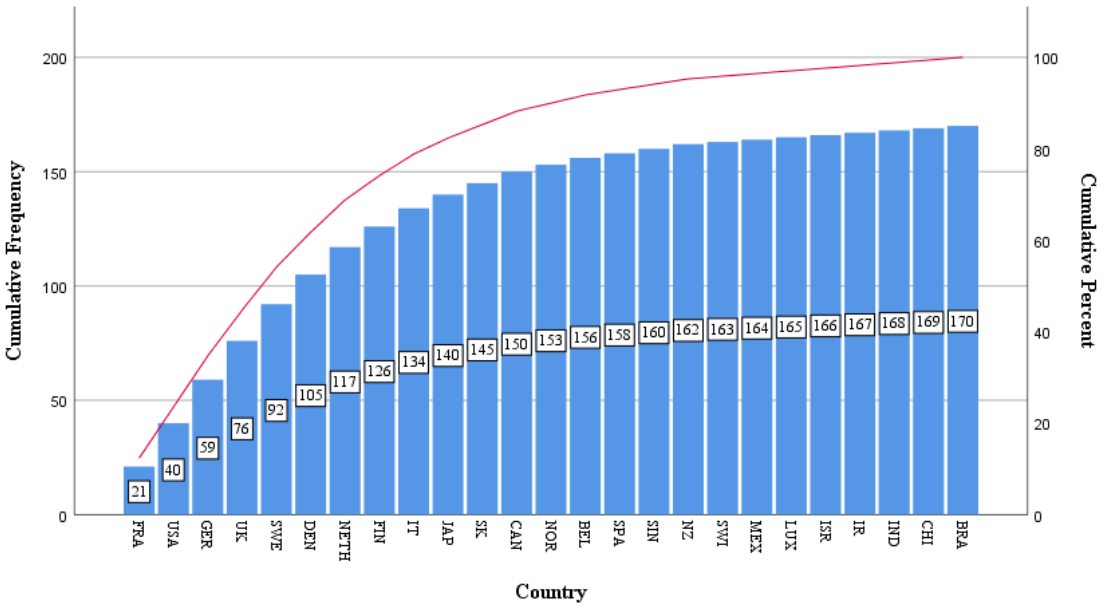
In addition to reviewing and analyzing ICED17 and ICED19 research papers, another objective of this study is to examine in detail the characteristics of the empirical studies published at ICED17 and ICED19. As described in “Methodology” section, six features of empirical studies were analyzed. In addition to the specific characteristics examined for each type of research paper, there are common characteristics investigated for each type of research paper.

Since the focus of this study is primarily on empirical studies, all the features of empirical studies at ICED17 and ICED19 were analyzed in detail in this section. First, the analyzed features for each type of research paper were examined for empirical studies and discussed by applying the corresponding descriptive statistics. Secondly, the descriptive statistics of the features specific to empirical studies were conducted and explained in detail by referring some ICED17 and ICED19 empirical research papers. The first part was examined under the title "General Features" and the second part under the title "Special Features of Empirical Studies".

4.1. Common Features

4.1.1. Countries of Universities or Research Centers

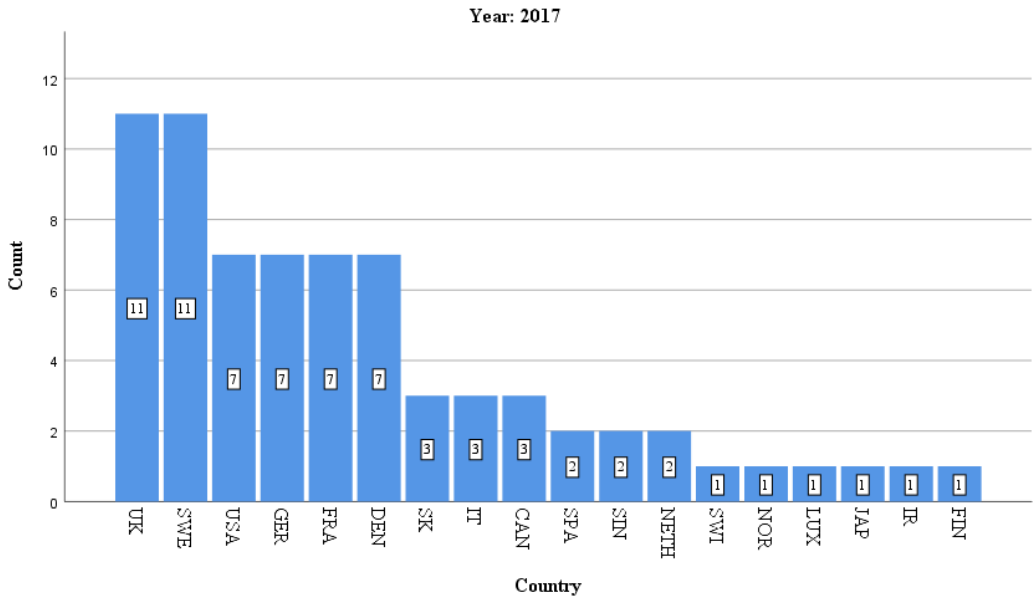
When examining the countries with universities or research centers where empirical studies were conducted, it appears that French universities conducted the most empirical studies, at 12.4 percent. In second place are German and American universities, each with 11.2 percent, and in third place are universities from the United Kingdom, with a rate of 10 percent. Pareto diagram showing the frequencies of the countries where universities are located is in Graph 7.



