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Industry 4.0 in architecture education

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ABSTRACT: The transformation of industry has brought a new concept of Industry 4.0, characterised by the innovation of production processes focused on digitisation, automation and interoperability. This has become an important turning point in industrial development. A new category of production has emerged in the form of smart factory. The objective of this article is to present a reflection of Industry 4.0 processes and trends in the education of typology and architecture of industrial buildings in the Faculty of Architecture and Design at Slovak University of Technology in Bratislava, Slovakia (FAD-STU), Bratislava, Slovakia. The authors recommend the extent to which innovative systems of production, logistics and distribution should influence the methodology and content of education in the design of industrial buildings. The result of their study is an innovative methodology for teaching the architectural design of industrial buildings in the context of new models of industry, based on the characteristics of smart manufacturing and Industry 4.0.

INTRODUCTION

Digital factories are a courageous concept currently viewed with astonishment, and it is difficult to imagine the industrial future of 2050 today. As Ray Kurzweil (an American inventor and futurist) writes, the right time and a favourable environment are necessary to implement inventions and innovations:

> *Inventing is a lot like surfing: you have to anticipate and catch the wave at just the right moment* [1].

The foundations of Industry 4.0 are based on the digitisation and *vertical* interconnection of intelligent systems for the article production, processes and services. Another feature is *the horizontal integration* through global networks and co-operation of partners across countries. Industry 4.0 will focus on mutual communication and co-operation of everything that has something to do with production (people, machines, equipment, logistics systems and products), on modern organisation and a model of companies offering services in the production system.

Industry 4.0 is generally regarded as the new digital industrial revolution. The human role in Industry 4.0 is still very important and essential, in its assumed complexity of work. Workers will have to be educated and trained to deal with this complexity by using new forms of planning methods and technologies [2].

Therefore, the following questions arise: will Industry 4.0 also affect the architectural typology and design concepts of industrial parks, areas and objects? What will be the place of the human being in the super modern industry? To what extent will changes in the education of future architects be needed? It will be about new determinants of production with an overlap into shaping the architecture of modern production companies of the future. A suitable degree of implementation of relatively complex systems and super modern technologies is required; for example, of the Internet of Things (IoT), big data, digital manufacturing or digital twins. An important fact is the consensus of advanced information technologies: IT production with advanced IT in the building [3].

From the point of view of teaching, it will be a continuous process, as the issue of typology of production object design has been part of the curricula in the Faculty of Architecture and Design at Slovak University of Technology in Bratislava (FAD-STU), Slovakia, for a long period of time [4]. The article presents the idea of transforming Industry 4.0 and grounded theory (GT) methods into a teaching process which, in a suitable and innovative way, enables students to acquire knowledge and basic skills.

SELECTED TERMS OF INDUSTRY 4.0

Within Industry 4.0, the real world is connected to the virtual one. Machines communicate with each other but also with people. They can respond to failures, by promptly modifying technological steps, so that production does not stop.

This has a positive effect on the minimisation of material errors, maintaining a shorter production process or on less demanding lines of operation [5]. A high degree of production rationality, transport of products and people is important, so that all processes in space and time can be precisely controlled digitally.

The breakthrough idea is to create *a digital twin* as a virtual model of a physical object, a principle applied by NASA in the Apollo project in the 1970s. It allows to remotely monitor the state of a real object in real time, to simulate various situations. By analogy, this is a continuous synchronisation between a real company and its digital counterpart, provided by the constant mirroring of both parties [6].

Elements of re-engineering appear in the concepts of industry which influence architectural solutions to various extents. Siemens, for example, mentions the following re-engineering elements in digital strategies: data management, automation, production quality control and monitoring, product integration, co-operation with research and development. Extensive machine-to-machine communication (M2M) and the Internet of Things (IoT) represent production with almost no human intervention. Most employees inevitably move to the research and development department.

