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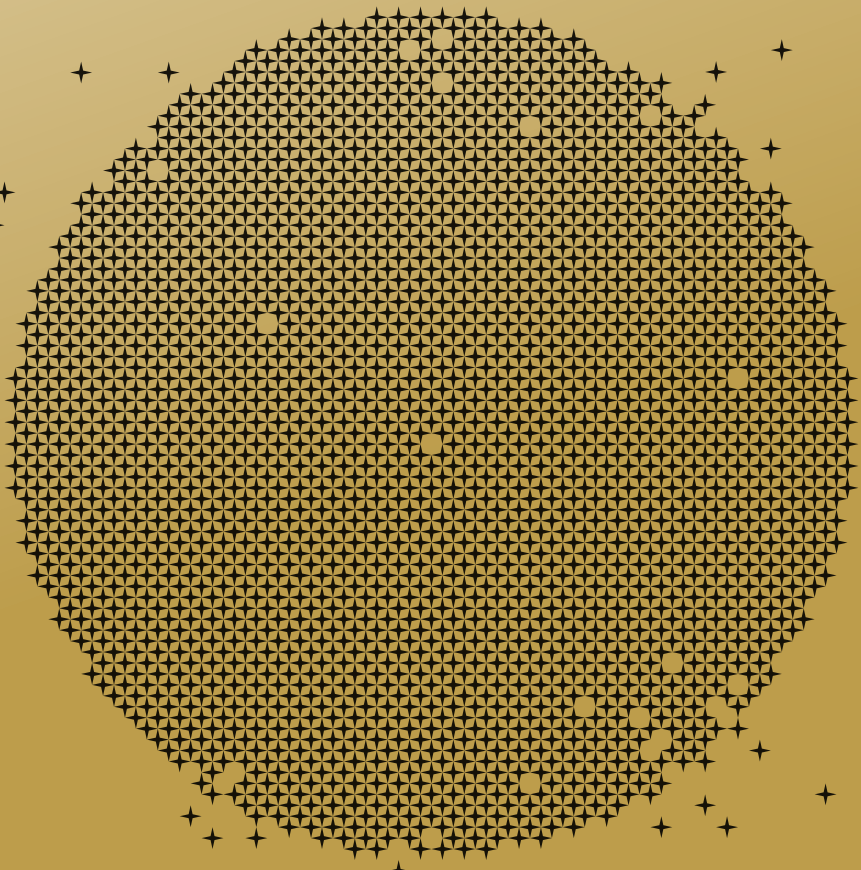

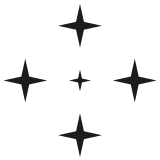

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Contents

SMART FACTORIES:
NEW PRODUCTION SPACES IN DIGITAL TRANSITION

Merve Pekdemir Başeğmez and Burak Asiliskender

ABSTRACT

Digital developments have affected humanity in industry and many areas in recent years. The new revolution, defined as Industry 4.0, is planned to ensure remote and digital machine–human collaboration for a new working life. Thanks to internet technologies, communication can be achieved in a digital network with the machines and robots used in production and the employees who manage and supervise them. In this new order, the possibility of people participating in the system remotely, leaving physical production to robots, and using smart production systems leads to factories turning into smart factories. While smart factories require a digital environment between humans and machines, they also bring humans and machines together for different functions.

As a result of the digital revolution, the transformation of factories into smart factories and innovations in the production space initiates a new discussion in industrial architecture. This study focuses on the spatial effects of the smart production model of the new factory revolution. The research aims to understand how digital production processes in smart factories change factory designs. For this reason, smart factory definitions were first researched in the literature, and future factory propositions were examined. Then, in this context, smart production spaces designed and built to produce new technologies since the day the new revolution was introduced were analysed. This study aims to present a projection for new production spaces with the morphological analyses performed. As a result, this study will form the basis for future studies as an architectural criticism of the transition process.