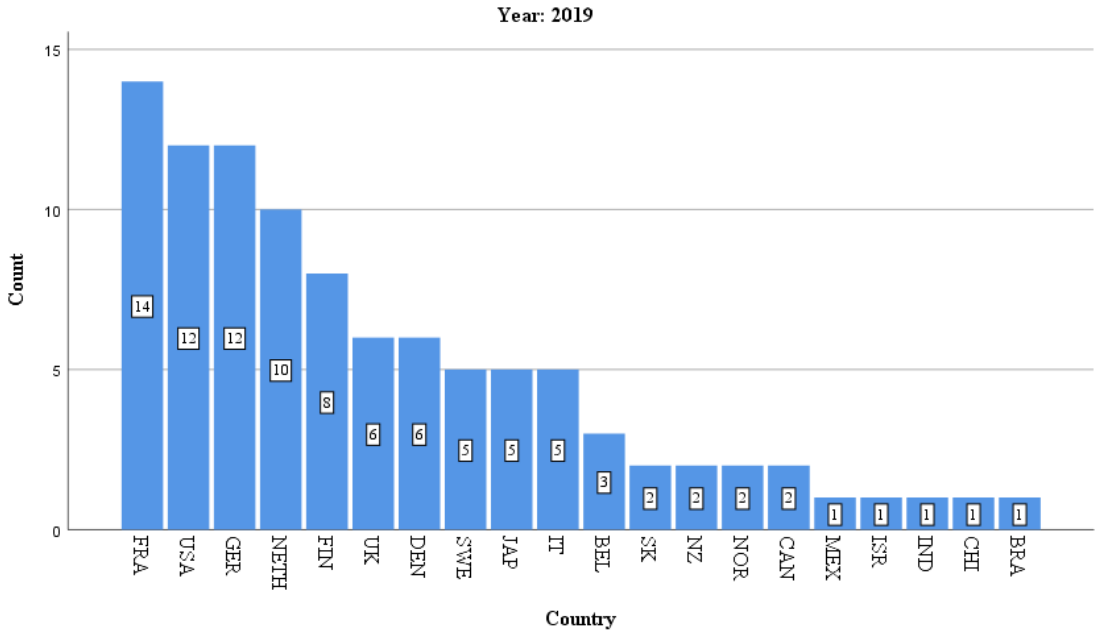
Graph 7. Pareto analysis of empirical research paper production by research centers or universities in different countries

In the results of the analysis made on the sum of the research papers, it was stated that Germany, France, UK and USA were in the first four places. When examined on the basis of empirical studies, it was found that these four countries are again the countries with the highest frequency.

In addition to the sum of the empirical studies in both years, the distribution of empirical studies by country was examined separately for ICED17 and ICED19. The results are shown in Graph 8 and 9.



Graph 8. Distribution of empirical studies at ICED17 conducted by universities or research centers in different countries

