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Technical and soft competencies in teaching architecture in the context of Industry 4.0

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ABSTRACT: Technical knowledge in architecture is very important and probably considered fundamental in traditional architectural design. However, mastering soft skills, such as cognitive flexibility, analytical and critical thinking or social awareness became more and more significant to engineer-architects' work. The empirical study presented here addresses the following research questions: does technical knowledge remain the main and most important type of know-how for engineer-architects or have soft skills gained new importance in designing architecture of the future? Based on a course given in the Faculty of Architecture at Wrocław University of Science and Technology (FA-WUST), Wrocław, Poland, a survey of students was conducted to determine whether they consider technical knowledge more important than soft skills in the conception and realisation of the factories of the future. The results demonstrate that soft skills are judged as important as technical knowledge in creating industrial architecture of the future. In conclusion, the study reveals that the teaching programme in architecture should also focus on acquiring soft skills.

INTRODUCTION

Industry 4.0 aims to seamlessly merge the real and virtual worlds into one complex, cyber-physical system. A series of unprecedented transformations and ground-breaking disruptions in science, technology and various areas of social life are associated with this evolution [1]. *As the world of manufacturing changes, the way factories are planned, constructed and operated will also change* [2]. This poses new challenges for engineering professionals across different sectors, including engineer-architects. In order to keep up and remain competitive in dynamic, ambiguous circumstances of the future, their activity, thus also education, cannot remain indifferent and must take into account the critical developments.

With this shift of paradigm in industry, the array of knowledge and skill requirements of engineer-architects is constantly expanding. Recently, in addition to the traditional approach emphasising job-related technical knowledge, personal and social competencies, as well as cognitive abilities are being increasingly demanded. In such a context, the research questions of this study are as follows:

- How is perceived the importance of technical knowledge in comparison to soft skills?
- Does technical knowledge remain the main and most important type of know-how for engineer-architects or have soft skills gained new importance in designing architecture of the future?

To answer these questions, a voluntary survey was carried out among students in the Faculty of Architecture at Wrocław University of Science and Technology (FA-WUST), Wrocław, Poland, who attended the *Factory of the Future* course. A distinctive feature of this course is to allow students to acquire both technical and soft competencies, to enable them to integrate and creatively interpret diverse knowledge and use the acquired abilities to solve future-oriented problems.

BACKGROUND

The term Industry 4.0 was introduced in 2011 at Hannover Fair as an initiative by academia, industry and the German government to strengthen the competitiveness of the manufacturing sector through the convergence of industrial production with digital technologies [3]. Over time, Industry 4.0 has become a global phenomenon, synonymous with a future-oriented vision of innovative, connected manufacturing. Due to its complexity and multidisciplinary nature, it has no clear definition [4][5].

One of the key ideas within Industry 4.0 is the *smart factory* (otherwise known as *digital* or *intelligent*) which envisions a *future factory as a state of a fully connected manufacturing system, mainly operating without human force* [5]. The aim is to achieve maximum productivity with the most efficient use of resources and energy [6].

Digital technologies, such as e.g. the Internet of things (IoT), big data, cloud computing, autonomous robots, additive manufacturing (AM) or artificial intelligence (AI), are at the core of this new factory model.

Architecture *carries the task of providing new spatial configurations which effectively facilitate these developments* [7]. The problem of how to design factory buildings of the future is beginning to arouse interest, although the research on the subject is still underdeveloped. Current studies focus mainly on technical and rarely on economic, social or sustainability aspects of Industry 4.0 [5][6].

ARUP, which is a multinational firm of designers, planners, engineers, architects, consultants and technical specialists, working across every aspect of today's built environment, explored this issue from different perspectives: *people, production and space*, concluding that the future factory *will need to become more flexible, adaptable, achieve better integration between buildings and processes, and be more resilient to economic and environmental shifts* [2]. For Rappaport, in regard to the redefinition and reconfiguration of industry, the idea of the vertical urban factory is a good way forward and offers the possibility of new thinking [8]. A detailed study of the spatial typology and design of workplaces influenced by Industry 4.0 was carried out by Pieczara, who analysed it in terms of architectural education [6].

Designing the factories of the future, certainly even more sophisticated and multifaceted than traditional industrial buildings, requires a new, holistic approach. In order to prepare engineer-architects to meet this challenge, the engineering education should enable them to acquire the relevant knowledge and skills.