#industrial architecture, #digital production, #production spaces, #smart factory, #machine and design

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INTRODUCTION: FACTORIES IN DIGITAL TRANSITION

Factories are the reflection of industry, technology, economy, and the resulting business life of architecture. The changing production methods since the Industrial Revolution have also transformed production spaces. The most remarkable invention of the revolution, the steam engine, has now evolved into robots that can work unmanned in production. Displaying and exhibiting production has become the primary design approach of the factories of the new era. A new revolution has been experienced in production recently with Industry 4.0. This revolution aims to individualise product, service, and distribution processes, make production methods more flexible, and increase smart products and production. Innovations provided by information and communication technologies enable transformations and digitalisation in production processes. It is widely known that the digitalisation of production also leads to the digitalisation of labour and spaces.

The new digital world provides many opportunities for humanity. Thanks to internet technologies, many things in daily life can be done remotely. We can shop, watch a live performance anywhere, attend studies, training, and conferences, and continue working remotely. Especially in industry, a revolution is taking place with the new collaboration between machines and humans. A new distribution of tasks is being organised between humans in the digital production part of work and machines in the physical production processes.

Digital production, smart production, and even unmanned production technologies are also defined as the second machine age in industrial history. Monitoring the production system over a virtual network and discussing a flexible production process requires much new research in this field. Although the effects of the smart factory on production technology and the economy are more prominent, it is also thought that digital transformation will cause significant changes in the environment and society. The increase in the need for qualified labour, the possibility of managing production from a virtual environment, a decrease or change in working hours, and even industrial migration will undoubtedly cause transformations in and around production areas. Therefore, discussing current and future innovations and goals of production is the first step in understanding the architecture of this transformation.

This study mainly focuses on the revolution in factories; new and innovative production spaces. The impact of the digital transformation that started in the industry on production spaces, the spatial needs of new factories, unmanned production areas defined as smart factories or dark factories, and spaces designed for machines constitute the primary research topics of the study. In this context, the study question the use of architectural terminology in smart factories and new production areas. . The first part of the study examines the definitions and innovations of Industry 4.0 and smart factories in the literature. The concepts and adjectives invented by the new and smart production model are presented. In the second part, the proposed and imagined possibilities for the future factory during the digital transition phase are examined, and new factory definitions in the literature are investigated. The third chapter discusses the relationship between Industry 4.0 and architecture and the first and innovative factory examples to understand the production spaces of the new revolution. Smart production areas designed and built in the last decade are analysed morphologically, and the transformation on a spatial scale is also examined. The factories examined as examples of the study are handled independently of a location or sector, and how the factory, as a production space, responds spatially to new technologies and developments is investigated. The spatial diversity in new factories is presented by examining the functional differences in these examples. While the study focuses on transformations in production, it also investigates how factories aim to create new interactions with people. Ultimately, this study aims to provide a ground investigation and projection for future factories.

COMPREHENDING INDUSTRY 4.0 AND THE SMART FACTORY

Industry has experienced four significant revolutions. The first revolution started with the invention of the steam engine, which increased the use of machinery in production. In the second revolution, electrical energy started to be used in factories, and the mass production model was the most significant innovation of this period. The third revolution was the introduction of computer technologies. Communication and internet technologies provided faster and smoother production and prepared the background for smart systems. The fourth industrial revolution, which uses smart technologies in production, also came up with Industry 4.0. This concept was first introduced by the German National Academy of Sciences and Engineering (Acatech) at the Hannover Fair in 2011 (Lu 2017). While Germany defines this revolution as Industry 4.0, the United States works with the terms Industrial Internet of Things (IIoT), Advanced Manufacturing (AM), Re-industrialisation (RI), and Internet of Things (IoT). Japan's Industrial Intelligence concept draws attention to machine-to-machine communication and autonomously controlled machines (Ernst and Frische 2015).