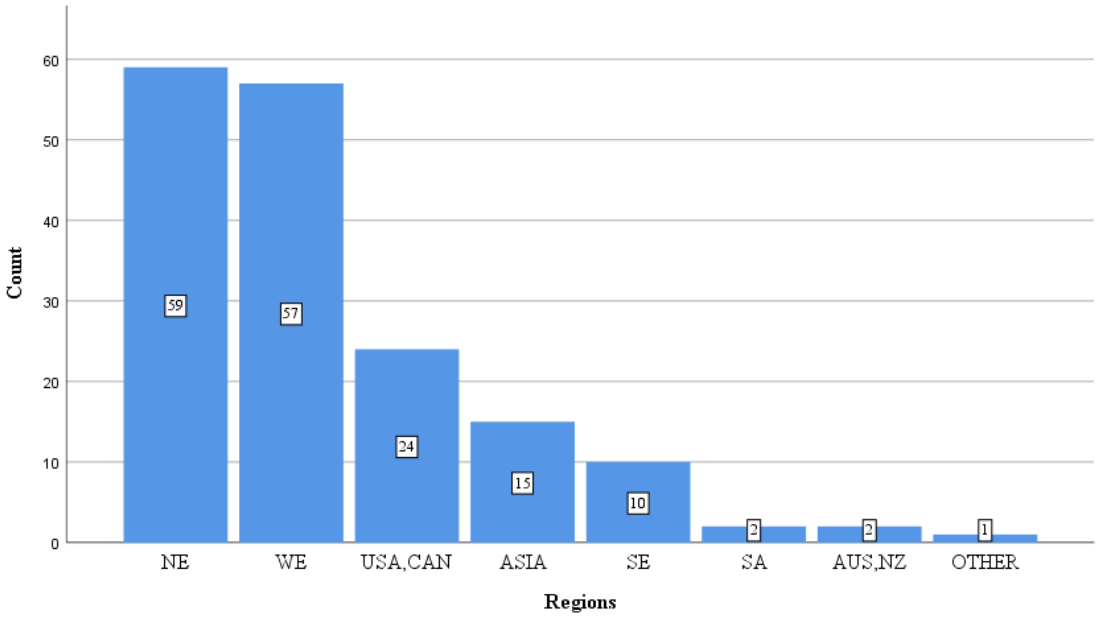


Graph 9. Distribution of empirical studies at ICED19 conducted by universities or research centers in different countries

As shown in Graph 8 and Graph 9, the United Kingdom and Sweden are the countries that have conducted the most empirical studies at ICED17, while France, the United States, and Germany have conducted the most empirical studies at ICED19.

4.1.2. Geographical Regions of The Universities or Research Centers

As explained in detail in the "Analysis" section, the countries where the research centers or universities of the research papers are located were grouped according to their geographical regions. Graph 10 results when the distribution of empirical research papers by geographic regions is examined.

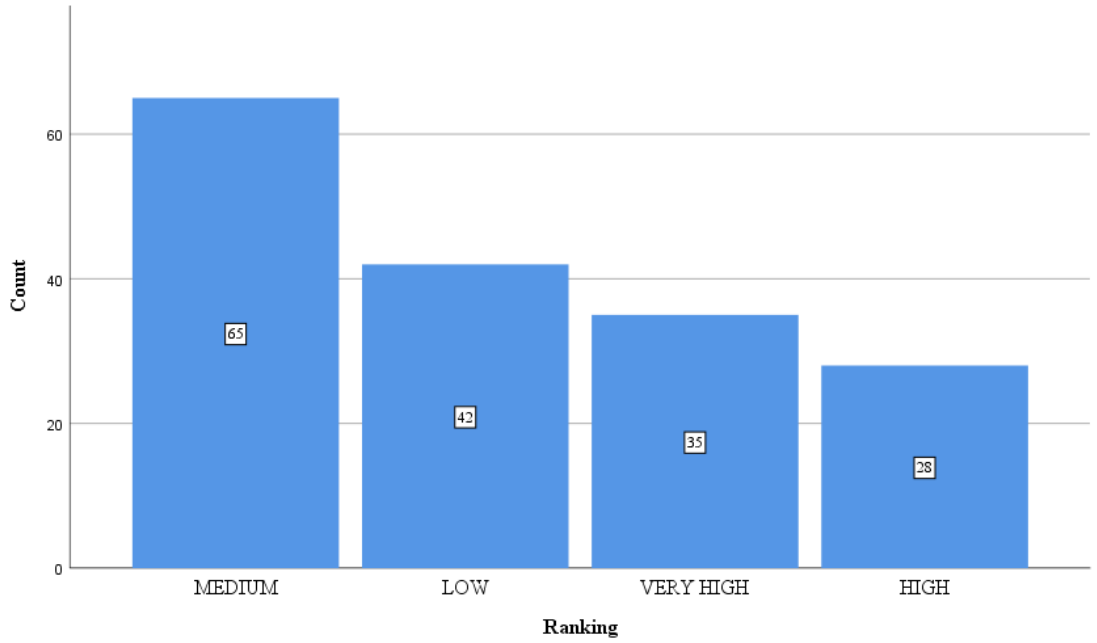


Graph 10. Distribution of empirical studies at ICED17 and ICED19 conducted by universities or research centers in different regions

As can be seen from Graph 10, Northern Europe accounts for the largest share of empirical studies at conferences, while those conducted in Western or Central Europe are a close second. The same ranking was obtained in the analysis for all research paper types, except for the rankings for Northern Europe and Western and Central Europe.