Technical skills are important and considered fundamental in traditional engineering education. The acquisition and ability to apply both general and discipline-specific knowledge provides the fundamental basis necessary to perform the required tasks. In the field of architecture, it includes, i.e. knowledge about building materials, structural systems, sustainable technologies, functional and spatial organisation, humanisation, aesthetics and building regulations. Technical skills also refer to the ability to work with tools used in architectural design, such as the utilisation of digital technologies (i.e. non-parametric, parametric or building performance simulation tools). Rapid technological advances require engineers to continually deepen the technical skills they already have and acquire new ones. *All technological skills, both advanced and basic, will see a substantial growth in demand. Advanced technologies require people who understand how they work and can innovate, develop, and adapt them* [9].

Technology literacy means also cross-disciplinary knowledge, which is considered essential in the complex, interconnected environment. The fusion of technologies from distant fields (e.g. architecture and synthetic biology) results in new trends and further innovations [1]. Industry 4.0 digital technology expertise enables architects to gain new working tools - augmented and virtual reality (AR/VR), and already mentioned above AM and AI. Robots are beginning to find practical application in innovative design and construction processes. In recent years, robotics was introduced to architectural courses in various universities, i.e. the Institute for Advanced Architecture of Catalonia (IAAC), Spain; RWTH Aachen University, Germany; ETH Zurich, Switzerland; and Gdańsk University of Technology, Poland.

A number of studies have found that traditional, domain-based knowledge and technical experience are not sufficient to succeed in the 21st Century environment [10-12]. *Discipline-specific competencies and transferable skills, when combined, enable people to take independent action* [13]. The literature on soft skills in the context of Industry 4.0 mainly focuses on engineers as factory workers; however, there is a need to address these issues also from the perspective of other stakeholders, such as designers of future factories.

Particularly important in the future-oriented engineering education is to prepare students, regardless of their discipline and professional field, to work in a volatile, uncertain, complex, ambiguous (VUCA) environment [10]. Thus, new abilities, approaches and behaviours that can be applied in different settings need to be learned and coped with. The 21st Century skills, known as *soft skills* in engineering and corporate training, are considered imperative in the changing world and gain particular attention from industrials and scholars. They include problem-solving and personal (social) skills that enable people to work, learn and communicate.

In the age of digitalisation and the evolution of AI, when the role of the human factor begins to be questioned, personal skills are considered increasingly important. *Demand for higher cognitive skills such as creativity, critical thinking and decision making, and complex information processing will grow through 2030, at cumulative double-digit rates* [9].

In the *Future of Jobs Report* published by the World Economic Forum in 2020, the skills identified as most important in the coming five years are mainly those classified as 21st Century skills. Analytical thinking and innovation, complex problem solving, critical thinking and analysis, creativity, are at the top of the priority list. A growing emphasis on personal development and self-management skills was also identified, which include active learning, resilience and flexibility [14].

EMPIRICAL STUDY

On the basis of the state of research, the following hypothesis can be formulated regarding the teaching of traditional architecture: having technical knowledge acquired at the university level, such as knowledge about innovative technologies for architectural and construction industry, about advanced digital technologies or about construction law and regulations, would be enough for practising architecture in the future. Nevertheless, in the context of Industry 4.0, another hypothesis may be formulated that learning soft skills, such as creativity, interpersonal communication and cooperation or emotional intelligence in social issues is equally important. The ensuing prediction of the first hypothesis for empirical testing, in which the importance of technical knowledge is compared to that of soft skills, is that students will give significantly higher scores to various types of technical knowledge than to various types of soft skills. In contrast, the prediction of the second hypothesis is that students will give similar scores to technical knowledge and to soft skills. To test these hypotheses, a voluntary survey was conducted among engineering-architecture students.

Participants were second-year Master's students who completed the course *Workplace Design Studio: Factory of the Future*. A total of 37 students (27 females and 10 males) participated in the survey, of which 22 attended the class in the 2020/2021 academic year, four in 2019/2020 and six in 2018/2019.

The survey contained 18 questions: seven questions about the importance of soft skills, seven questions about the importance of technical knowledge and four questions about the students' general evaluation of the class. Specifically, the importance of the following soft skills was tested: creativity, interpersonal communication and cooperation, emotional intelligence in social issues (e.g. customer centricity), critical thinking (i.e. reflective, challenging thinking about different concepts and relationships between ideas), analytical thinking (i.e. deconstruction of the problem into smaller subgroups and their analysis based on facts and data), cognitive flexibility (i.e. open mind and flexible thinking) and interdisciplinary thinking.

