Industry 5.0 as a Tool for Strenghtening Urban Resilience Against Disaster Risks

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Abstract
Each Industrial Revolution throughout history has brought about significant economic, social, and spatial transformations, with cities serving as the primary arenas of these changes. This paper investigates how production paradigms shaped by Industry 5.0 in the 21st century may transform urban metabolic systems and contribute to enhancing urban resilience. Introduced by the European Commission in 2021, Industry 5.0 differs from previous industrial models by prioritizing human-centric, sustainable, and resilient production approaches. In this context, urban forms and metabolic structures aligned with Industry 5.0 are expected to offer new frameworks for developing resilient urban environments, particularly in response to crises such as climate change and natural disasters. Through a comprehensive review of the literature on Industry 5.0, urban resilience, and urban metabolism, this study outlines the fundamental characteristics of an Industry 5.0-oriented urban environment and proposes a conceptual model to guide planning and design practices.

Keywords: Industry 5.0, Urban Resilience, Urban Crises, City Planning

1. Introduction
Natural disasters such as floods and earthquakes, which have disrupted economies, ecosystems, and cities worldwide, have been significantly intensified by human-induced environmental degradation. In particular, the growing number of warnings about anthropogenic climate change suggest that humanity may be approaching the sixth mass extinction of life on Earth. In this context, the transition from the “Age of Progress” to the “Age of Resilience” marks a profound philosophical and psychological restructuring in how humanity perceives nature and its place within it (Rifkin, 2022).

The Age of Resilience is characterized by a shift from efficiency to adaptability, from productivity to renewability, from seller-buyer markets to provider-user networks, from centralized supply chains to distributed ones, from corporate conglomerates to high-tech SMEs, from globalization to localization, and from negative externalities to circular systems. In this transformative process, the fact that more than half of the global population now resides in urban areas positions cities as critical actors in shaping this new paradigm.

Industry 5.0 is increasingly considered a key driver in this transformation. This thesis assumes that integrating Industry 5.0—a new phase in industrial development—into urban metabolic processes can enhance urban resilience against disasters.

2. Problem Definition
“Cities are spaces that enable the coexistence, interaction, and integrated functioning of individuals, networks, organizations, and various infrastructure components.” (Eraydın, 2022, p.50). With the Industrial Revolution, cities underwent radical changes in scale, and these transformations brought by industrialization became the main driving force of change in the 19th century. As a result, they created the most degenerated urban environments the world had ever seen; cities became overcrowded and unhealthy spaces (Mumford, 1961/2007).

Since then, cities have become both amplifiers of disasters and the places most affected by them. One-third of the world’s topsoil has been degraded since the 19th century, and studies suggest that only 60 years of arable soil remain to feed the global population. Moreover, the planet’s oxygen levels are depleting at a rate not seen in two billion years. One of the most critical reasons for this is that emissions resulting from global climate change have increased ocean temperatures, leading to the destruction of phytoplankton — one of the planet’s primary oxygen sources (Rifkin, 2022).

As emissions driven by climate change continue to raise the Earth's temperature, the frequency of disasters such as floods, hurricanes, and droughts is also increasing. These disasters — whether climate-induced or natural events like earthquakes — affect the sustainability of urban systems and bring the issue of urban resilience to the forefront. The planning approach that Jane Jacobs referred to as "orthodox city planning," which remains in effect today — one that divides cities into distinct functional zones — is considered inadequate in addressing such challenges. Instead, the transformation emerging around Industry 5.0 within urban metabolism is seen as a potential tool to strengthen urban resilience.

3. Disaster Risks

Disasters are defined as serious disruptions in the functioning of a community or society that result in widespread human, material, economic, or environmental losses. These disruptions often exceed the affected community's or society's ability to cope using its own resources. Disaster risk, on the other hand, refers to the potential for such losses to occur in the future, within a given time period and among a specific population. It is shaped by the interplay between natural or human-induced hazards and the vulnerability of the exposed elements (Şenol Balaban, 2017).

In the contemporary era, the majority of the world's population resides in urban areas—a trend that is projected to accelerate in the coming decades. This urban concentration amplifies exposure to hazards, making cities critical arenas for both disaster risk and resilience. Urban areas are increasingly affected not only by acute, high-impact events such as earthquakes or floods but also by slow-onset and cumulative stresses, including heatwaves, water scarcity, and land degradation, which are exacerbated by climate change (Rifkin, 2022).

Moreover, anthropogenic pressures—such as uncontrolled urban sprawl, excessive resource consumption, pollution, and ecological degradation—further erode the resilience of urban systems. These pressures often stem from unsustainable development practices and inadequate planning frameworks. Consequently, cities become more vulnerable to cascading risks, where one disruption (e.g., a heatwave) may trigger or exacerbate others (e.g., energy shortages, health crises) (Gencer et al., 2018).

