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Evolution of Production Spaces: A Historical Review for Projecting Smart Factories

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Abstract

Factories are transforming not only mechanically and technologically but also architecturally due to emerging developments in the industry and fabrication: This new process, called the Second Machine Age or Industry 4.0, a new model is designed in production by providing the human-machine partnership over a virtual network. It is aimed that the machines used in production and the people participating in different stages of production can work in different spaces. In time, jobs that require human power will be replaced by robots, and a new order is being considered where there will be no people in production spaces, and they can work in the virtual environment. Production for human beings is mostly from material production to digital production; labour will turn into digital labour. For this reason, it is thought that production spaces will turn into smart factories with only machines and production robots and no workers. And now the question is: what is a smart factory?

The revolutions in the industry history started with the invention of the steam engine; then, new technological revolutions were experienced with the use of electricity in production, the development of automation systems and internet-based systems. While technology and production tools are constantly changing, these developments also affect production spaces. Factories are also transforming to keep up with these rapid and continuous physical and fictional innovations. This study focuses on the architectural evolution of factories by following the technological revolutions of the industry. It examines the main criteria in the process of change and transformation of factories and spatial reflections of the revolutions. It establishes a relationship between production technology and the needs of the production spaces and seeks references from past samples. The study aims to review the historical background for generating a projection to new production spaces and to be a new discussion for future factories.

Keywords:
Factory, industrial building, industry and architecture, industry 4.0, production space

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INTRODUCTION

Machines becoming the pioneers of production, the change of energy from steam power to electricity, the use of mass production, the control of production from screens with computerized systems, technological revolutions have been experienced in the industry and production spaces have constantly changed to respond to different needs with these developments. Each technological development has created different needs in the spaces. The new industrial revolution, Industry 4.0, indicates a radical transformation process will occur in the production spaces. The revolution, which will change many production methods, describes a timeless and spaceless production model with machine-human cooperation. Time, space and human relations constantly change in the transforming and renewing world. In parallel with the innovations in the industry from the past to the present, architecture has both been affected by the process and has affected the process. Especially in the last period, internet technologies and digitalization have created excitement in architecture and every field.

The last industrial revolution, defined as digitalization in production, has brought about many economic and social changes. With innovations such as the revolution that changed many common production methods, internet-based systems, and the cooperation between machines and humans, a transformation has begun in and around the production space. The place of the smart factory is also a new field of study for the architectural discipline. One of the remarkable works in this field is Nina Rappaport's idea of a Vertical Urban Factory. Rappaport looks for alternative spaces in the city for new production spaces and argues that production can be moved to multi-storey buildings, which will happen with new financial, real estate, technological, and managerial strategies. Rappaport defines the typology of the vertical urban factory as a multi-storey factory and says that the production process can flow from the top down or the bottom up (Rappaport, 2019). It has been pointed out that the new industrial revolution created hybrid spaces in another work. The spatial proposal for the new industrial revolution is to place high-compact industrial zones between high-density residential blocks and create a 'super urban symbiosis' that bridges the gap between work and life. The Vertical Urban Factory project indicates that the new industrial revolution has created hybrid spaces. It points out that common industrial areas will be formed from a factory model per company, as in previous factories (Lane & Rappaport, 2020). Furthermore, smart factories, where mobile workers are connected to production virtually, will provide organic, real-time production, unlike the modern assembly line. It will offer a spatial economy rather than an isolated heterotopia (Rappaport, 2009). The basis of this idea is not mass production but small production batches.

As well as the new production spaces, it is discussed where these spaces will be and how they will re-establish a relationship with cities. Tali

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Hatuka defines the concept of production close to the city, fed by the city-industry dynamic, as New Industrial Urbanism (Hatuka, 2021). Hatuka argues that the new technological evolution has changed the physical structure of the factory, distribution processes, innovation networks, and access needs. The new industrial urbanism is not a very new concept. During the first industrial revolution, many people worked in or near where they lived. However, mass production has led to spatial divisions. The distances between living and working areas have increased.

In contrast, Hatuka is researching new industrial cities based on these developments, not how the city will be affected by Industry 4.0, questions how cities will embrace the new industry. The basis of this new concept is Industry 4.0, industrial ecosystem and industrial ecology. Industry 4.0 refers to digitalization and innovations such as artificial intelligence, autonomous machines, biotechnology, and digitalization between production processes and consumption. The industrial ecosystem refers to higher energy efficiency, cleaner and quieter industrial processes resulting from these innovations. It aims to encourage the innovation and growth of the region and manufacturers by locating product-oriented grouping and production at various points. On the other hand, industrial ecology draws attention to environmental issues, sustainability, energy efficiency and waste reduction while creating industrial zones. Proximity, integration and improved accessibility are essential for developing a new industrial system.