Gorecky et al. (2016) have defined Industry 4.0 as a synonym for the production of tomorrow and summarised it as the digitisation of business processes, increased internal and external communication, and the modularisation of smart machines, products, and equipment. In the future, the production criteria are envisaged as mechatronic changeability, individualised mass production, and internal-external communication. The modular separation of the production lines in traditional factories will enable the system and space to be reduced and transported. However, in this whole process, production is only possible with an excellent virtual network.

The production space for the smart systems of Industry 4.0 is also defined as the smart factory. The smart factory technically ensures that all machines, robots, sensors, and production lines work interconnectedly and automatically. In addition, smart editing detects and prevents machine problems that exchange information for the entire system and manage the entire process (Gabriel and Pessl 2016). In factories that produce remote solutions to all the complexity in production, direct communication is provided between people and machines.

Yoona, Shin and Suh (2012) define the smart factory as the "Ubiquitous Factory (U-Factory)." Ridgway, Clegg and Williams (2013) use the title "Factory of Future" in their study about the new production areas and Industry 4.0. It is stated that future factories will enable better use of technologies; on the other hand, access, monitoring, and control of these technologies. In this context, the "Easily Reconfigurable Factory" is defined as a proposal for the future factories. The concepts for this factory are an open value chain, flexible production, human-centred manufacturing and crowdsourcing, anything-as-a-service, and symbiotic ecosystem business models. Wang et al. (2016) draw attention to the beneficial outcomes of smart factories, such as flexibility, productivity, resource and energy efficiency, transparency, promoting integration, profitability, and friendliness to staff.

Smart production is also defined as lights-out or dark production, a process led by machines without the need for any human being in the production process. For this reason, new production spaces are also called dark factories. The dark factory was built in Japan not only as a factory but as a production facility. The industrial park owned by FANUC consists of twenty-two factories and is used by robots. Robots can produce another robot without human intervention and do it nonstop (Hunt 2017). Similarly, Siemens Amberg Factory has created an efficient and error-free production ecosystem (Digital Transformation n.d.). Thanks to the digital twin created, the factory can be viewed online, and the systems can be viewed remotely.

Industry 4.0 affects the economy and societies globally, bringing innovations in many fields thanks to robotics, artificial intelligence, nanotechnology, and 3D applications. When robots are integrated this

much into life, the first question or problem that comes to mind is the unemployment that may occur due to their existence. However, this situation provides different and new job opportunities for people. In digital production, people are now completely on the labour-intensive side of production.

Digitalisation has been transforming business life and working environments, such as factories, for a while. Virtual participation interviews with applications such as augmented reality and holograms are now common and frequently used. Participants who are not in the same place as each other can conduct interviews, presentations, and discussions. Therefore, the space is expected to respond to virtual needs. Although remote work can often be done with a computer and phone, there is also a need for more flexible spaces that are planned with technological equipment and are prepared for instant and variable working conditions. The presence of wireless systems and cloud data, digital glasses that work with eye movements, digital walls, and virtual keyboards help transition to flexibility. Future workspaces will likely transform into spaces open to common uses, can be personalised for a short time, and offer alternatives.

These definitions and propositions lead us to the following questions: What will the production spaces of the future be like? Who will work in the factory, or where will humans work? In the smart production system, when the physical tasks are left to the machines, the employment of workers in the factory will decrease. For this reason, factories are thought to be working areas only for machines over time. Every place can be a working place for a worker who joins the system from a virtual network. In this context, Strozzi et al. (2017) point out that although new technologies and models of the Industrial Revolution have been defined, the available information for smart factories is insufficient. Kumar, Narkhede and Jain (2018) draw attention to human comfort, environmental problems, and industrial sustainability for changes in employee and workplace relations. Industry 4.0 and smart factories are fields of research that will require different disciplines to work together despite their short history. In addition to its technological, economic, and social transformations, the spatial transformation process is also exciting. For this reason, in addition to the research on the new revolution of the industry and smart factories, the new factory architecture is also fascinating and constitutes the focus of this study.