In this context, enhancing urban resilience requires a shift toward integrative and anticipatory planning approaches that not only mitigate risks but also address the underlying causes of vulnerability. This includes investing in adaptive infrastructure, promoting inclusive governance, strengthening social safety nets, and preserving and restoring urban ecosystems.

An Industry 5.0-oriented urbanization model and production relations—innovative, sustainable, human-centric, and resilient—can serve as a strategic tool in strengthening cities' capacity to cope with crises.

4. Urban Resilience

With the ongoing and intensifying effects of urban crises such as global climate change, it is expected that the world will undergo radical transformations, and that existing ecosystems and settlements will be exposed to these changes. To cope with various shocks that cities may experience—particularly those caused by climate change—the concept of urban resilience has been introduced. To better understand urban resilience, it is helpful to first discuss the broader concept of resilience. The term "resilience" originates from the Latin word resilio, which means "to bounce back" (Klein, Nichols, Thomalla, 2003; as cited in Meerow, Newell, Stults, 2016). In line with this definition, resilient systems are described as structures that maintain functionality in the face of shocks and can rapidly restore systems after disruptions or breakdowns (Bruneau et al., 2003; O'Rourke, 2007; McBain, Wilkes, Ritter, 2010; as cited in Tyler, Moench, 2012). Resilience increases the capacity to cope with encountered challenges and is therefore often considered the opposite of vulnerability (Adger, 2000). The concept of resilience has been adopted by various disciplines. Originally rooted in physics, it was defined as the ability of materials to withstand external forces and maintain elasticity under pressure (Gordon, 1978; as cited in Galderisi, 2014). Later, the term gained prominence in fields such as psychology and ecology. The modern understanding of resilience is often traced back to Holling's work in 1973 (Meerow, Newell, Stults, 2016). Holling's perspective emerged as a critique of the traditional ecological paradigm put forth by Clements (1936), which claimed that ecosystems possessed a static structure. A review of the resilience literature reveals that different types of resilience have been identified, generally distinguished based on the concept of equilibrium. These include engineering resilience, which is based on a single equilibrium state; ecological resilience, which allows for multiple equilibrium states; and approaches focused on dynamic non-equilibrium (Holling, 1996; Folke, 2006; Davoudi, 2012; as cited in Meerow, Newell, Stults, 2016).

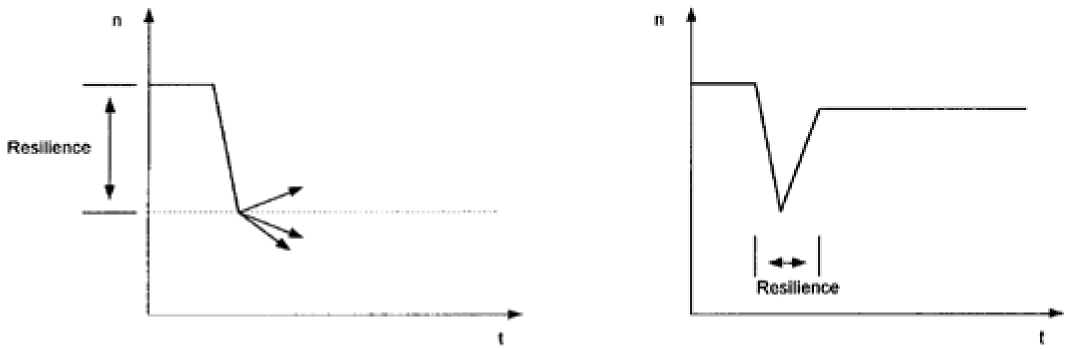

Figure 1 "Resilience Types Based on Different Equilibrium Conditions: Ecological (Left) vs. Engineering (Right) (Adger, 2000)"

As shown in Figure 1, engineering resilience depicted on the right side of the diagram refers to a single-state equilibrium. This understanding of resilience defines the capacity of a system to return to its original or near-original state after a shock or disruption (Holling, 1996; as cited in Meerow, Newell, Stults, 2016). The engineering resilience approach is commonly used in fields such as disaster management, psychology, and economics (Pendall et al., 2010; as cited in Meerow, Newell, Stults, 2016). In this context, resilience is defined as the rate at which a system recovers from disruption (Adger, 2000).