4.1.3. Ranking of The Universities or Research Centers

As explained in the previous chapter, in addition to the geographical regions in which universities or research centers are located, the ranking of these institutions according to their success was also determined. When the analysis was performed for empirical studies, the result shown in Graph 11 was obtained.



Graph 11. Distribution of empirical studies at ICED17 and ICED19 by the rankings of universities or research centers

As can be calculated from the distribution of research papers given above, 38.2 percent of the empirical studies at ICED17 and ICED19 are written by the authors from middle ranked universities. In addition, looking at the results in the analysis chapter, it can be seen that the papers from medium-ranked universities account for 38.1 percent of all papers.

As with the general distribution of research papers, it can be seen that low-ranking universities take second place. Moreover, while the rate is 24.7 percent here, it is 27.5 percent in the general distribution. From these two comparative results, the possibility of university rankings of research papers to be equally divided in each research type can be considered, but for this, it is necessary to make calculations for other types of research.

4.1.4. Types of Theory Referenced in Empirical Research Papers

Another characteristic analyzed for each study type is the type of theory referenced. As explained in the "Analysis" chapter, some studies refer to design theories, while others refer to other theories. In some studies, there are even no references to any theories.

From the results presented in the Analysis section, 63 percent of ICED17 and ICED19 contributions include other theories and 10 percent include design theories. However, 27 percent of the papers do not refer to any theory. However, 27 percent of the papers do not refer to any theory. The rates for empirical studies (in the order of the categories just

mentioned) are very close to the rates for research papers overall, at 66 percent, 7 percent, and 27 percent, respectively.

4.1.5. Methodology Description, Data Collection and Data Analysis

It is seen that, with the exception of 2 studies from ICED19 all the empirical studies contain a clear explanation of the methods or approaches used in the research. This means that about 99 percent of the empirical studies contain a clear description of the methodology. It was already noted in the Analysis chapter that almost 97 percent of ICED17 and ICED19 studies clearly explained the methodology.

Another characteristic that was examined for ICED papers is data collection. It was calculated that almost 7 percent of the research papers do not include a data collection section. In 94 percent of the remaining research papers, the research methodology of the data collection process is clearly described. Regarding empirical studies, in ICED17 only 2 and in ICED19 only 5 research papers do not include data collection. In the remaining ICED17 papers, the data collection methodology is clearly described, while in ICED19 only 4 papers do not clearly explain the data collection procedure.

Data analysis is the last common feature tested for all research types. It can be seen that all ICED17 and ICED19 contributions include data analysis. While the data analysis procedure is clearly explained in all ICED17 papers, only two papers in ICED19 lack a clear description of the data analysis method.

In Analysis chapter it was found that 44 papers, or almost 5 percent of all papers, the research method used in the data analysis is not explained. It can be concluded that the percentage of empirical studies that do not include a clear description of the data analysis procedure/method is very low when compared to the total number of papers that do not include a clear description of the data analysis. In addition, it is noted that a total of 65 papers do not include data analysis. However, it should be noticed that in all empirical studies there is an analysis of the data. Considering the general characteristics of empirical studies, it cannot be said that this result is unanticipated. This is because empirical studies aim to investigate real processes, and this is only possible with an appropriate methodology of data collection and an interpretation of the data with a systematic data analysis procedure.

4.1.6. Industrial Involvement

From the results obtained in Analysis chapter, it can be seen that overall, only 28 percent of the research contains industry involvement. However, as mentioned in the Analysis chapter, empirical studies are the type of research that contains the most industry contribution, with a share of 42.4 percent. For the purpose of examining a real-world scenario, two environments can be considered. One is the educational environment, which consists of universities and research centers, and the other is the industrial environment, which includes companies. It is not wrong to say that almost half of the empirical studies of ICED17 and ICED19 were conducted in an educational environment and the other half in an industrial environment.

4.1.7. Referencing Patterns

In Analysis chapter, some descriptive statistics based on referencing patterns were conducted and interpreted. Here, the referencing patterns were examined only for empirical studies at both conferences.