In smart factories, new jobs require high qualifications, especially those defined in the management department. In the production hall of the factory, the work of human labour decreases or even ends completely. The workflow requires a scenario, and human-machine interaction is a part of this scenario. Marta Pieczera describes three models of human-machine interaction in production: automation, specialization, and hybrid (Pieczara, 2020). Since Industry 4.0 brings together architecture and other disciplines, the question of what a new generation factory will be like will undoubtedly be discussed for a long time. The production facilities, offices, shipping and storage areas differ according to the sector. Pieczara states that this triple model has been scripted to meet basic needs.

Julia Reisinger, Iva Kovacic and Patrick Hollinsky also provide a systematic design guide for flexible industrial buildings (Reisinger, Hollinsky, & Kovacic, 2021). In this study, parameters for building design according to Industry 4.0 requirements have been prepared. Researchers focus on goals, parameters, planning processes, success factors and recommendations. As a result, this study also forms a basis during the project development phase.

With the innovations provided by internet technologies, physical, spatial and temporal boundaries have disappeared. In general, while research on the digital infrastructure of smart factories has concentrated, spatial studies are more limited. In this context, the study questions smart factories through architectural terminology, mainly focuses on the evolution of the factory and aims to contribute to this evolution process. The article is structured as follows: first of all, the four technological revolutions of the industry and the factories corresponding to these revolutions are examined through a literature review. While choosing these factory buildings, the focus is on the functional design of the production spaces, regardless of industry or production, and the production technology of the period is taken into account. It also has examined the innovations in the production spaces and smart factories that have emerged today. Second, morphological analyses have been made and coded in the production spaces. The effects on factory architecture in four industrial revolutions are presented based on the literature review and analysis. Technology, production methods, design criteria of the factory, and functional planning have discussed the evolution of the factory in the whole process. Finally, architectural possibilities for the factory of the future are discussed. This study aims to develop a historical background for designing new production spaces to summarise the whole process since the industrial revolution.

EVOLUTION OF FACTORIES

The word "factory" emerged in Europe about a hundred years before the revolution in the 1600s. Individually produced products took their final form in a different place, and this building where the product was assembled was defined factory (Marsh, 2019). After the Industrial Revolution, factories began to be built rapidly in which machines mostly shelter, workers enter and leave at a particular hour, raw materials are stored, products are produced, and a significant amount of energy is constantly spent. A systematic and planned production process has been entered, and production has increased rapidly with the inclusion of machines. Although the product may differ slightly according to the sector or geography, the essential architectural elements that define the design of the factory are similar. The factory was organized around the energy source, machines, production flow and workers in its simplest form.

The most remarkable invention of the revolution, which started in England in the middle of the 18th century and spread rapidly to Europe and North America, became the steam engine and the most significant power source in production. As the way of production changes, the need for machines has increased over time, and even type, weight, and size have changed. The old workshops were insufficient for the new production, and new buildings were designed to suit the needs. 18th-century factories were described as square brick buildings with bare walls, a monotonous form, and limited embellishments (Marsh, 2019). In these factories, the priority was not architectural aesthetics but functionality.

The factory began to change physically with each new technology in production. At the beginning of the 20th century, Henri Ford's system for the automotive industry caused a new and effective revolution. This

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method, called Fordism, adopted standardization as a principle at every production stage. In this system, which Ford designed to speed up the construction of the Model T, he described each step of production and divided it into eighty-four parts. Thus, Ford planned the whole system by assigning employees for each step. Henri Ford paved the way to give more space to machines in production with this assembly line he built. He implemented this system using Frederick W. Taylor's management system (Freeman & Soete , 2004). Frederick Winslow Taylor defined process management by calculating the movement and time required to perform a task and developed Taylorism's management style. Thanks to Fordism and Taylorism, machines started to partner with human labour in the new factories. Production was programmed with machine-human cooperation. Factories were designed according to the size and width of the assembly line required for production and the machines used. The location of factories has also been decided by the procurement of raw materials and the transportation of products. In addition, the new materials used in the buildings, the construction technique, and the architectural style made the factory buildings the leading structures of the period.

In the second half of the 20th century, computer and automation technology have made production control more accessible. Unlike the previous production line, the system could be controlled by a computer, not an individual. Although it was considered a great innovation, computers were not fast enough to compete with humans initially. First, existing buildings for robots to speed up production had to comply with this new organization. Technological infrastructures like floor and wall sensor systems and visual guidance signs have developed. In addition, there was a rapid increase in consumption with the effect of globalization in this period. The factories started to spread worldwide.