In contrast, the ecological resilience approach argues that systems can have more than one stable equilibrium. According to this view, systems may shift from one stability state to another in response to disturbances (Holling, 1996; as cited in Meerow, Newell, Stults, 2016). Rather than emphasizing the ability to return to a previous state, ecological resilience focuses on understanding how complex, nonlinear, and self-organizing systems respond to change (Berkes et al., 1998; Holling, 2001; Walker et al., 2004; Bankoff et al., 2004; as cited in Galderisi, 2014). Holling (1996) emphasized that while the traditional understanding of resilience in engineering disciplines is based on stability, efficiency, and predictability, ecological resilience refers to a system's capacity to absorb change and continue functioning (Holling, 1973, 1996; Galderisi, 2014; as cited in Meerow, Newell, Stults, 2016).

Beyond these two approaches, the more recent dynamic non-equilibrium perspective suggests that systems do not have a fixed balance and are in a constant state of change (Pickett, Cadenasso, Grove, 2004; as cited in Meerow, Newell, Stults, 2016). In this framework, the concept of resilience moves away from simply "bouncing back" and instead focuses on the capacity of a system to manage change (Matyas, Pelling, 2014; as cited in Meerow, Newell, Stults, 2016).

Based on these dynamic approaches, Holling (1973) developed the concept of resilience to explain the sustainability of ecosystems in the face of events such as fires, droughts, and floods (Marcus, Colding, 2014). In socio-ecological systems, resilience is defined by three core attributes:

• The ability of a system to maintain control over its structure and function despite disturbances,
• The capacity for self-organization,
• The ability to learn and adapt.

• Additionally, other attributes associated with resilience include:
• Maintaining core functions or developing new methods to fulfill them,
• Having backup capacities to meet demands under extreme stress,
• The ability to absorb shocks and disruptive changes (Tyler, Moench, 2012; Marcus, Colding, 2014).

Within this framework, resilience has increasingly been viewed as a strategic response to the impacts of global climate change on both natural and human systems. Resilient systems maintain functionality not through the strength of individual components, but through strengthening and diversifying the functional relationships between them (Tyler, Moench, 2012).

The increasing impact of climate change and other shocks on cities in recent years has affected millions of people and necessitated the development of risk reduction and adaptation policies. As a result, the concept of resilience has entered the urban planning discourse, giving rise to the broader concept of urban resilience, which encompasses issues from infrastructure to basic services (UN-HABITAT, DIMSUR, 2020). Urban resilience is defined as the capacity of especially low-income, marginalized, and excluded populations to survive and thrive amid urban risks (ARUP & Rockefeller Foundation City Resilience Index, 2014). This approach does not solely focus on minimizing losses due to disasters but seeks to enhance system performance against multiple threats. Approaches developed to assess urban resilience can be grouped into four categories (ARUP & Rockefeller Foundation, 2014):

Asset-based approaches: Focus on physical assets (infrastructure, buildings, etc.), but may overlook abstract values (social networks, culture, knowledge, etc.).

System-based approaches: Consider the city as a meta-system composed of social, economic, and physical subsystems, emphasizing inter-systemic and holistic thinking.

Sector-based approaches: Focus on the resilience of sub-systems such as transportation, health, or energy, rather than overall urban resilience.

Performance-based approaches: Emphasize the city's capacity to maintain core functions. This approach evaluates performance as a combination of systems, actors, and practices, while addressing interdependencies across different scales.

According to ARUP (2014), resilient urban systems should possess the following attributes:

Reflectiveness: The capacity to accept uncertainty and change by learning from the past and integrating it into decision-making processes.

Robustness: Well-designed and well-managed structures that can withstand hazardous events without severe damage or loss of function.

Redundancy: The presence of alternative options and backup capacities to ensure functional continuity.

Flexibility: The ability to adapt to changing conditions. This attribute is especially associated with decentralized and modular infrastructure approaches.

5. Industrial Revolutions and Cities
The relationship between the city and production has been inextricably intertwined. The extensive history of the city from the Industrial Revolution to the present can be traced through the changing role of industry within it—from being a driver of growth to becoming a source of political and social upheaval (Lane & Rappaport, 2020). Throughout history, production has constituted a fundamental function of cities and, as such, has consistently

been attributed a privileged position within the urban context. This centrality is also reflected in mythological narratives. For instance, in Greek mythology, the story of Prometheus giving fire to humanity after stealing it from the gods is interpreted not merely as the transfer of a physical element, but as the symbolic transmission of knowledge, technology, and civilization. The gifting of fire represents a significant turning point in human history, enabling people to protect themselves from the cold, cook food, and develop more complex tools and production techniques. In a similar vein, the Industrial Revolutions marked critical historical junctures that radically transformed modes of production and, consequently, had profound effects on urban structures, societal organization, and everyday life. This section examines how the five historical Industrial Revolutions have reshaped production processes and, in turn, reconfigured urban systems.