The types of technical knowledge tested were: innovative technologies for architectural and construction industry (e.g. smart materials, new construction techniques, such as additive manufacturing); advanced digital technologies (e.g. IoT, AI, big data, VR); construction law and regulations; ecological technologies; humanisation of the workplace; working conditions resulting from changing the nature of work (e.g. coworking, remote work, flexibility); and aesthetics and design.

The general questions were: *How important, do you think, soft skills/technical knowledge are/is to meet the challenges of designing industrial architecture in the coming future*? In the context of addressing future critical challenges in industrial architecture, the specific questions were supposed to gauge the students' perceived importance of the class to allow them to look at industrial architecture in a wider context than before, the importance of the class to gain new competencies (knowledge and skills), and the importance of technical competencies on the one hand, and of soft skills on the other.

Participants had to answer on a 6-point Likert-scale, with values from 0 to 5, where 0 means not important at all and 5 means very important.

The survey was prepared and distributed by means of Qualtrics. Participants read all the questions, which appeared in a random manner to avoid having an order effect in the results.

RESULTS

First were analysed the scores given by students to the questions which assessed the importance of the class to allow them to look at industrial architecture in a wider context than before, and the importance of the class to gain new competencies (knowledge and skills). The students' scores to these two questions, a mean of 4.53 to the former and of 4.28 to the latter, reveal that they positively evaluated the class, which had great importance in allowing them to better understand challenges of industrial architecture than before taking the class and to acquire new competencies. It may be considered that their evaluations of the importance of soft skills and of technical knowledge is reliable.

Data about importance of soft skills and of technical knowledge was analysed by means of Friedman's two-way ANOVA by ranks using the Microsoft SPSS software. This statistical analysis is used to compare two or more quantitative variables in a set of data containing dependent samples in which the measurement scale is ordinal. The null hypothesis of the statistical analysis is that the distributions of the scores given by participants to two or more questions are the same.

To answer the research questions, this study investigated by means of ANOVA the following issues in the data: 1) the mean scores given by students to all types of soft skills were compared with the mean scores given to all types of technical knowledge; 2) the scores given to the general question about the importance of soft skills were compared with those given to the general question about the importance of general knowledge; 3) the scores given were compared to the seven types of technical knowledge; and 4) the scores given were compared to the seven soft skills.

The first ANOVA revealed that students gave comparable scores to questions about the importance of soft skills (M = 4.27, SD = 0.446), and to questions about the importance of technical knowledge (M = 4.12, SD = 0.531), $\chi^2(1) = 0.444$, $p = 0.505$.

The second ANOVA revealed that students gave comparable scores to the question about their general evaluation of the importance of soft skills (M = 4.00, SD =1.073) and to the question about the importance of technical knowledge (M = 3.75, SD = 1.052), $\chi^2(1) = 0.727$, $p = 0.394$.

The third ANOVA revealed that the distributions of the scores given to the seven types of technical knowledge tested were not similar, $\chi^2(6) = 20.180$, $p = 0.000$. Specifically, this study found that knowledge about construction law and regulations (M = 3.54, SD = 1.346) received statistically significant lower scores than several other types of technical knowledge; namely, working conditions resulting from changing the nature of work had M = 4.25 and SD = 0.824; innovative technologies for architectural and construction industry had M = 4.46 and SD = 0.767; and ecological issues had M = 4.49 and SD = 0.901, as shown in Figure 1. In addition, this study found that knowledge about aesthetics and design received statistically significant lower scores than knowledge about ecological technologies. No statistically significant difference was found among the score given to the other types of technical knowledge.

The fourth ANOVA revealed that the distributions of the scores given to the seven soft skills tested were not similar, $\chi^2(6) = 22.427$, $p = 0.001$. Specifically, this study found that interpersonal communication and cooperation that had M = 4.03 and SD = 0.687, as well as emotional intelligence with M = 3.89 and SD = 1.022, received statistically significant lower scores than cognitive flexibility with M = 4.59 and SD = 0.686, as shown in Figure 1. No statistically significant difference was found among the score given to the other soft skills.

The survey results are shown in Figure 1.