	ICED17	**ICED19**
References to Previous ICEDs	23 (32%)	28 (28%)
No References to Previous ICEDs	48 (68%)	71 (72%)

Table 20. Distribution of empirical studies referencing previous ICEDs at ICED17 and ICED19

As Table 20 shows, only 30 percent of empirical studies refer to previous ICEDs. Considering that this rate is 36 percent for all types of research, it can be said that empirical studies are one of the types of research that cause it to be this low.

		ICED17	ICED19
References made to pervious work by authors	No reference	23 (32%)	30 (30%)
	References to own ICED works	12 (17%)	12 (12%)
	References to own other publications	36 (51%)	57 (58%)

Table 21. Percentages of empirical research papers that refer to previous publications of the authors at ICED17 and ICED19

The results in Table 21 show that 68 percent of the empirical studies at ICED17 and 70 percent of the empirical studies at ICED19 contain a reference to one of the authors' own previous publications. However, the proportion of references to the authors' own previous ICED papers is only 17 percent in ICED17 and 12 percent in ICED19. Comparing the result with the rates for the overall contributions shows that they are close. In total, while 16.2 percent of the contributions refer to the authors' own previous ICED work, 58.4 percent of the contributions contain references to the authors' own other publications, and only 25.4 percent of the contributions do not refer to the authors' previous studies.

In Analysis chapter, a comparison of the two referencing rates was made between the current study and the study conducted 20 years ago. In this section, the same comparison was made for empirical studies only.

		ICED97 and ICED99	ICED17 and ICED19
References made to pervious work by authors	No reference	55%	31%
	References to own ICED works	15%	14%
	References to own other publications	30%	55%

Table 22. Percentages of empirical research papers that refer to previous publications of the authors at ICED97 and ICED99 and ICED17 and ICED19

It was found that the proportion of empirical studies that refer to authors' own previous work has increased by 24 percent. The reason for this could be the increasing number of design research studies produced by the same authors over the last 20 years. However, the same trend could not be observed for the proportion of contributions containing references to the authors' own previous ICED works. Although an increase in the ratio of contributions to ICEDs by the same authors is expected in 20 years, it is shown that this ratio has increased by 1 percent over these 20 years.

4.2. Special Features of Empirical Studies

4.2.1. General Purpose

As it is explained in "Methodology" section, empirical studies were examined in three categories as the general purpose of the research conducted. The purpose of the research might be to monitor a design process as it is, or to monitor the application of a particular tool or method in the design process. However, some empirical studies may not provide a clear explanation of the general purpose of the research.

	ICED17	ICED19	AVERAGE
Nature of Design	23 (33%)	24 (24%)	47 (28%)
Specific Tools/Method	47 (66%)	69 (70%)	116 (68%)
Unclear	1 (1%)	6 (6%)	7 (4%)

Table 23. General objective of the empirical studies at ICED17 and ICED19

As can be seen from the Table 23, 96 percent of ICED17 and ICED19 empirical research clearly identifies the general purpose. In addition, it is seen that application/test/use of a specific tool or method is the most common general purpose of the empirical studies. On the other hand, 28 percent of empirical studies aim to monitor the design process as it is.

For instance, in the study by Becattini et. al. (2017), a joint analysis of gestures and speech was conducted to understand the behavior of designers and customers during a collaborative design meeting. The joint analysis was applied to a real case study involving an Italian firm and its customers. The benefits of the joint analysis were validated with this study. From this it can be deduced that the general purpose of the study is to evaluate the application of a method. Another example for this general purpose can be the study of Atzberger and Paetzold (2019). In this study, the current challenges of agile

development for hardware were analyzed via latest surveys and empirical data. The aim of this study is to display the current state of its challenges and make comparisons with the study conducted seven years ago by Ovesen (2012).

The study of Thoring et. al. (2019) can be a good example for "nature of design" category. The study aims to explore what examples of creative spaces exist in real organizations that provide certain physical attributes to facilitate creative activities. To learn more about potential attributes of creative work environments, a case study was conducted in 18 different organizations, examining real-world examples of creative workspaces. During the study, direct observations were conducted and open-ended questions about the usage of workspaces were asked to one of the employees at each institution. As is clear here, the goal of the study is not to apply any method, but to examine the design characteristics of specific areas as they are.

4.2.2. Research Approach

The approach used during the empirical research is another characteristic that should be examined. As explained in "Methodology" section, research can be quantitative, via surveys, or qualitative, via case studies or interviews. In addition, the research approach of some empirical studies may not be clearly stated.