5.1 Cities Before Industrial Revolutions

Before the emergence of the First Industrial Revolution in the 19th century, cities were essentially small-scale settlements based on a trade economy and a rigid social order inherited from the tradition of feudalism. Sjoberg (1960) presented an idealized model of the social geography of the pre-industrial city. At its core, this model reflects the spatial expression of the division of the pre-industrial city into a small elite and much larger lower classes and marginalized groups (Knox & Pinch, 2010).

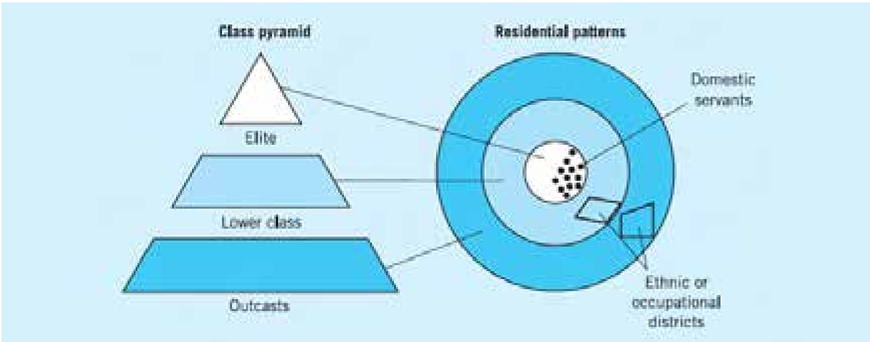

Figure 2 Sjoberg's idealized model of the social and geographical structure of the preindustrial city. (Radford, 1979; akt. Knox ve Pinch, 2010)

As shown in Figure 2, in the pre-industrial city, the elite generally lived around a pleasant and calm central area, while the lower classes and marginalized groups resided in poorly built and waste-filled surroundings. According to Sjoberg, the elite consisted of groups that managed and controlled the city's religious, political, administrative, and social functions (Sjoberg, 1960; cited in Knox & Pinch, 2010).

Although there was no highly diversified population beyond the core area inhabited by the upper classes, lower-class populations did exist. Distinct socio-economic clusters emerged as a result of the spatial coexistence of different types of artisans, and these were reinforced by social organizations such as guilds, which encouraged the spatial clustering of guild members. Poorer, less organized groups within the city — such as ethnic and religious minorities — found themselves in the outer neighborhoods, in expansive yet densely populated areas characterized by substandard and unhealthy housing areas (Knox & Pinch, 2010).

In each occupational district, housing, workshops, and storage spaces were arranged not horizontally, but vertically. Workshops were located on the ground floor, the living quarters of the master's family occupied the floor above, and the uppermost levels housed workers and storage rooms. This model of the city, in which spatial differentiation was dominated by a mosaic of occupational areas, contributed to a second dimension of class and status stratification that was more vertical than horizontal. The pre-industrial city has often been portrayed as a pedestrian city in which everything was physical and the distance between home and workplace was tightly constrained by the patriarchal and familial organization of labor (Knox and Pinch, 2010). In general, pre-industrial cities based on mercantilist production were characterized by a close relationship between workshops and housing areas. However, with the advent of the Industrial Revolution in the 19th century, urban form began to shift: production areas were organized on the inner periphery of the rapidly expanding city, strategically connected to steam-powered railways and maritime transport systems (Çalışkan & Çağlar, 2023).

5.2 First Industrial Revolution (Industry 1.0)

Revolutions can be defined as major milestones in history. A revolution is a turbulent and transformative event—and a series of actions—that seeks to change a nation, a region, or a society, including its production processes and, more recently, its business world (Groumpos, 2021). The First Industrial Revolution (Industry 1.0) took place in the second half of the 18th century and the early 19th century. It caused profound transformations in production processes, initially in England and then worldwide, significantly affecting economic and social systems (Mohajan, 2019). In England, James Watt invented the first steam engine in 1776, and in the years that followed, the steam engine became a transformative phenomenon across Europe and America (Rifkin, 2022). This transformation is considered the starting point of the Industrial Revolution. With Watt's steam engine being used as the primary source of power, the revolution included the shift from manual to machine-based production, the development of new chemicals, the use of steam and water as main energy sources, the emergence of machinery, and the rise of mechanized factory systems (Groumpos, 2021). Economic historians argue that the onset of Industry 1.0 was one of the most significant developments in human history since the domestication of animals and plants and the beginning of agriculture (Weightman, 2010; as cited in Groumpos, 2021). The innovations brought by Industry 1.0 affected almost every aspect of people's daily lives. For example, by the end of the 18th century, with the dissolution of feudalism in Europe, waves of peasants without land ownership began migrating to cities where industrial production took place. This long-term migration movement gave birth to the urban working class (Koca, 2020). Along with these migrations, agricultural production was pushed into the background, while industrial production came to the fore. The importance of capital and labor in wealth creation was emphasized, and the resulting changes marked a transition from an agricultural and feudal society to an industrial and capitalist one (Rifkin, 2022; Prisceru, 2016; as cited in Kılıç, 2023).