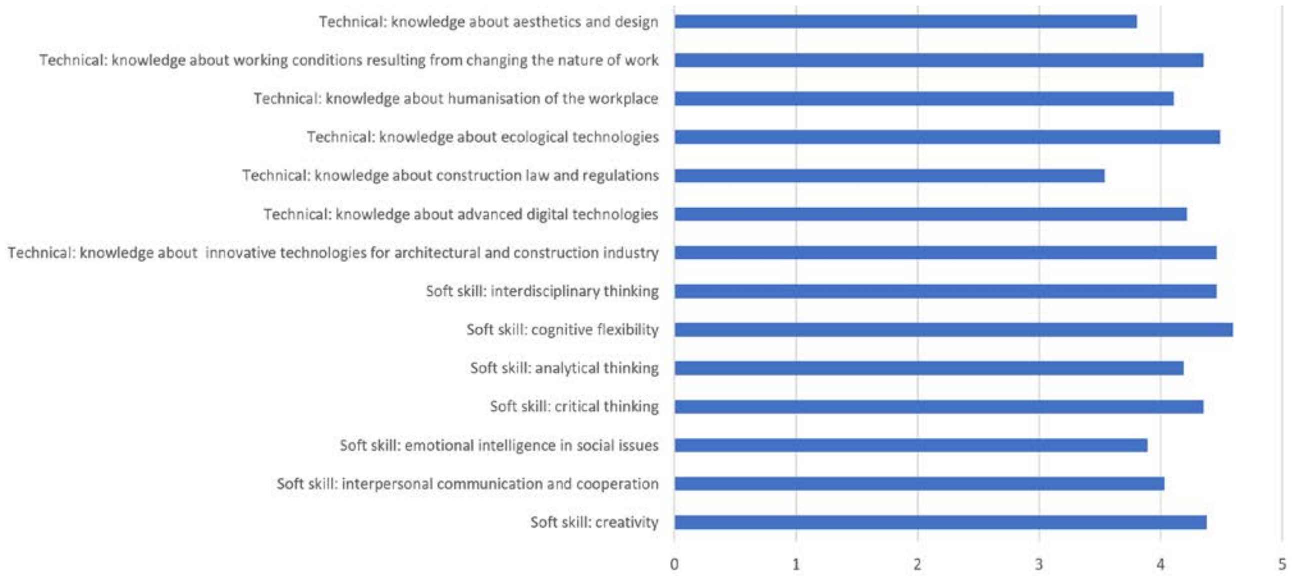

Figure 1: Mean scores given for technical knowledge and soft skills.

DISCUSSION

This study attempted to answer the question of students' perceived importance of technical knowledge versus soft skills in studying architecture in the context of Industry 4.0. The results of the survey indicate that students at the FA-WUST view the importance of both types of knowledge and skills in a comparable way. Therefore, the results do not support the first hypothesis, that technical knowledge gained during studies is sufficient to practice the architecture profession in the future, while learning soft skills is less important. In contrast, it provides evidence supportive of the second hypothesis. As the survey results show, both hard skills (i.e. specific, teachable technical knowledge acquired during academic education) and soft skills (which include self-management, social and emotional competencies) are perceived as equally important in meeting the challenges of industrial architecture design in the coming future.

The analysis of the evaluations of the different types of technical knowledge revealed that students perceived some types of technical knowledge as essential for designing architecture of the future.

First, the highest ratings were given to knowledge about green technologies. This indicates a high environmental awareness among young people and the understanding that ecological issues are essential for future development. A sustainable approach to both industrial activity and architecture is particularly important, as it is believed, that smart factories of the future will not be dirty, smoky plants, and *will have to operate with greater material and energy efficiency while providing safe and healthy working conditions* [2]. Therefore, knowledge of various environmental technologies, such as renewable energy technologies, environmentally friendly materials, circular economy solutions, etc, is necessary in architectural education.

Second, in the 21st Century, with extremely rapid advancement in various fields of science, the knowledge of innovative technologies for architecture and construction is another key element in students' education. For this reason, this type of technical knowledge also received high scores. Indeed, smart materials and brand-new construction techniques create new opportunities in design. Knowledge of robotics or additive manufacturing technologies for example, lead to new functional and formal visions of factory architecture and are of great interest to students.

Third, the high scores given to knowledge about working conditions resulting from changes in the nature of work are related to various disruptions occurring in the modern world. On the one hand, there is the beginning of reorganisation of industrial and social activity associated with the transition to Industry 4.0 - digital technologies are changing man-machine relationships, occupations and working methods. On the other hand, recent changes, such as those related to Covid-19, which have contributed to remote working and the use of digital tools on a larger scale, make it clear that the future is uncertain and change comes unexpectedly. For engineer-architects, knowledge of various working conditions is important in order to create buildings that are responsive to rapidly changing and even yet unknown requirements of the future workplace.