Revolutionary changes have taken place in the logistics concepts. The optimisation of logistics flows is based on *a push or pull system* which has an impact on the management of the entire company. Companies use tools that are the most efficient for a given production and eliminate waste, and apply the philosophy of lean production [7]. An inspiring example in logistics is *the Ocado hive system*. It integrates the grid system and takes advantage of the similarity of a hive functioning in the bee-house [8]. Sustainable concepts include emerging production in local networks, global information transfer, global data business work and locally made products [9].

MANIFESTATION IN ARCHITECTURE

The fundamental issue will be the transformation of Industry 4.0 and of digital processes, the architectural materialisation of innovations in the production space and the determination of the working environment. The underlying structure of large organisms, such as a smart city is an inspiration. It confirms the need for a comprehensive application of modern digital-age tools at all levels - from production technologies to the architectural and urban design of industrial production areas and buildings in the digital era [10].

Several authors point out the complexity of *smart*. It is not possible to talk about *smart* in a large organism, if progress is applied in only one area. A good example is the concept of a smart city as a multidimensional organism, where tools and innovative approaches are applied in all components and activities of the city [11].

A smart production company is characterised as a complex organism monitoring progress and applying innovation throughout its system. The concept of Factory 56 Mercedes-Benz (Sindelfingen) is a case in point. As one of the most modern car factories in the world, it is a well-functioning large, flexible *paperless* organism with an innovative energy concept.

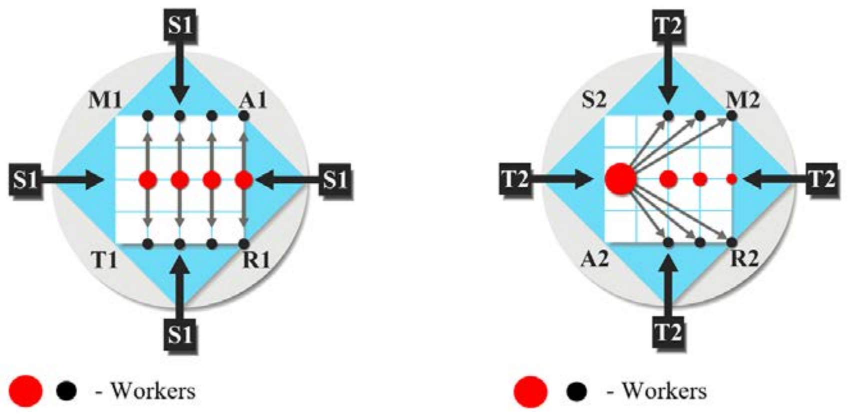
The connection of Industry 4.0 and smart technologies with architecture is characterised by key determinants, as shown in Figure 1. The chosen acronym SMART is a methodical visual aid in teaching which decrypts the determinants as follows:

S sustainability - an overall concept based on sustainable principles (industrial eco-park);
M materiality - application of low tech in the construction and material solutions of buildings (to use local or recycled materials);
A aesthetic - quality architecture, harmonisation of people and architecture;
R research in the field of production and transformation in architecture;
T technology and environment technology at a high level (environment work).

Figure 1: Increase of determinants in the current industrial architecture and Industry 4.0.

The basic methodological tool for teaching innovation is the creation of architectural conceptual models of digital production. The main areas of change relate to overall sustainability, energy efficiency, universality, interoperability and harmonisation from localisation to architectural details and employee involvement in innovation processes, as demonstrated in Figure 2.

Considering the industry location, it seems appropriate to place some parts of production in a residential area, thereby bringing a change in the view of the innovative factory architecture. The identification and harmonisation of the employee with his or her company plays an important role there [12][13].



a) b)

Figure 2: Models of industry; a) model of current industry - relationship of determinants and workers in the process of industrial production, the determinant of sustainability dominates; b) model of Industry 4.0 - relationship of determinants and workers in the IT management of production, the determinant of technology dominates.