The development of industry and the accompanying migration waves led to profound qualitative and quantitative changes in urban systems, especially in Europe (Benevolo, 1993/2006). For instance, London's population, which was around 1 million at the end of the 18th century, rose to 2.5 million by 1851; Manchester's population, which was around 12,000 in the 1760s, reached approximately 450,000 by the mid-19th century (Benevolo, 1993/2006). However, this rapid urbanization and population growth negatively impacted quality of life; low-income groups and workers were condemned to live in unhealthy and inadequate conditions, while everyday life became dominated by issues such as social inequality, poverty, and social instability (Kılıç, 2023).

When examining the spatial effects of Industry 1.0 on urban areas, it becomes clear that industrialization—the dominant force of the 19th century—created the most degraded urban environment ever seen up to that point (Mumford, 2007). The political foundation of this new type of urban clustering was built on three pillars: the abolition of guilds and thus the dismantling of traditional labor organization, the establishment of an open competitive market for labor and goods, and the acquisition of overseas colonies to supply raw materials and serve as markets ready to absorb the surplus products of mechanized industry (Mumford, 2007). The economic foundations of the new industry in cities were based on the exploitation of coal mines, iron, and the introduction of steam power (Mumford, 2007). Industrial facilities were established in cities close to ports and railway stations, which facilitated access to markets and raw materials, turning them into major destinations for intense rural migration. With innovations in transportation, the movement of people and goods became easier (Sharma and Singhi, 2020). Factories were typically built along rivers or near rail lines leading to rivers, and there was no planning principle aimed at keeping noisy or health-damaging industrial activities away from residential areas (Mumford, 2007).

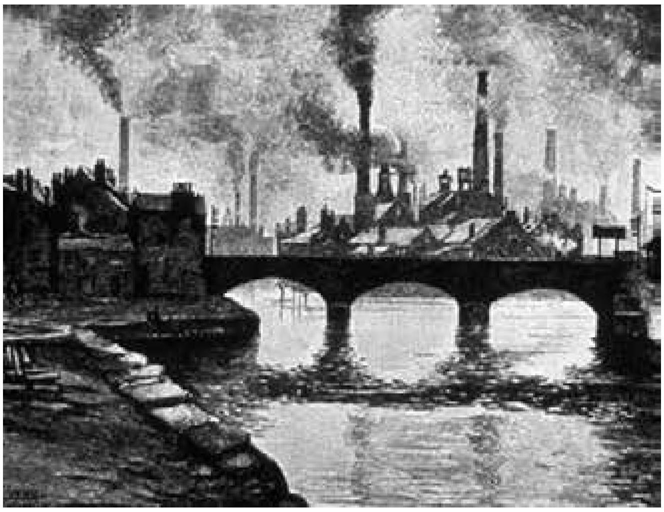

Figure 3 Industrial towns contained many polluting factories [URL 1]

As illustrated in the figüre 3, the placement of production zones in city centers led to inefficient land use, contributing to urban sprawl and traffic congestion. Basic municipal services were often absent in these new industrial towns. A general lack of hygiene prevailed. Deficiencies in access to sunlight, clean water, fresh air, and food were so widespread that they caused significant health and sanitation problems for large segments of the population (Mumford, 2007).

5.3 Second Industrial Revolution (Industry 2.0)

Due to the slow adoption of the original innovations of Industry 1.0—such as mechanized spinning and weaving—and the saturation of markets, an economic stagnation was experienced from the late 1830s to the mid-1840s (Donovan, 1997; cited in Groumpos, 2021). The Second Industrial Revolution (Industry 2.0) began in the 19th century with the discovery of electricity and the development of the assembly line through the use of new technologies (Groumpos, 2021). The United Kingdom, which played the leading role during Industry 1.0, began to give way to countries such as Germany and the United States (Koca, 2020).

Industry 2.0 marks a period during which industrial products developed significantly in terms of both quantity and diversity. The technological innovations of this period include electricity, electronics, mechanical devices, and automobiles (Kılıç, 2023). During this era, the steam engine was replaced by petroleum-based electric vehicles, a defining feature of Industry 2.0 (Koca, 2020). One of the major intellectual architects of this revolution was Frederick W. Taylor. In his book The Principles of Scientific Management, Taylor aimed to place efficiency in production at the center of modern civilization. His ideas, later systematized under the name Taylorism, were based on separating management and planning from the execution of tasks in the production department and subdividing the general production process into simpler parts to increase productivity. This method emphasized the coordination of each subtask and the separation of intellectual and manual labor.