SEEKING NEW PRODUCTION SPACE IN THE DIGITAL AGE

It is fact that Fordism and Taylorism have shaped the production industry for decades. When computer technologies developed, changes began in the cooperation of machines and humans in the factory.

Workers tasked with using machines in mass production started to use machines that control the operation of machines, direct them, and detect problems in digital production. Workstations were installed on the production lines, and after the linear production lines in mass production, a piecewise and real-time production model was adopted. Nina Rappaport (2009) also draws attention to the changes in duties and definitions upon the change in the system, as workers are being called "partners" and "team players" rather than "workers." It can be said that mass-production factories have entered a transformation process both technically, spatially, and socially in the age of the smart industry.

Rappaport (2017) claims that factories are keys to unlocking the spatial logic of society. In the 200-year history of industrialisation and urbanisation, technology, capital, labour, and ultimately the factory have been constantly transformed. Rappaport associates modern factories with production and contemporary examples with consumption. For this reason, Rappaport describes the new revolution of the industry as consumption of production.

Rappaport (2019) looks for alternative areas in the city for future production areas with the idea of a Vertical Urban Factory. This proposition considers that production can be moved to multi-story buildings. In other words, vertical production will bridge between work and life with production settlement in high-density residential areas. Rappaport describes it as a "super-urban symbiosis" (Rappaport 2019). In addition, Rappaport (2022) also presents the Hybrid Factory/Hybrid City proposal, which is the future of flexible and innovative cities with a hybrid model of sustainable production, advanced production systems, and new technologies. In this study, participating researchers question mixed uses, including production, re-used factory buildings, and their potential in the near future.

While Industry 4.0 defines a flexible production system, some things that have changed with digitalisation are business organisations, the organisation of cities, and relations of people with the place where they work. Vicente Guallart (2021) emphasises that, due to the change in the traditional industry, spaces that make urban life easier with logistics and distribution dominated by robots have emerged. Gullart (2021) defines this as post-human architecture. In the first step, the digital world increased the number of freelancers, and shared working spaces began to emerge. As a result, there is a partnership in the production spaces. In Industry 4.0 technology, the same machine can produce a bicycle and a chair and be sold in the same environment.

For this reason, it is the digital age model that products are close to where they are consumed. Guallart (2021) has described this as from Co-working to Co-factory. He defines the digital post-industrial

city as a productive, ecologically self-sufficient bio city. He sees the city as a part of nature rather than growing against nature. Guallart's proposal, Local Digital Production, is also a model based on on-site and on-demand production. Guallart criticises the concentration of the traditional industrial model in large factories and the concentration of factories in a few regions and describes these areas as places where labour is cheap worldwide. It has led to a commitment to a place in the world and a company for almost everything. Local Digital Production aims to restore production to cities with medium-sized factories or workshops. With the innovations brought by this digital production model, it is thought that the factory will cause less noise and environmental pollution and be more easily integrated in cities.

Another innovation of smart production is the possibility of customising products. In the changing world, producing and purchasing products with personal preferences, not with the impositions of mass production, is attractive to consumers. Simulating the process makes it possible to produce different products on the same production line. The production of the planning before the physical production enables the detection of errors and deficiencies, and as a result, a non-problem production is ensured. Thus, the factory provides unique production services to more customers. In addition, this situation allows smart factories to meet people with production, unlike dark factories. Experience factories are also a new proposed scenario for future factories (Hüttenhain ve Kübler 2021). Until recently, only employees and managers could access factories. The factory has become a place that everyone can visit, and this has breathed new life into urban production. Besides the smart factories, experience factories result from Industry 4.0.