The ideal architectural model of Industry 4.0 solves the following projections in the hierarchy:

a) industrial park - area - sustainable territorial concept, re-usability;
b) industrial area - sustainable territorial concept, re-usability;
c) building - modularity, flexibility, variability, re-usability;
d) production technology - use of lean production (lean manufacturing), automation and digitisation, minimisation of pollutant production;
e) production and working environment - design of a building with zero consumption or with energy gains (water and waste recycling).

In this context, the timeless thoughts of maestro Alvaro Aalto are:

> *To make architecture more human means better architecture ...This goal can be accomplished only by architectural methods - by the creation and combination of different technical things in such a way that they will provide for the human being the most harmonious* [14].

At the same time, Aalto brings to mind the need to use technical equipment only to such extent that it is necessary, so that it does not deform, control and destroy nature.

METHODOLOGY OF TEACHING IN THE CONTEXT OF NEW MODELS OF INDUSTRY - DISCUSSION

The transformational process of teaching architecture is characterised by the use of methods that motivate, support creativity, lead to teamwork, support analytical and critical thinking. In such an education, it is important to promote and develop analytical and synthetic thinking in synergy with the development of learners' creativity [15]. The field of industrial architecture and Industry 4.0 currently requires the interconnection of a number of the above-mentioned systems, as well as a change in teaching. As Pusca and Northwood pointed out:

> *Change is not an easy process, but it is a necessary process, if the goal is to achieve exceptional undergraduate education that meets the need of a continuously changing environment. All universities want to ensure their engineering programmes are relevant to the 21st Century, and to establish or maintain an international reputation for high quality undergraduate education* [16].

In architectural research and education, academics look for the methods that best describe the interdisciplinary nature of architecture. Through an interdisciplinary course the students can learn how to break down their limitations and open up to the knowledge and skills transfer [17].

Architectural research is not about a single method. Scientists adapt and use approaches from various disciplines, including the humanities, natural and social sciences to match the needs of architectural research. A grounded theory (GT) approach can be helpful as it appropriately reflects the given area of research [18]. GT is based on the principle of data collection, sorting and cyclical evaluation - data coding, analysis and reflections which are repeated several times according to a predetermined plan [19]. GT has its place in general pedagogy, in the humanities and is the subject of many studies [20][21].

It is an inspiring approach that encourages researchers to interact persistently with the relevant data, being constantly involved with emerging data analyses. According to the method of grounded theory, the research problem continuously shapes the analyses [22][23].

The choice of GT suits the constant movement, and thus the transformation of the Industry 4.0 phenomenon in architecture and its teaching. Technology is constantly developing and changing, and therefore transforming the teaching methods and the setting of the learning process, with further major changes are expected in the near future [24]. This requires sufficient insight into the studied issues and a certain amount of imagination, but also appropriate inspiration [25]. It opens up space for the creativity of the teacher and student, as well as flexibility in creating design procedures. The initiation of proactive behaviour in the context of GT application in teaching correlates with the creativity of students and the originality of their outputs. Avsec emphasises:

Students need to apply a wide range of knowledge and skills, where innovative behaviour is required [26].

Research

The research presented in this article was carried out in the Faculty of Architecture and Design at Slovak University of Technology in Bratislava, Slovakia (FAD-STU). In the first phase of GT application, an interview can be used for data collection. As part of this research, a structured interview, also with regard to Covid 19, was replaced by a questionnaire including 97 students. The aim was to find out: the interest of FAD-STU students in the issue, the reasons for modifying the model and the teaching content of industrial buildings design.

A Google form was used with four questions in regard to the basic knowledge of students (question 2 and 3) and their interest in the topic of Industry 4.0 within the teaching process (question 1 and 4).