To achieve this, Taylor advocated for the standardization of all worker actions within a work environment in which laborers were not distinguished from the machines they operated, essentially treating workers as an extension of the production apparatus (Koca, 2020; Rifkin, 2022). As a result, a vertically rigid division of labor and hierarchy emerged, leading to a high degree of differentiation in tasks and positions. This allowed for the execution of work by unskilled or semi-skilled labor, reducing businesses' dependency on skilled workers (Koca, 2020).

Two innovators, Henry Ford and Taiichi Ohno, adopted and expanded upon Taylor's theory. Ford pioneered the use of moving assembly lines to meet rising demand, while Ohno, the architect of the Toyota Production System, emphasized product variety by focusing on customer needs (Yin et al., 2018; cited in Çelik, 2023). In the Fordist system, based on Ford's production technique, a fixed relationship was established between unskilled labor and machinery. The moving assembly line standardized production, increased the number of products per worker, and created economies of scale, ultimately aiming to enhance productivity and profit (Tokol, 2000).

By the 1870s, the use of electricity had become widespread. Technological advancements in production also affected other industrial fields such as iron-steel, chemical, transportation, and other manufacturing sectors (Kılıç, 2023). The significance of electricity grew steadily, beginning with the invention of the electric motor in 1821 and the dynamo in 1831, followed by the telegraph, arc lamp, and ring dynamo. Later innovations such as electric railways, electric blankets and stoves, electric trams, the modern lightbulb, multiphase electric motors, and transformers solidified electricity's critical role (Çelik, 2023).

In the realm of transportation, railways became faster, safer, and more comfortable during the Second Industrial Revolution. After 1870, ships began to be constructed increasingly from steel, enabling the building of larger, stronger, and faster vessels. The invention of the steam turbine in 1884 and subsequent advancements triggered a major revolution in maritime transport. The emergence of interchangeable parts and mass production at the end of the 19th century spurred the development of the automobile industry. By 1914, Henry Ford was selling nearly a quarter-million Model T cars annually. The development of the airplane further expanded the scale of transportation (Çelik, 2023).

With Industry 2.0, advancements in production technology facilitated the widespread adoption of various technological systems, including telegraph and railway networks that had previously been concentrated in a few industrial cities, as well as infrastructure for gas and water supply and sewage systems (Groumpos, 2021). Along with increasing urbanization, devices such as electric lighting, radio, and the telephone transformed how people lived and communicated. These innovations have led to the perception that the modern world was realized through Industry 2.0 (Groumpos, 2021).

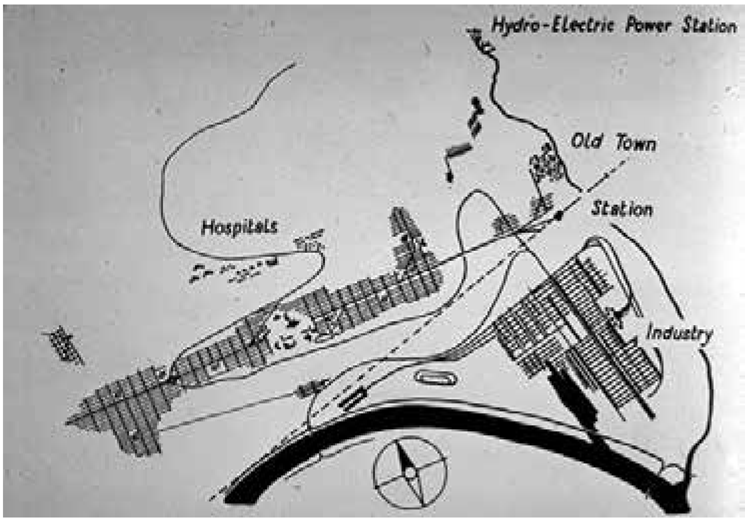

Figure 4 Tony Garnier's La Cite Industrielle Model [URL 2]

The urban planning approach that emerged during this period primarily aimed to respond to the urban problems caused by the First Industrial Revolution and to enhance production efficiency (Eraydın, 2022). As illustrated in the model developed by Tony Garnier—La Cité Industrielle—a city designed between 1899 and 1904 envisioned a settlement for 35,000 inhabitants. In this city, four essential functions were designated: living, working, recreation, and health, which were reflected in designated residential areas, industrial buildings, train stations, and other necessary public facilities. The model emphasized the physical integration of these functions through pedestrian pathways and transport systems, while ensuring industrial facilities were located close to energy sources and transportation infrastructure as a core principle (Eraydın, 2022).