	ICED17	ICED19	AVERAGE
Case Study/Interview	56 (79%)	71 (72%)	127 (75%)
Survey	12 (17%)	23 (23%)	35 (21%)
Both	3 (4%)	3 (3%)	6 (3%)
Unclear	-	2 (2%)	2 (1%)

Table 24. Research approaches used in the empirical studies at ICED17 and ICED19

As can be seen from the Table 24, more than 70 percent of the empirical studies for both conferences are conducted qualitatively, and the most common research approaches for qualitative research are case studies and interviews.

An empirical study conducted by Wölfel et al. (2017) can be a good example for interview approach. In this study, a series of expert interviews were conducted to analyze the current state of user participation in industrial goods development. The interviews were conducted with ten experts whose working in the design departments or board members

responsible for design at German technology firms. Interviews have lasted 1-hour and have been audio recorded and transcribed.

According to Flyvbierg (2006), case studies have the benefit of being representative examples that bring researchers close to real-life situations through a hands-on, contextual experience. In addition, case studies enable data gathering through various exploratory techniques such as interviews, observations, and documents (Baxter and Jack, 2008), which facilitates the collection of detailed information from various stakeholders (Yin, 2014, Eisenhardt and Graebner, 2007). A good example for a case study approach can be the study conducted by Lorenzini, Olsson and Larsson (2017). In this study, user involvement was explored within the pharmaceutical context by exploring the current role of older patients in the design and development of pharmaceutical packaging. The case study consists of one drug manufacturer and one pharmaceutical packaging supplier. The reason for choosing these two companies is to benefit from the complementary perspectives of both. It is assumed that each of these firms is being representative of its industry and is using industry standard practices. Three main sources of data were used: documents publicly available from the companies, in-depth interviews with the experts on the field of pharmaceutical technology and development, and internal materials such as drawings of the pharmaceutical packaging development process provided by the experts.

It is seen that only 21 percent of the empirical studies at ICED17 and ICED19 in total are conducted via surveys. The study conducted by Patel et. al. (2017) can be a good example for survey approach. The focus of the study presented in the paper is to assess students' perceptions of their classmates' technical skills. This was a study conducted in the Pre-Capstone course and data was collected using a survey instrument. The survey consisting of 39 questions was a required course task during week six and week sixteen of the course. This represents the beginning of the service design project and its completion. The two different time frames offered the opportunity to study changes in students' perspectives on the technical skills of their classmates.

3 percent of the total empirical studies at ICED17 and ICED19 was conducted via both case study and interview approach. In Atzberger and Paetzold's study (2019) the goal is to provide a holistic perspective on the challenges still associated with agile physical product development in 2018. Both latest surveys about agile development from the literature and workshops with experts were used as data sources. In the study conducted by Brisco, Whitfield and Grierson (2017) the purpose was to explore how students use

social media as part of their collaborative work during the global design project and how they perceive the level of support. The data was collected via surveys and semi-structures interviews with students and academics of the global design class.

As it seen from the Table 24, research approach in empirical studies is mostly clear. Only the research approach in 2 research papers at ICED19 is unclear.

4.2.3. Analysis Unit

In order to conduct empirical studies, different units of analysis can be used. The distribution of analysis units used in ICED17 and ICED19 research papers are given in Table 25.

	ICED17	ICED19	AVERAGE
Individual	57 (80%)	59 (60%)	116 (68%)
Project/Team	3 (4%)	14 (14%)	17 (10%)
Firm/Company	8 (12%)	13 (13%)	21 (12%)
Project/Team and Individual	-	3 (3%)	3 (2%)
Unclear	3 (4%)	10 (10%)	13 (8%)

Table 25. Analysis unit of the empirical studies at ICED17 and ICED19

As can be seen from the results in Table 25, the most common unit of analysis used in empirical studies in both ICED17 and ICED19 is the individual unit, with 80 percent and 60 percent, respectively. In McKay et. al. (2017), the goal was to explore the potential of embedded design structures to decipher the complexity of design decisions that have a strong impact on the performance of the development process (by causing rework), and to identify the elements that contribute to this complexity. An engineering company's development process was used for empirical observation. Interviews were conducted with six experts of the company individually.

As seen in Table 25, only 12 percent of empirical studies are conducted with companies. For example, in the study conducted by Talas et al. (2017), limitations of information and communication technologies usage was explored in the context of collaborative design with suppliers. Three case studies at the company level were conducted to examine the external use of ICT. The companies in the study are the three large industrial companies that are recognized as leaders in their national and/or regional markets. Two companies

were examined in the role of customer company and the other company in the role of supplier company.