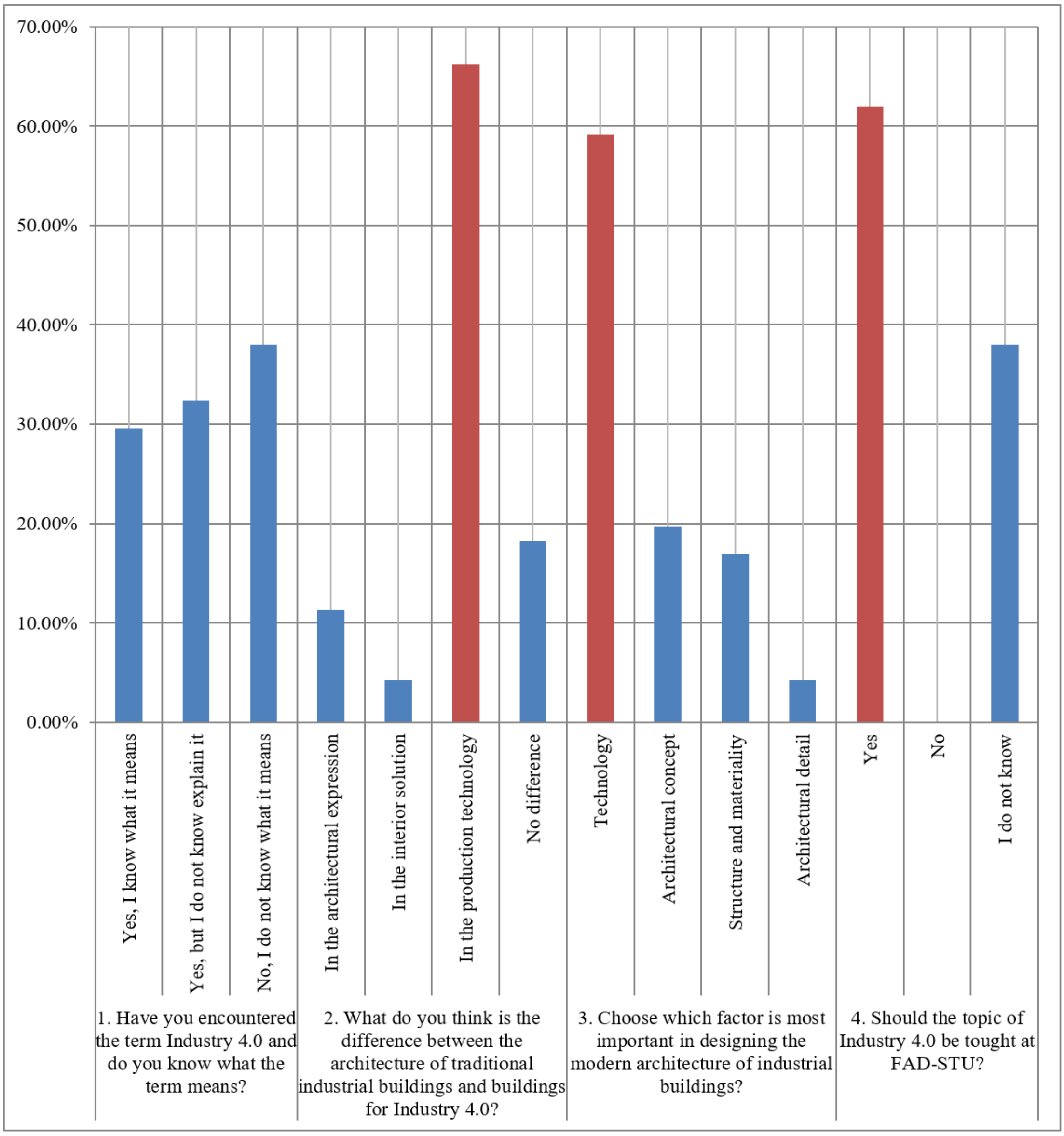


Figure 3: Students' responses to the questionnaire in percentages.

As can be seen in Figure 3, 40% of the students do not know what the term Industry 4.0 means, and at the same time each of the respondents wants the topic to be taught in the FAD-STU. Almost 70% of the students intuitively feel the difference between the architecture of traditional industrial buildings and buildings for Industry 4.0 in the production technology used in each instance, but in this context they cannot specify the differences. It is surprising that only 19% of the students consider the architectural concept to be the most important factor in the creation of modern architecture of industrial buildings. However, overall they are interested in Industry 4.0 and the issues within this topic.