Following the 1929 economic crisis, serial/Fordist production necessitated a redefinition of the urban-industry relationship. During this period, the Keynesian theories introduced by John Maynard Keynes also influenced the approach to the city. Contrary to the classical economists like Adam Smith—who dominated the previous era and emphasized the primacy of individual interests over societal ones—Keynes advocated for a greater role and function of the state in the national economy. He argued that the state should play an active role in ensuring efficient resource allocation, promoting economic development, maintaining price stability, achieving full employment, and establishing a more equitable income distribution (Yılmaz, 2009; Rifkin, 2022). These ideas also transformed perspectives on urbanism and planning.

Another urban approach related to the Second Industrial Revolution emerged through the CIAM (Congrès Internationaux d'Architecture Moderne) meetings held in the 20th century. The urban model discussed in CIAM was a response to the rapid urbanization, unhealthy housing environments, pollution, and congestion brought about by industrial society (Günay, 1988; cited in Eraydın, 2022). CIAM's most significant proposal was to define the city through four primary functions—dwelling, working, recreation, and transportation—and to spatially separate these functions into a distinct urban land use pattern. This approach claimed that by isolating industrial facilities from other urban functions, the environmental, transportation, and complexity-related problems could be mitigated (Eraydın, 2022).

5.4 Third Industrial Revolution (Industry 3.0)
It is acknowledged that the Third Industrial Revolution (Industry 3.0) emerged after the end of World War II, with the development of memory, programmable controls, and computer technology, leading to partial automation (Groumpos, 2021). Unlike Industry 1.0 and Industry 2.0 in terms of quality, the core components of Industry 3.0 include the internet, information and communication technologies, digital communication, and microelectronics, among others (Koca, 2020). Following the advancement of these technologies, the entire production process began to be automated without human assistance. For this reason, Industry 3.0 is also referred to as the automation and digital revolution (Groumpos, 2021; Kılıç, 2023).

The economic crisis of the 1970s marked a shift away from Fordist and Keynesian policies that had dominated the previous period, ushering in an era of neoliberal policies (Eraydın, 2023). Industry 3.0 represents the transition from an industrial society to an information society. During this period, flexible manufacturing systems were introduced to enable shorter production times, more personalized products, and quicker responses to consumer demands (Sharma, Singh, 2020). This process can also be described as a transition from economies of scale to economies of scope.

After the economic crisis of the 1970s, the new production order defining the global economy began to spatially fragment. Less developed countries became integrated into new production chains as subcontracted manufacturers, while deindustrialization processes started to occur in developed countries (Eraydın, 2023). During this time, many labor-intensive manufacturing units with outdated technologies shut down, and vast urban areas—especially those on the urban peripheries that hosted these industries—were abandoned (Eraydın, 2023). In the Industry 3.0 process, supply chains gradually acquired a global character, and no product was produced entirely in one single location anymore (Koca, 2020).

When examining the effects of Industry 3.0 on cities, a duality becomes apparent. In the Global North, considered developed, many large industrial units were shut down, and the number of people living in cities and working in industry significantly declined. To prevent deindustrialization, these cities attempted to create a production order based on knowledge and new technologies. During this period—characterized by the globalization of services and the growing dominance of new service sectors—reduced state intervention in the economy and a return to free market conditions defined a new accumulation regime. These processes led to problems such as rising income inequality, unemployment, and social fragmentation in cities (Eraydın, 2023).

Since the capacities of developing Global South countries were insufficient to fully implement new forms of production, a dual structure emerged in both production and labor markets. In these countries, while there were mass-production factories and an organized workforce, there also emerged small-scale production enterprises and an informal labor market (Eraydın, 2023). Global South cities, which sought to become subcontracted production hubs in global markets, did not undergo a deindustrialization process; however, they became new playgrounds for capital focused on the real estate sector. During this period, the cities of Global South countries experienced major transformation and destruction due to a construction-led growth model. It is also observed that low-tech industries employing relatively cheap labor compared to developed countries were again located on the urban peripheries (Eraydın, 2023).

5.5 Fourth Industrial Revolution

The Fourth Industrial Revolution (Industry 4.0) was introduced at the 2011 Hannover Fair in Germany as a series of actions by the German government aimed at implementing its high-tech strategies (Xu et al., 2021; Kılıç, 2023). The primary objective of Industry 4.0 is to compete with manufacturing-centered countries such as India and China, and to prevent the outflow of wealth from developed countries like those in the European Union and the United States (Kılıç, 2023). To achieve this, Industry 4.0 is considered a stage that promotes and supports collaboration in production, transitions, and the integration of learning and knowledge flows among different types of manufacturers (Hatuka, Ben-Joseph, 2023).