As shown in Table 25, only 4 percent of ICED17 papers and only 14 percent of ICED19 papers use project or team as the unit of analysis. The study by Dai and Velde (2017) investigates how much explicit knowledge can be extracted from meeting data of design projects conducted by master students at the University of Twente. The unit of analysis is the project or team, as 11 design projects conducted by 11 design project teams of master's students were studied using project meetings.

In 3 studies at ICED19, it was determined that both individual and project and/or team were used as the analysis unit. In the study conducted by Loweth et. al. (2019), the focus was on the information that engineering students think about when they participate in a needs assessment, the relationships between these thoughts and the results of the experience, and content that is missing from these thoughts that may be critical to the design project. Data collected during this study included individual reflection diaries completed by each team member at the end of each day, field notes about the team's data gathering practices and audio recordings of the nightly group conversations. Here, it is seen that both individual and team level analyzes were made.

Finally, the unit of analysis appears to be unclear in only 8 percent of the total empirical studies in ICED17 and ICED19.

4.2.4. Declaration of the Sample Size

While ICED17 and ICED19 papers usually describe the number of units of analysis, sample size or number of cases, some papers do not include sample size information, or the sample size is not fully understood. The distribution of research papers whether they contain the analysis unit or not is shown in Table 26.

	ICED17	ICED19	AVERAGE
Clear	69 (97%)	91 (92%)	160 (94%)
Not Clear	2 (3%)	8 (8%)	10 (6%)

Table 26. Declaration of the sample size used in empirical studies at ICED17 and ICED19

As can be seen from Table 26, the sample size is clearly declared in 94% of the empirical studies at ICED17 and ICED19. The study by Cantamessa (2003) states that the sample

size is declared only in 59 percent of the empirical research papers at ICED97 and ICED99. This suggests that this proportion has increased sharply over the past 20 years, which may indicate that more details are now being considered in empirical studies.

4.2.5. Execution Time

Another feature of empirical studies is when the study was conducted. As explained in the Methodology section, some studies are conducted within the process under study, while other studies are conducted with data on the process after it has ended.

	ICED17	ICED19	AVERAGE
During the Process	36 (51%)	31 (31%)	67 (40%)
After/Retrospective	34 (48%)	67 (68%)	101 (59%)
Both	1 (1%)	1 (1%)	3 (1%)

Table 27. Time of execution of empirical studies at ICED17 and ICED19

From Table 27, it is seen that almost half of the empirical studies at ICED17 were carried out during the process, and the other half was carried out after the process. On the other hand, 68 percent of the ICED19 empirical studies were carried out after the process ended. At both conferences, a research paper includes empirical observation both during and after the process.

The study of Patel et al. (2017) which is mentioned before can be a good example for the empirical studies conducted during the process. Here, survey was used as a research approach and the data was collected from the senior students on the sixth week and during the final week of pre-capstone senior design course.

On the other hand, the study carried out by Jarrar and Anis (2017) is an example of retrospective studies. In this study, it was aimed to investigate the general impact of entrepreneurship on engineering design education. As a sample, students who took Technology Entrepreneurship course in the last four years were selected and a questionnaire was sent to more than 320 students. This study is retrospective because it measures the effect of this course on the entrepreneurship skills of students who have taken that course before.

As mentioned above, at ICED17 and ICED19 there are only 2 empirical studies which were conducted both during and after the process. Asadi et. al. (2017) and Loweth et al. (2019) are the papers which includes both of the timings.

In Asadi et al. (2017), Integrated Product Development (IPD) approach was studied by observing the design project of an international multidisciplinary team of PhD students. The aim was to highlight the main factors that have negative and positive impacts on the IPD process. Two types of data sources were used for the study. The first data was collected during the IPD training course from the students. A case study involving the development of a washing device for the elderly using the IPD approach was conducted with the students. In this phase, the main data sources were project documents and team observation. Data gathering continued after the project was completed. A meeting was held with the students, and they were asked about their experiences and insights. The goal was to analyze the positive and negative aspects of their work process.

The study of Loweth et. al. (2019) was mentioned in the previous sections as an example for the analysis unit consisting of both team and individual levels. In this study a team of undergraduate students from a large Midwestern university were monitored as they planned and implemented a week-long needs assessment effort in a rural South American community. Data were collected both during and after the trip. Initially, data were collected from student diaries that each student was asked to complete at the end of each day, field notes about the team's experiences during data gathering and audio tapes of the nightly team sessions. After returning from the trip, retrospective interviews were conducted to obtain supplementary data on participants' perceptions of their data collection and needs assessment experiences.