The application of GT stimulates critical thinking and creative solutions, and it eliminates students' dilemmas in regard to challenging issues during teaching. The algorithm for acquiring new knowledge is hierarchically arranged as follows:

1. Data collection (interdisciplinary - typology, constructions, materials, technologies, logistics, etc);
2. Open coding - searching for information in data sources from various areas that affect Industry 4.0, selection by importance;
3. Categorisation by a specified key;
4. Axial coding - comparison and creation of relations between sorted data elements (categories), verification of new relations and connections;
5. Selective coding - selection of created categories;
6. Theoretical notes - writing, sketches - creatively free, the source of ideas are based on comparison,
   Hypothesis - comparison of the new and the original, confirmation of the new concept,
   Constant comparison of analyses and verification - reverse process, new theories.

Figure 4 demonstrates the basic algorithm and GT application in the teaching of architecture, incorporating Industry 4.0 in the components of the chosen acronym SMART.

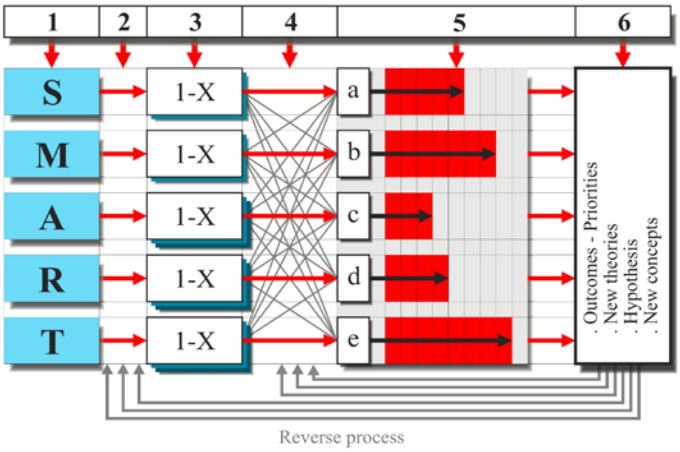


Figure 4: GT application in the designing process of the architecture for Industry 4.0.

The figure shows the interconnection of parallel data lines, the evaluation of several indicators and the revision of relations, the circular nature of the research with the possibility of returning to any stage according to specific conditions and objectives. After the overall evaluation of the analysis results and verifications, the area and degree of importance of the individual factors can be determined.

CONCLUSIONS

The dynamic advancement of information technology requires visionary thinking in building *the factories of the future*, interdisciplinarity and teamwork, therefore, modern educational processes should place emphasis on stimulating and strengthening cognitive flexibility [27]. Modern production and a factory can be imagined as *a factory for innovations.* IT determines the creation of production premises which must be taken into account in the teaching of architecture. Architectural education is based on complex methods which, together with innovative content, significantly contribute to the attractiveness of the educational offer in the FAD-STU.

The presented methodology and models are one of the possible ways, which emphasise creative and analytical thinking so important in subjects, such as design studios. Lianto stated that:

> *Grounded theory is useful in the architectural research because it generates a new substantive concept, based on a phenomenon happened in the daily life* [28].

It is based on a constant reassessment of the relations between sustainability, architecture and technology, arising from the cyclical evaluation of data. It creates a degree of uncertainty that has a positive effect on the development of students' critical thinking.

When creating an architecture for Industry 4.0 responsive to technological progress, one cannot forget its sustainable and human dimension. This reminder is the motto of many architects reflected in their works. Technology is meant to serve the human beings. The Czech writer and satirist Karel Čapek in his science-fiction play R.U.R. written in 1920, confirms the utopian idea about the production; and not just the production:

> *The production should be as simple as possible and the product practically the best* [29].

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