Revolutions also significantly affect the development of cities. Using digitalisation, artificial intelligence, and autonomous robots in production processes will bring a new order from production to consumption, and even urbanisation. Tali Hatuka (2021) discusses a model in which city industry dynamics are more integrated into her proposal, called "New Industrial Urbanism." Industrial urbanism is a socio-spatial concept that integrates production with the city. This proposal mainly targets the local economy and small and medium-sized producers and entrepreneurs. This proposal is linked to the concepts of Industry 4.0, industrial ecosystem, and industrial ecology.

Industry 4.0 and the innovations it provides directly affect production areas. Digital production methods and now unmanned production provide an error-free, fast, and economical process in industry. For this reason, factories, the workplace of machines, robots and humans, are now turning into production spaces where physical labour is absent and where robots actively participate. While the methods of unmanned production or robotic production are being discussed in factories dur-

ing this transition period, the factory is also looking for different ways to connect people. In this context, while searching for the new state of the factory in this study, a conceptual analysis was first made, and alternative names for the new production spaces were investigated. In addition to the smart or dark adjectives of the factory, it also gives an idea about its experience, urban and hybrid names, and the new relationships it will establish with the city and humans.

CONCEIVING A NEW PRODUCTION SPACE

While the research and development process for Industry 4.0 technology continues, this process undoubtedly affects production spaces. Although factories serve the transformation process of raw materials into products, they are planned according to different spatial needs according to product type, production method, and production process. Since the Industrial Revolution, factories have generally been buildings where large machines were housed, people worked in cooperation with the machine, and a group managed, planned, and controlled all processes. However, the smart production model carries the human and machine collaboration in the factory to a digital network. This innovation presents people with the opportunity to do their production work remotely.

The transition of the industry introduces a new division of labour between humans and robots. In this division of work, the production hall is left to the machines, while other work can be moved outside the factory. In this study, the production spaces planned and built after Industry 4.0 are analysed to understand the factory in the new order brought by the revolution. Morphological analyses were carried out in the factories subject to the study, and the spatial transformations of new-type factories in smart production processes were examined. Research has been done on how and for what purpose human beings meet again with production—the primary function of the factory. For this reason, the most important research criterion was that the selected samples included new production technologies and how they communicate with humans and naturally with the environment, regardless of the sector. In other words, the study questions the new spatial projection of production.

Wittenstein Innovation Factory, one of the first smart production spaces, draws attention due to its innovative space approach during the transition to Industry 4.0. Unlike the old ones, this factory combines development and production activities, but it has been designed flexibly with modular expansion options. Co-working space, offices, a production hall, and shipping are designed to be parallel in this factory, but the innovation division has grown significantly. Customers can access the production and project sections from the open gallery

("The Innovation Factory" n.d.). A flexible working environment has been designed next to a flexible production space, not only where production takes place but also as a co-working place.