In the 21st century, the relationship humans establish with machines precedes other human relations in production. In order to keep up with the fast rhythm of daily life, many jobs in the industry are left to machines. Over time, the machine has ceased to be a tool for doing the job and has become the main element that does the job. Thanks to the opportunities provided by Industry 4.0, humans will be able to move away from the factory as production processes can be controlled remotely. As a result, it is thought that the details of human comfort in production will gradually decrease. Considering that cities and settlements exist with production, the economic, sociological and architectural role of the factory in every revolution is remarkable. For this reason, besides the technological features of future factories, their spatial transformation is also critical for the built environment.

The First Industrial Revolution: The Birth of the Factory

The birth of the factory has been based on replacing human power with machine power. In the past, individual workshops were used with traditional production methods, but over time, it was seen that these places could not respond to the changing production methods and needs. The industrial revolution was a breaking point for production and consumption. New inventions have replaced traditional production methods, and production and consumption have increased more than ever. In this process, radical changes were experienced in social life. One of the most significant results of the revolution was forming a new working class, who left agricultural activities and came from the countryside and spent most of their time in the factory. According to Eric Hobsbawm, the transformation of nobles into manufacturers and peasants into factory workers in return for wages began to change people's lifestyles and needs (Hobsbawm, 1996). Edward Thompson argues that the working class is a self-forming process in environmental and human relations. Thompson examined the end of life in the village due to production relations in the city, the struggle to exist against the bourgeoisie, and the process of finding a place in the city (Thompson, 1966). Another of the fundamental things that changed with the revolution was time. In pre-modern societies, time was organized with daily work in mind; time is organized not as minutes, hours, days, or months but as sunrise and sunset, seasonal changes. Everyday life starts with the sunrise and ends with the sunset; star movements, precipitation-drought times, and seasonal weather conditions have shown how to determine the time. This routine in social life forms the basis of tradition, and time is a determining factor for this cycle (Giddens, 1991). In the 18th century, changes in daily life practices and work remuneration became necessary. The use of clocks, especially in public spaces, has begun to increase. David Harvey explains that the changes in time are determined by the changes in space (Harvey, 1992). This age forced all people to live together, and new settlements began to be built. Every society or geography affected by the industrial revolution had to keep up with this innovation.

When Thomas Newcomen invented the first steam engine in 1712, this technology was used to drain coal mines. Later, James Watt developed this technology and made it an essential part of the industry. However, since the steam engine is hot, noisy, and dangerous, the factories have affected the whole environment where they are located. On the one hand, while new cities were formed around the factory, on the other hand, problems began to be experienced in these cities. There was an intense migration from the countryside to the newly established cities, and the rapidly increasing population caused poor living conditions. Modern urban studies began to solve these problems in the cities. It has begun planning and building, reconsidering factory and worker housing (Benevolo, 1971). With the planning of industrial areas, healthier settlements were designed for the population migrating from rural to urban areas. While creating these settlements, the diversity of transportation, infrastructure, and social facilities has been essential to the planning.

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The factory, which started to become an essential part of life with the revolution, was also one of the main problems of urbanization. The dwelling and transportation of workers were essential factors for the location of the factory. For this reason, not only the factory but also the environment was designed. A direct relationship was established between the physical locations of factories, houses, and public spaces. It was quite new in those years that the employer also solved the housing problem for the workers. As a solution to these and similar problems, company towns emerged during this period. Their environments were similar, as manufacturing often required similar needs like water power. The company towns, built quickly with significant capital, differed from other towns. In the towns initially built in America, there were houses, shops, schools, and even chapels, which was the plan of companies. The population of the towns was usually one or two thousand, and the workers who lived here often established their own culture. The company determined the working hours, daily activities, and the rules in the town to maintain the social order and expected the residents to follow the rules (Garner, 1992). One of the first company towns, the Saltaire Factory, was an industrial village built in England between 1851 and 53. Architects Henry Lockwood and William Mawson designed the outside of the factory and the town where residences, schools, hospitals, and religious sites are located. The factory was located close to the railway and canal. Comfort was considered for the workers, and the inside of the factory was well-heated and ventilated. More than three thousand people were working at different ages with different skills and different wages.

The residences were separated from the factory by rail. Most of the workers lived in the newly built village. The houses were close together, and it was a very dense area (Styles, 1990). The whole process for the factory was carefully organized. The main divisions of the manufacture of alpaca were sorting, washing, drying, plucking, combing, drawing, roving, spinning, weaving, dyeing, pressing, finishing, and folding. The fact that all these steps were gathered in the same building made Saltaire a model. The village consisted of factories, 800 residences, 45 almshouses, institutes, baths, churches, and parks (Dewhirst, 1960).