4.2.6. Presence of Conclusions/Implications for Practice

The final feature of empirical studies is whether the implications of the findings for practice in education or industry are indicated.

	ICED17	ICED19	AVERAGE
Conclusions	71 (100%)	93 (94%)	164 (97%)
No Conclusions	-	6 (6%)	6 (3%)

Table 28. Presence of conclusions/implications for practice (education or industry) in empirical studies at ICED17 and ICED19

As can be seen from Table 28, in all of the empirical studies at ICED17, impact of findings on practical application is discussed. At ICED19, only six of the research papers fall into the “conclusion/implications for practice are not present” category. In general, however, it can be said that 97 percent of the research papers mention the future usefulness of the

results of empirical studies for researchers and the areas in which they can be used in industry and education.

For instance, in the study of Faludi et. al. (2017), the goal was to analyze which design method drive innovation and sustainability value. To conduct this study three design methods were tested, and these were The Natural Step, Whole System Mapping, and Biomimicry. A previous hypothesis that research and ideation activities primarily drive innovation, while goal setting and analysis activities drive sustainability was tested on the students in UC Berkeley's one of the undergraduate classes and one of the graduate classes. Workshops were conducted during the classes and after each workshop, a survey was filled by each student. Also, additional data was collected from students' final reports. Survey results were analyzed, and it is concluded that different design activities are valued differently. After the analysis previous hypothesis was verified. However, the difference between the idea generation activities and goal setting was found to be lower than expected and idea generation activities were rated as high as goal setting or analysis in terms of sustainability. From the results of the survey, the suggestions were given for the professors of different design methods. It is also mentioned that analyzing what students value about sustainable design practices and why, can facilitate improved design practice. In addition, some suggestions were made to promote the adoption of design methods and to make sustainable design a good design practice.

CONCLUSION

This study aimed to examine the debate on engineering design research methodology and to contribute to this debate by analyzing research papers published in ICED17 and ICED19. In this context, a categorization method based on Cantamessa's (2003) study was used. After reviewing all the research papers published in ICED17 and ICED19, the papers were classified into 5 categories based on their type. Specific characteristics were defined for each of these categories and all types of research papers were analyzed based on these characteristics. Since the focus of this study is on empirical studies, only the characteristics defined for empirical research papers were discussed in detail in this study. However, in Analysis chapter, characteristics common to all types of research papers were examined and the results were compared with those obtained in Cantamessa (2003).

So many descriptive statistics were performed for the research papers published at both conferences that it is not possible to summarize them here. Therefore, only a few key findings are summarized here. First, it should be noted that the most common type of research at both conferences was implementation studies. In addition, the largest contribution was made by universities or research centers in Western and Central Europe, especially German universities. It is noted that most of the contributions included both data collection and data analysis and that, in general, the methodology used for data collection and data analysis was clearly explained. Industry participation was another feature that was examined and the percentage of industry involvement in the conference papers was only 28 percent.

Referencing patterns were the last common feature examined for all type of research papers and were used as a measure of how well the researchers were aware of the prior literature. Compared to the results obtained 20 years ago, it can be noted that the proportion of papers referring to previous ICEDs has not increased significantly. However, a significant increase in the proportion of research papers referring to their authors' own earlier publications was identified.

The main characteristics that need to be summarized for empirical studies are the following. In most empirical studies, the general objective is to test/implement a particular tool or method in the design process, and most empirical studies were conducted qualitatively, i.e., through case studies or interviews. In addition to the research approach, the sample size was also examined, and it was found that in most empirical studies the unit of analysis is clearly defined. It is also seen that a significant portion of the empirical studies were conducted within the process under study, while a certain

portion of the others were conducted with data on the process after its completion. In addition, it was found that in almost all empirical studies, the way in which the method or tool under study would be applied was mentioned at the end of the study.

Although the current study is based on research conducted 20 years ago, some updates have been made to reflect the recommendations and findings of the earlier study as well as the needs of today's academic world. In addition, most of the analyses performed were compared with the results obtained 20 years ago. Thanks to these comparisons, it was possible to see the changes in ICED papers over 20 years. In this regard, comparisons can be made with this research and previous research by performing a similar analysis for upcoming ICEDs in future studies.

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