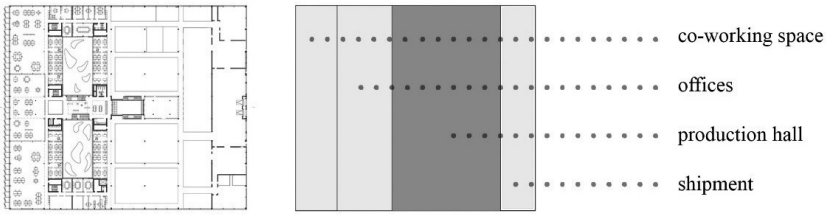


FIGURE 1. *Wittenstein Innovation Factory, 2014, Germany.*

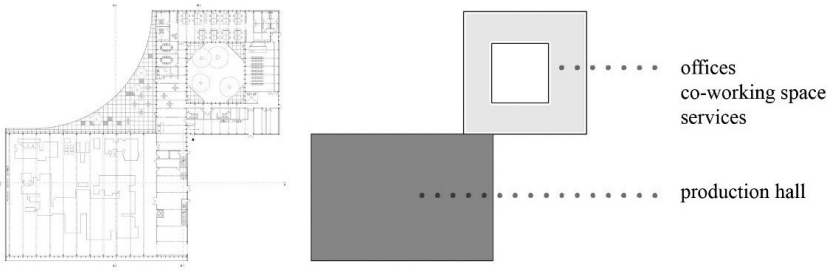
In a similar example, where the factory and innovation are combined, Arena 2036 is conceived as a research centre for the next generation of cars. A flexible and dynamic studio is envisaged to develop and produce innovative production technologies for this centre. Arena 36 aims to bring together different professional perspectives, working cultures, and approaches and bring innovations produced in collaboration with other disciplines to the industry. Another aim of the formation, whose focal point is the automobile industry, is to contribute to shaping the future production style in the digitalisation process (Arena 2036 n.d.). The building has a large production hall, offices, and a warehouse, similar to old factories. However, unlike old factories, the production hall is designed to provide flexibility and variability, can be adapted to the combination of humans and machines, accommodates various test equipment, and has mobile offices.

FIGURE 2. *Arena36, 2016, Germany.*

One of the first examples of a smart factory after innovation and research factories is Trumpf Smart Factory. Product design, production, and delivery processes are designed to comply with Industry 4.0 technologies. The production is digital, remotely controlled, and continues uninterruptedly. Thanks to the "skywalk" designed in the production hall, visitors can watch the production. In addition, in "control rooms," visitors are informed about critical real-time process indicators from ongoing production. In the other part of the factory there are offices, co-working spaces, an auditorium, and a café ("Trumpf Smart Factory" n.d.). This factory combines two functions: production and exhibition.

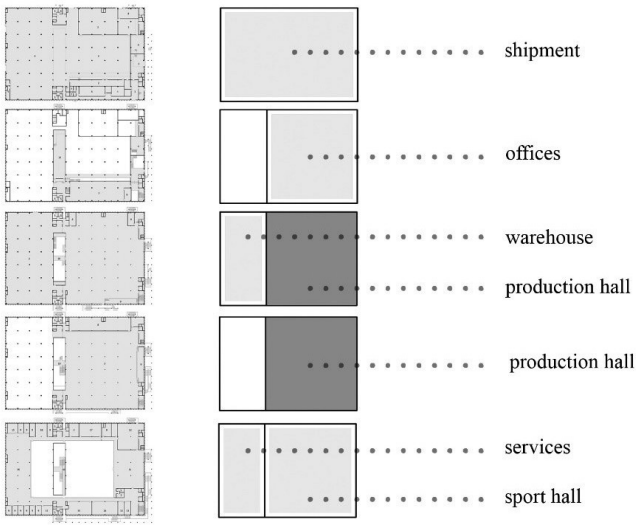
The fact that the factory can be visited and the production can be monitored and exhibited is the most significant innovation that distinguishes the future factory from traditional factories.

FIGURE 3. *Trumpf Smart Factory, 2017, USA.*



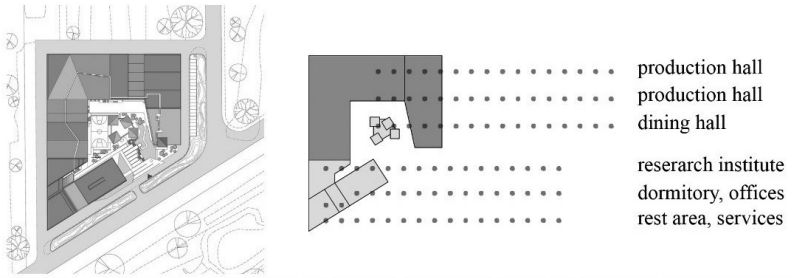
One of the places where smart technologies and smart production systems are used the most is undoubtedly China. The Future Stitch Smart Factory, built in the economic development zone in Haining, China, in 2018, is quite different from traditional factories. In the factory, where socks and sports equipment are produced, there are also places for sports events and artistic activities. The factory was designed to be multi-story, and visitor circulation was created to exhibit the product and production. In addition, this circulation was continued outside the building, and a temporary open area was created for the employees. The galleries in the interior provide an experience for both production and other activities. A basketball court and a roof terrace were designed in the section where production was not carried out. The factory entrance is common for employees and visitors ("Future Stitch" n.d.).