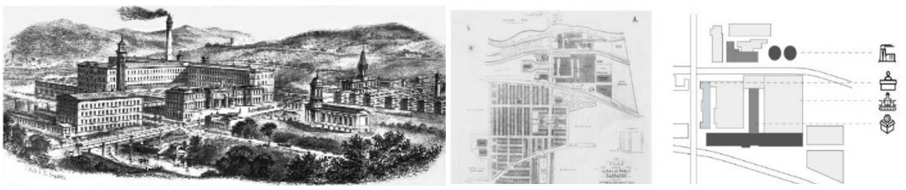

Figure 1. Saltaire Factory

In the same years, George M. Pullman worked with architect Solon Beman and landscape architect Nathaniel Barrett for the company town he would establish south of Chicago. Firstly, the factory was built in the town. The administrative offices were located in front of the factory.

There was a machine shop, drying rooms, a pattern shop, a blacksmith shop and a water town. Unlike existing company towns in the U.S.A., Pullman wanted to create a better environment for its employees. Everyone, from managers to workers, was intended to live in this town and benefit equally from public services and planned recreation areas. It was planned to improve the unhealthy conditions in the industrial areas (Buder, 1967).

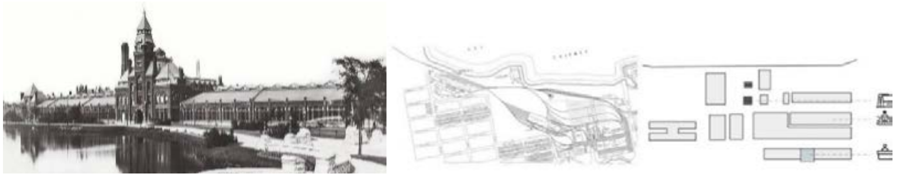

Figure 2. Pullman Factory

The Second Industrial Revolution: Modern Factory

The second industrial revolution developed especially with mass production and assembly line. As the production style changed, the machines used in the factories also diversified and became new parameters that determined the size of the space, the ceiling height, and the area's width. The pioneer of the assembly line in the early 20th century, Ford needed a new factory to manufacture the Model T. For this, he worked with architect Albert Khan in Highland Park, north of Detroit. Khan designed a four-story main building and a one-story production building. The priority was for the workers to receive natural light and modern ventilation and heating systems. Ford wanted to provide a clean working area and set up the assembly line in 1913, and in a short time, like a year, all assembly was done on a moving line and opened the doors of the factory to everyone to show this work to the whole world (Pollard, 1995). After this work, the industrial areas in Detroit, designed by Albert Kahn, Julius Kahn, and Earnest Wilby, set the standards of Fordist production for the whole world.

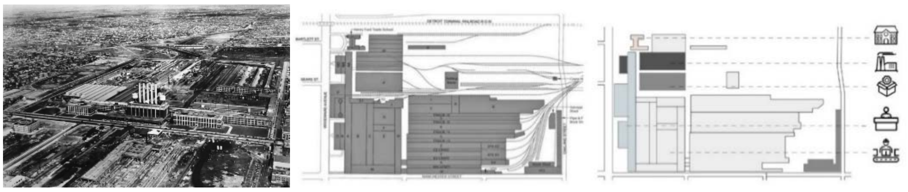

Figure 3. Highland Park Ford Factory

Peter Behrens' A.E.G. Turbin Factory attracted attention due to the designed details for changing demands and technologies in the industry. Behrens designed the A.E.G. factory and all the designs, from the brand's font to the product designs. The spatial needs of the factory were determined by Oscar Lasche, A.E.G.'s production manager. Large spaces were needed for the vast engines at the A.E.G. production facility. The production hall was supposed to house two large cranes in height and width used to assemble the turbines.

Moreover, it needed to arrive wagons at the building for transport. Side halls were designed for storage and other works. This building, designed

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with reinforced concrete and steel structure, became a pioneer for industrial buildings and modern architecture (Aitchison, 2016).

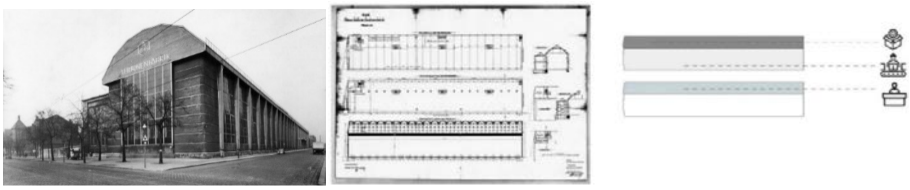

Figure 4. AEG Turbine Factory

One of the pioneering buildings of modern architecture and factories was the Fagus Factory in Alfeld. The factory consisted of multiple buildings that housed different functions such as production, storage, and office. Eduard Werner designed the planning of the building and the offices. Later, Walter Gropius and Adolf Meyer were commissioned to enlarge the main building and renovate its façades. The most significant contribution of the architects was the design they made for the office building. The building was described as a new union of art and technology. The design soon became the new face of international style (Darley, 2003).