Fourth, compared to the aforementioned types of technical knowledge, the survey results showed significantly lower ratings for the importance of knowledge of construction law and regulations. This type of knowledge is essential for architectural practice and teaching of traditional industrial architecture, which are based on a linear approach, processing defined and verified data. Teaching architecture of the future, which by definition is unpredictable, requires a different way of thinking that does not focus excessively on current norms and regulations but takes into account the variability and ambiguity of information to be acquired. Regulations change over time and they depend on the location of the plant being designed. Thus, more important than to master specific knowledge about norms and regulations *hic et nunc* is the awareness of the need to acquire the ability to interpret a multitude of data to be taken into account for dealing with the needs of Industry 4.0.

Importantly, the survey brought into light the importance of soft skills in designing industrial architecture. Among the soft skills tested, cognitive flexibility was evaluated as more important than interpersonal communication and cooperation, as well as emotional intelligence. At the same time, cognitive flexibility was evaluated as important as interdisciplinary thinking, analytical thinking, critical thinking and creativity. This finding stems naturally from the nature of the task that is to envision the factories of the future. These results also bring into light that students, with dual training - architecture and engineering - have full awareness of the important role that interdisciplinarity plays in such an enterprise.

This is due to the fact that Industry 4.0 requires a holistic approach to planning, design, construction, use and end-of-life management. More and more specialists are involved in these processes, and the demands in many aspects (i.e. comfort, efficiency, economy, etc) are increasing which implies the need to constantly learn and acquire new skills. According to the conducted study, students at the FA-WUST are aware that to respond to the challenges of the coming future they need more than just technical knowledge.

Indeed, creating a new model of an organisation, such as the Factory of the Future requires perceiving it as a system consisting of different, interrelated and interacting elements; with emphasis on the need to grasp the changes taking place both within it and in the world around it. In such a context, architectural design is moving towards a non-linear, dynamic approach which involves adopting different points of view and ways of thinking, undertaking activities that are not founded solely on proven data and repetitive tasks, but are largely based on speculation, questions and the exploration of new, often unknown areas. There is no one-fits-all solution but there are different possible approaches to different issues.

The vision of the future according to the Industry 4.0 concept forces a constant readiness to solving new and multifaceted problems. This requires innovation, interdisciplinarity, teamwork and open-mindedness. Therefore, modern educational processes should place emphasis on stimulating and strengthening cognitive flexibility. Another important aspect is the need to focus on developing creativity, which includes not only solving problems but also searching for and formulating them [15]. Openness to different perspectives takes on special significance in the changing environment; hence, exploration and creativity is more important than *the ability to correctly select and apply one of the existing models* [6].

With the introduction of advanced technologies on an ever-increasing scale (especially digital technologies central to Industry 4.0), there will be an increased need for professionals with finely tuned social and emotional skills that machines have not yet mastered to such a high degree. A broad set of skills acquired by humans will be effective in performing difficult, complex, interdisciplinary tasks.

Considering the fact that one of the most important features of the future smart factory is responsiveness to rapidly changing demands, thus personalised production and customers centricity, it is interesting to note that emotional intelligence in social issues received statistically significant lower scores in comparison to others soft skills. Interpersonal competencies related to communication and cooperation also received less attention, despite the fact that students are aware of the interdisciplinary nature of designing in the future, which means, among other things, collaboration and cooperation in larger, multidisciplinary and often international groups.

CONCLUSIONS

The most relevant, and thus the most important type of knowledge in the traditional way of conceiving and designing industrial buildings has been, up to recently, knowledge about various technical aspects of construction, functionality, efficiency and aesthetics, among others. However, with the advent of unprecedented challenges, a new type of phenomenon appeared - Industry 4.0 - calling for novel skills indispensable to imagine future or even, futuristic architectural realisations.

The outlined study provides empirical evidence that soft skills are perceived by architecture students as important as technical knowledge in the conception and realisation of the factories of the future. Indeed, in the context of rapid and complex changes, technical knowledge is not the only and most important criterion of professional engineering competencies. Equally important is the acquisition of soft skills that enable to find solutions in non-standard situations, for which appropriate solutions and procedures have not yet been developed and proven effective. The professional future of engineer-architects will be determined by their expertise, as well as by their flexibility, adaptability to new realities and ability to learn.

Therefore, it can be concluded, that engineering education for architects should take into account the need to develop technical knowledge, and also focus on acquiring soft skills. It should be highlighted that both types of competencies do not stand in opposition to each other, they are part of a whole; and a diverse, broad range of skills is crucial for further development in the context of Industry 4.0.

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