FIGURE 4. *Future Stitch Smart Factory, 2018, China.*



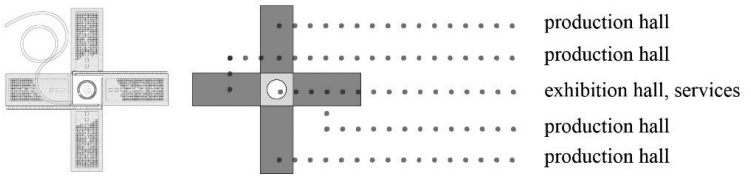
The number of industrial cities in China has been increasing in recent years, guided by the traditional economic growth model. Production organisation is effective for these production areas with low costs and high efficiency. In this context, Zhejiang Factory is attractive with its design approach. It creates a new order not only for the production area but also for the industrial workers who will work or even live there. The architect of the factory first created a courtyard to provide easy access to the space, surrounded by the production workshop, laboratories, offices, and living spaces. The dining hall and life service centre were designed at the centre of the site. In addition, the architect designed a stairway that continues inside and outside the building to connect all the units. Besides its primary function, the stairs serve as a break and rest area ("Zhejiang Perfect Production Factory" n.d.).

FIGURE 5. *Zhejiang Perfect Production Factory, 2019, China.*



The Plus Factory, built in Norway, is a new-generation factory that demonstrates how smart production technologies can be integrated with space. The furniture factory, which has a sustainable production, is designed with walking paths and camping areas in the forest. The factory consists of warehouse units, a colour workshop, a wood workshop, and an assembly workshop connected to the main space (The Plus for Vestre n.d.). There are offices and co-working spaces in the centre. The factory is an open workspace for robots and an exhibition space for visitors. In the factory where smart production methods were applied, sensor maps were made for robots on the ground. These colourful maps are also a guide for visitors. While flexible and remotely controllable systems provide flexibility in the space, the whole process has become experienceable for users.

FIGURE 6. *The Plus Factory, 2020, Norway.*



Machines have started to take a more active role in production processes, which has caused radical changes in factories. Innovations in production technology have enabled the restructuring of production stages and new alternative functions were added to the production function of the factory. Although smart production brings machines and people together in a virtual network, new production spaces bring people and production together in different relationships.

In its simplest form, the factory consists of a production hall specialised according to the product, offices, a management department where production is planned, and a storage area where raw materials and products are stored and shipped. The main space of the factory, the production hall, is designed following the physical conditions of the necessary machines and production line according to the product and production method. In the factories, infrastructures and installations for machines as important as the working comfort of humans. Nowadays, research and development, co-working spaces, exhibition halls, sports halls, rest areas and even dormitories have been added to the factories.

Although Industry 4.0 has provided the opportunity to work remotely, offices continue to exist in the first smart production factories. Especially in innovation factories, offices are designed as common working areas. Common working and common production suggest the possibility of common use for factory buildings soon. In this context, Guallart's common factory proposal, which promotes diversification of production in the same place, is probable for next-generation production areas.

New factories have functions that are not significantly related to production, apart from their primary function. As in Trumpf and Plus Factory, the production process has become observable, experienceable, and exhibitable. This relationship between factories and people is a step for the industry to return to the city. It is seen that each function added to the production will bring the factory closer to the city, and industrial environments may have been formed before Tali Hatuka's industrial urbanism proposal. Similarly, Future Stitch Smart Factory has brought together daily activities such as sports with production to find a place in the city. In addition, the architecture specific to its location has been conserved, and the factory was built as a multi-story building. It can be said that Nina Rappaport's idea of the Vertical Urban Factory is a viable alternative to bring production to existing cities consisting of multi-story buildings.