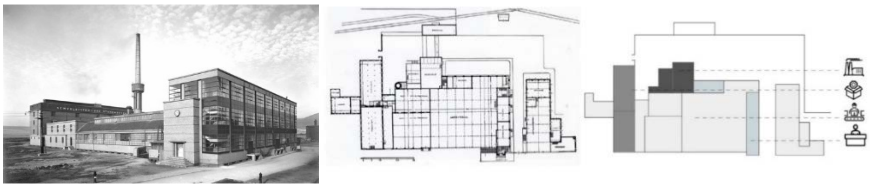

Figure 5. Fagus Factory

Fiat Factory, designed in Italy in the same years, was a modern interpretation of Ford's mass-production model. In the factory, designed as five floors, raw materials were entered from the ground and included in production on each floor. There was a test track in the attic for the cars out of production. It was the largest automobile factory in its period, and production has continued for many years (Cook, 2015).

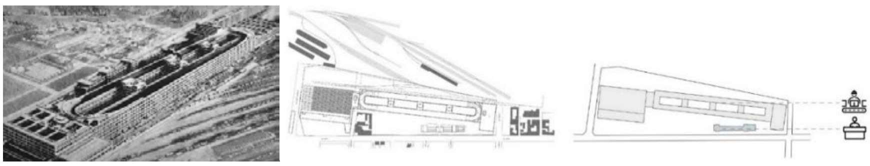

Figure 6. Fiat Factory

The Van Nelle Factory, opened in Rotterdam in 1923 to package foodstuffs such as tea, cocoa, and coffee, was also built as a storeyed factory. The works and production steps in the factory determined the design of the building. Consisting of a curvy administration building and an eight-story production structure, the building had a modern look with curtain walls, cross conveyor belts, concrete floors, white ceramic tile walls in the interior, and stainless-steel handrails. In addition, it was planned to make an open production to the outside with its transparent façade. It was also desired to create a healthy environment for employees (Darley, 2003).

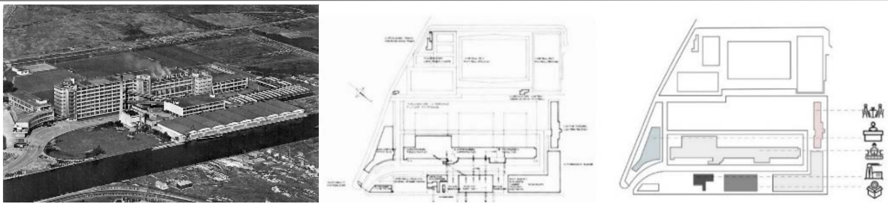

Figure 7. Van Nelle Factory

The Third Industrial Revolution: Factory as Sales Tool

The industry has undergone many changes since the first revolution. Many specific industries, such as service, research, and logistics, have developed from primary industries, such as agriculture, mining, and manufacturing. Thanks to advances in globalization, technology, and transportation, the impacts of the industry have changed dramatically. The first reflection of this is seen in the built environment. In the second half of the last century, the speed of production technology led to the emergence of new consumption culture over time and dragged humanity to new orders in daily life. Consumption has overtaken production over time. With this change, Fordist production left its place in post-Fordist production. David Harvey says that this transition lacks flexibility in production (Harvey, 1992). The idea of flexibility and the search for new life have become popular and have determined the new steps of capitalism. While this transformation was designing new production systems, it did not finish industrial production; moreover, it caused it to grow with more significant percentages. Toyota Motor Company developed the just-in-time model in production to avoid waste or excess stock in its warehouses. Toyota engineers developed the 'Andon Boards' digital board to monitor the production process and analyze the situation (Rappaport, 2009). This sign board allowed the workers to easily see the problems on the production line and develop quick solutions. By the 1970s, computer controls and C.N.C. machines were fully involved in production, and workers began to use the systems that ran them, not the machines that produced them. Managing machines from smaller machines changed worker activities and job descriptions. After the linearity of the Fordist production model, different spatial organizations and modules began to be tried, like R&D areas, "solar system" layouts, "mainstreet" spines for increased personnel interaction, the "fractal," housing the management near the workers, centralizing break areas, developing communal entries for both workers and management. Labourers are being called "partners" and "team players" rather than "workers." (Rappaport, 2009). Thus, new factories were re-mechanized with workstations and computers. Workstations also reduced the indoor mobility of the workers. Similarly, computers work on modelling, quality control, problems, solutions, and production capacity. In this way, workers could work with robots and manage many jobs remotely.

In this period, when production was composed of materials, new steps were taken in information, communication, and service. Negri and Hardt explained this as immaterial labour. With this thought, production started to eliminate spatial and temporal limitations. Labor has crossed

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factory boundaries. The distinction between mental and manual labour has changed over time (Hardt & Negri, 2001). Negri and Hardt also criticized the disciplinary attitude of the Fordist regime and expressed their troubles and argued that the Fordist order turned society into a factory, which was normalized. Globalization has accelerated this process considerably. Internet and telecommunication shortened the distance between producer and consumer. Asian countries, affluent in raw materials, have started to become new centres of industry where production is intense. The number of production structures increased and became industrial zones or parks.

The convergence of the factories and the creation of a campus or a region positively affects the exhibition and marketing of the products and the logistics benefits. As a production campus, Vitra Campus, located in Weil am Rhein, Germany, is a remarkable example, thanks to its design. When the old site of the Vitra factory burned down in 1981, the company wanted to design a brand-new campus. It becomes a place where Vitra's designs and buildings are exhibited. First, Nicolas Grimshaw designed two factories. The factories were built with prefabricated elements and covered with aluminum facade elements. Later, the campus is enriched with the designs of names such as Zaha Hadid, Tadao Ando, Frank Gehry, Herzog & de Meuron, SANAA, Alvaro Siza, and Kean Prouvé. One of the remarkable factories belongs to Frank Gehry. The building entrance door resembles the Frank Gehry design museum next to the factory. The factory includes production halls, storage, test rooms, and offices. Windows of the factory are designed so that visitors can see the production process (Vitra Campus, 2021).

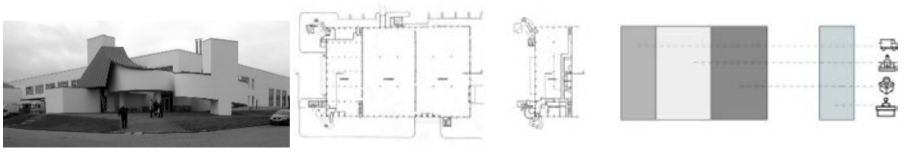

Figure 8. Vitra Faactory

While the factories were designed, the type and size of the production were the priority, but it pioneered the architecture of many factory periods. Coop-Himmelblau argues that industry is a culture and that this can emerge with a multidimensional design, even with economic and functional constraints. The Funder Werk Factory building, designed by Coop-Himmelblau in Austria, has entirely different details for a factory. The production section is designed as a head-body with offices and laboratories. On the facade of the building, which is a paper-coating factory, chimneys, transparent roof detail, and red facade elements increase the visibility of the building aesthetically as well as their static functions (Funder Werk, 2021).

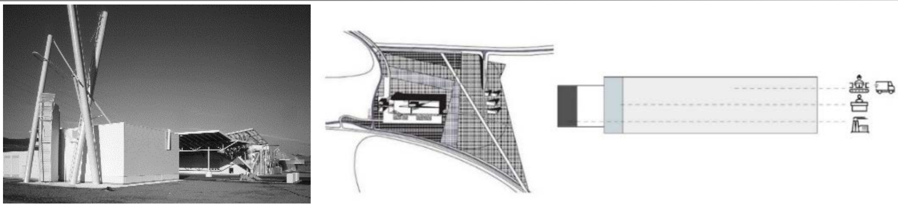

Figure 9. Funder Werk Factory

The fact that the factories are visible or noticeable is also effective in marketing the products produced. Henn Architecture has produced exhibitable with the Transparent Factory designed in Dresden. The main goal of the automobile manufacturing company is to show customers and visitors how the automobile is produced. For this, the factory building has been designed to be completely transparent. Production steps can be followed on every building floor, and the product can be tested in the same building. In addition to production, this factory is planned to be used for some facilities like exhibitions and concerts (Glaserne Manufaktur, 2021).

Figure 10. Transparent Factory

The Forth Industrial Revolution: Smart Factory

Industry 4.0, the most popular concept of the new industrial revolution, was introduced by the German National Academy of Science and Engineering (Acatech) at the Hannover Fair in 2011. The technology describes a smart manufacturing model that is digitalized and customized according to customer needs, enabling simultaneous communication and connection between people, machines, and products. A flexible production model is aimed at this technology. The transformation from uniform production to personalized production and direct participation of users in production will be provided. This system, which Germany established to expand production borders, is accepted as the fourth industrial revolution worldwide. Although many studies on the subject are still conceptual, systems such as plan, design, manufacturing, operation and maintenance are being developed for production (Kang, et al., 2016). Thanks to production technologies and devices, information and communication systems, and data integration, it aims to make factories more efficient, safer, and environmentally. These factories will produce with the Internet of Things (IoT) technologies. In IoT technology, sensors and artificial intelligence drive production and maintenance; mobile and augmented reality devices provide information processing and productivity to employees; cloud computing systems enable data to be shared and stored. Cyber-physical systems are also a new generation of technology that combines computer applications and physical systems.

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It enables human-machine partnership and helps decision-making processes.