One of the most significant innovations of this digital transformation is the relationship that humans establish with the machine and space. After innovative research and experience examples, Zhejiang Perfect Production Factory draws attention to bringing production directly to life. While Industry 4.0 aims to move people away from the factory and to communicate in a virtual network, a new relationship emerges between production and daily life.

Although Industry 4.0 and the smart factory are still very new, when the examples are examined, functions that are not directly related to production, such as exhibitions and sports activities, are seen in addition to common work areas. Under the leadership of new technologies, factories have gained new functions besides production and enabled production to establish different relations with people. While production continues unmanned only with machines, the process is still available for humans to experience. Far from the city and the social environment, the factory has become a part of daily life again. People are invited to the factory and are asked to experience the production process and spend time with different activities.

In the first factory examples of Industry 4.0, researching and co-working spaces draw attention, while in more recent ones, the functions are diversified. In addition, the boundaries within the space are reduced, and the primary functional areas of the factory, such as production shipping, are gathered in a single space, and this space becomes exhibitable. The increase in mixed-use area independent of the product and production of the factory is transforming the factory both architecturally and intellectually.

Examined examples indicate that new functions may soon be added to the factory. Smart production has transformed the factory into a place that produces, and exhibits, and where we shop, study, research, and, most importantly, experience. The factory has become a new show-off space, and architectural aesthetic concerns have increased again. In this respect, the factory looks quite different from the twentieth century Fordist image. Tatiana Mazali (2020) says that, for this, "*Production chains are established that look like showrooms, where even the machines become beautiful*."

The dominance of the machines in production has also caused the users coming to factories to change. In this case, the factory is not just where production takes place, or production is no longer done only in the factory. The factory is designed for different functions at the same time as production. New users can visit the factory not only to produce or participate in production but also to experience it.

CONCLUSION: IMAGINING THE FACTORY IN THE FUTURE

Industry 4.0 is not only the revolution of industry but also the alteration of the machines and production spaces. In addition to the physical aspects, the labour, knowledge, and power that create the factory are also transforming. The relationship of production with time, people, and space is being re-established. Production actors are transitioning from humans to machines, from machines to digital screens, and from digital screens to robots. This transition introduces humanity to a digital culture.

New production spaces are defined as smart factories consisting of machines. However, after the smart factory, suggestions such as innovation factory, factory of the future, vertical urban factory, hybrid factory, green factory, and co-factory are included in the smart production areas. The new revolution in industry brings humans and production together in different relationships.

As a result of the many opportunities offered to humanity by the digital revolution, a new order is expected in working life, production spaces and social environment. Remote working, involvement in smart production and virtual connections between machines and humans have transformed the factory. While it was thought that the factory would be left only to machines in this revolution, many people who were not directly related to production became the new users of the factories. On the one hand, production can be experienced, on the other hand, a new relationship is established between the product, the producer and the consumer. In this way, the factory and production are looking for ways to back to the city.

As a result of the comparative analyses carried out in this study, it is seen that while factories provide spatial solutions to new production methods, a new factory typology also emerges. In this state, the factory is trying to become a part of daily life again. It is seen that the factory architecture of the twenty-first century has transformed into hybrid or hi-flex production areas where other functions besides production are included in the design. Therefore, the results of the study provide a basis for future studies in the design of production areas and processes.

In summary, while the digital transition in production technology brings together people and production in a digital environment, factories are turning into places where these new production methods are experienced, exhibited, and even used for other functions. Not only the production methods in the factory change, but also the technical structure of the factory required for these methods, its relationship with its user, environment and city. In this respect, the study initiates a new discussion about the factory architecture of the future by drawing attention to the spatial diversity of new production spaces.

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