Unlike the old production methods, everything without production is moved out of the factory in smart production technology, and production is left only to machines. Every step that manages production is performed in a virtual network. Information is received, stored and controlled. Communication with machines is provided over the network. The most significant difference between smart and other methods is that production can be done flexibly, not on a production line. Machines can be programmed according to product, need and process. These new production spaces are defined as smart factories. In addition to the definition of smart factory, there are also definitions such as U-Factory (Ubiquitous Factory), the factory of things, the factory in the real-time frame and the intelligent factory of the future (Hozdić, 2015). Nina Rappaport says that factories are the key to unravelling the spatial logic of society (Rappaport, 2017). Rappaport defines the factory as predictive, not prescriptive, and explores the need for sustainable growth for two centuries of industrialization and urbanization; and also summarizes this period as the consumption of production. She argues that production still determines the social organization and that consumption is a difficult concept and is not the only economic factor of post-industrial society.

One of the first examples of the fourth revolution, The Trumpf Smart Factory in the U.S.A., designed by Barkow Leibinger, consists of a factory and exhibition space. The designers aim to transform high-tech machinery and production processes into exhibitions by constructing two completely different functions in the same building. The design aims to experience Industry 4.0 technology from product design to production and delivery. The factory, designed as two large volumes, was built in a green area. One of the rectangular buildings is planned as a production hall and the other as an office, café, and auditorium. A particular viewing area, '*skywalk*', was created for visitors by designers inside the production hall (Trumpf Smart Factory, 2021).

Figure 11. Trumpf Smart Factory

Smart technologies are used intensively in China, and the number of smart production facilities is also increasing. The Future Stitch Smart Factory, located in the economic development zone in Haining in 2018, is one of the first examples. For the factory, production workshops and a visit circulation that allows the exhibition of the process from raw material to product are designed on each floor. The galleries to the east and west create an experience for the bottom-up production process and activities. There are a basketball court and a roof garden. The factory entrance door is common for both administrative staff and visitors. Stairs and corridors are designed outside the building, creating temporary open spaces for employees (Future Stitch Smart Factory Azl Architects, 2021).

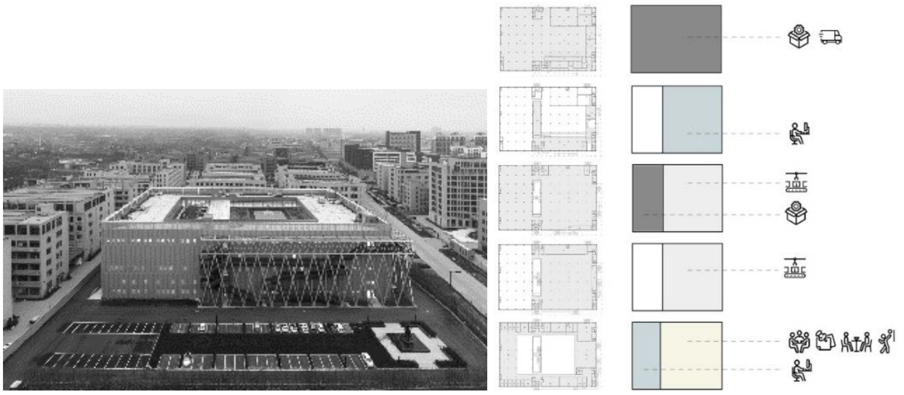

Figure 12. Future Stitch Smart Factory

Another smart factory, The Plus Furniture Factory, built in Norway, draws attention to both sustainable goals and aims to produce with new technology. In this factory where the furniture will be produced, it has been aimed to use smart robots, driverless trucks, and tablet computers to manage the factory. The factory consists of four main halls connected in the centre: a warehouse, a colour workshop, a wood workshop, and an assembly workshop. Logistics offices and exhibition space are connected to all halls in the center. This area has been designed transparently and has turned into a courtyard open to all visitors, where the production process is also exhibited. Coloured sensor maps were designed for robots on the factory floor, and these maps were considered clues to guide visitors through the production process (Sustainable Furniture Factory, 2021).

Figure 13. The Plus Furniture Factory

MORPHOLOGICAL CODING IN THE PRODUCTION SPACES

Since the Industrial Revolution, the factory has established relationships with people, machines, and cities and pioneered architecture and urban development. It is seen that they have undergone critical changes not only in terms of technology but also environmental and spatial in the short history of the factories. Although the use of the steam engine was the turning point of the industry, the use of new energy sources and technologies in a short time accelerated the progress in production. The use of electricity has increased mechanization and laid the groundwork for computer and automation systems. Nowadays, the internet, cyber-physical systems and robotics technologies create smart production systems integrating with automation systems (Table 1). One of the most

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important contributions of the new system is that it enables flexibility in production. The production process is managed with digital data from the beginning to the end. Therefore, smart products, smart production, and smart factory are the innovative concepts of this revolution.

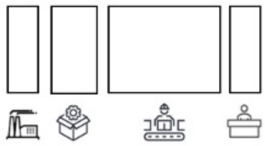
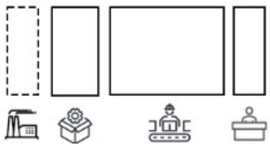
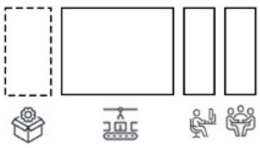
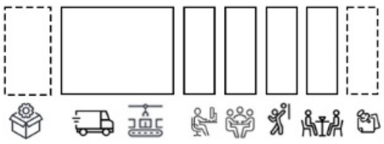
While production is moving from workshops to factories, it causes some difficulties both in production spaces and its surroundings, but this has been one of the most critical planning data for the cities of the 20th century. Factories were initially conceived as a part of the company town with their housing areas, schools, hospitals, and social areas, and later pioneered the establishment and growth of larger cities with residential areas. In the second half of the 20th century, the number of factories increased, and the factories started to create their production campuses or regions to meet the increasing consumer demand. Nowadays, smart factories have trying to reconnect with the city.

Table.1 Industrial Revolutions and Factories in Evolution

	1. industrial revolution	**2. industrial revolution**	**3. industrial revolution**	**4. industrial revolution**
period	late 18.th / early 19. th century	late 19. th / mid 20. th century	second half of 20. th century	early 21. th century / -
technology	water power, steam power	electricity	computer and automation	Internet of Things, cyber-physical systems, robotics
production methods	mechanization	mass production	automation	digitalization
place of factory	company town	city, industry park	industry zone, industry park	city
design criteria of factory	transportation, raw materials, technical infrastructure	production line, machines, manufacturing equipment, management, production, storage, physical strain, health/safety	process design, manufacturing method, assembly method, logistics method	exhibiting the product and production process
functional planning	production, management, storage	production, management, storage	production, management, storage	re-creation, production, management, storage

At the beginning of the industrial revolution, the factory was defined as the place where product assembly was made, and it was located close to the railway for raw material supply and product shipment. Production, storage, and management steps were designed as different buildings in the factories established in the company towns. With the need for faster and more diverse production, the second industrial revolution led to a process where company towns gradually decreased, and more individual factories were built. The production and management departments built the factory, and the additional production steps were designed in the production hall. Mass production enabled the factory interior to be designed more planned. The steps of production and the dimensions of the machines to be used formed the physical data of the space. In addition, in this period, new construction techniques and materials were tried in the factory buildings, and the factories became the leading building of the period. In the third revolution of the industry, the factory started to provide new functions besides its function (Table 2). The fact that the production can now be exhibited has started to change/transform the factory buildings and their environment. Humans have been included in the process not only as a producer but also as a viewer.

Table.2 Industrial Revolutions and Production Spaces

1.industrial revolution		engine house storage production hall offices
2.industrial revolution		engine house storage production hall offices
3.industrial revolution		storage production hall offices cafe / common space
4.industrial revolution		storage production hall/shipping offices cafe / common space sport hall exhibition

Exhibiting and displaying the production that started with Ford has also become the basic design approach of the factories of the new era. Similarly, the changing production and consumption relations have transformed new production spaces. The last revolution of the industry tends to transform the factory completely. Since the production process can be controlled remotely, the factory would only belong to the machines. Leaving production to machines alone will lead to significant changes in production spaces. When the first samples are examined, spatial diversity in factories draws attention. Common areas, co-working spaces, exhibition spaces, and even more daily activities such as sports have been added to the production spaces. This newness in spaces suggests that production and factories will become a part of daily life again.

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CONCLUSION

Since the first revolution, critical changes have been observed in technology, production method, place of production, factory design criteria, and functional planning. Although the fourth revolution is still in-process, the effects of the change in the industry are remarkable when the examples of smart factories designed are examined. Unlike the previous ones, it is seen that new functions not directly related to the production process have been added to the factory buildings. The human being has been removed from the place as a producer and invited as a consumer. For this reason, alternative spaces have been proposed for meeting production and consumption demand and establishing direct contact with the consumer. The product exhibit and production process have been the main criteria of architectural designs. Thanks to the remote, unmanned production technology, it can be thought that the management and office parts will also leave the factory in time. Moreover, new functions can be added to the factory in the same way.

Factories have been the reflection of technology and even the conditions of the economy in architecture. Therefore, discussing the recent and future innovations and aims of manufacturing is essential for understanding the architecture of this transformation. How the production spaces of the future will be, how they will relate to their surroundings, and how they will affect cities is one of the new fields of study for architecture. In conclusion, this study examines the functional evolution of the factory and intends to provoke new discussions for future factories by projecting the features of production spaces.

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Resume

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