There are two main reasons behind the emergence of Industry 4.0:

• First, it is the return of factories to their home countries. Following the 2008 economic crisis, many Western countries had shifted production to various countries—especially in the Far East—due to low labor and resource costs. Industry 4.0 represents the process of bringing this production back home.

• Second, the primary impact of globalization on the economy is the liberalization and mobilization of capital. With the liberalization of capital flows, capital tends to move toward countries where it can yield the highest profit (Koca, 2020).

The technological scope of Industry 4.0 is extensive and includes technologies such as cloud computing, the Internet of Things (IoT), artificial intelligence, autonomous robots, and blockchain, all aimed at creating smart factories (Barata, Kayser, 2023). Industry 4.0 has led to the development of cyber-physical production systems that integrate information technology and operational technology within enterprises and supply chains (Grabowska et al., 2022). The trends and impacts of this revolution can be observed across all macro and micro scales of the market.

The core principles of Industry 4.0 can be summarized as follows:

• Service-oriented reference architecture,
• Smart, self-organizing cyber-physical systems,
• Adaptability and flexibility to changing requirements,
• Optimization for overall equipment effectiveness,
• Data integration across disciplines and throughout the entire life cycle,
• Reliable and secure communication between enterprises (Xu et al., 2021).

The rapid increase in the application of Industry 4.0 technologies today and the tendency of businesses to remove human labor from production systems have raised concerns for workers, society, and governments. In Industry 4.0, the working environment is defined by integrated, advanced, and resilient production techniques equipped with sensors monitoring machines and advanced communication systems—rarely mentioning the role of existing workers (Grabowska et al., 2022). The main focus of Industry 4.0 policies is to withdraw human resources from production processes and replace them with autonomous and optimized industrial tools (Koca, 2020). The technologies of Industry 4.0 typically require more knowledge than what is available to engineers, skilled manufacturers, or the traditionally low-skilled workforce (Rappaport, 2023).

When examining the relationship between Industry 4.0 and cities, it is based on the understanding of cities as innovation ecosystems. The speed and breadth with which cities adopt and distribute technology—supported by flexible policy frameworks—will determine their ability to compete in attracting talent. It is argued that having ultra-fast broadband, using digital technologies for transportation energy consumption and waste recycling, will make cities more livable and increase their competitiveness (Schwab, 2016). Cities can actively invest to create opportunities for digital transformation in order to attract entrepreneurs and investors to innovative ventures, and to encourage established businesses to align themselves with Industry 4.0 opportunities. According to the innovation organization NESTA, the five cities identified as having the most effective policy environments for promoting innovation are New York, London, Helsinki, Barcelona, and Amsterdam (Schwab, 2016).

In Industry 4.0-focused production, a dual structure can be observed in the relationship between cities and industry. The first of these structures refers to the attraction of small producers to urban areas. While large, vertically integrated companies dominated national production in previous industrial revolutions, today's production landscape consists of decentralized networks of small, specialized firms, largely operating in the United States (Rappaport, Lane, 2020). The other structure is characterized by large-scale areas containing standardized industrial buildings and surrounded by various boundaries. Autonomous industrial zones, usually located near infrastructure such as railways or airports, contribute to regional development, but may also compete with and weaken the economies of traditional industrial zones in nearby cities (Hatuka, Ben-Joseph, 2023).

Critics argue that Industry 4.0 aligns with long-term neoliberal capitalist models that emphasize profitability and prioritize shareholders, while intensifying several prevalent social and environmental concerns such as regional inequality, environmental degradation, and the fragility of the global economy (Javaid et al., 2020; cited in Ghobakloo et al., 2022). Automation may particularly have adverse effects on rapidly growing markets and developing countries, as these nations risk losing their comparative advantage in the production of labor-intensive goods and services (Schwab, 2016).

6. Emergence and Development of Indusry 5.0

The COVID-19 crisis that emerged in 2019 clearly demonstrated the need to reassess existing working methods and approaches. This crisis further deepened the vulnerabilities of industrial systems—such as fragile strategic value chains—and increased the necessity for both flexible and robust innovations to address these weaknesses (Breque et al., 2021).

6.1 The Emergence and Definition of Industry 5.0

In this context, the European Commission published a report in 2021 titled "Industry 5.0: Towards a Sustainable, Human-centric and Resilient European Industry" (Xu et al., 2021). Still in its early stages of development, Industry 5.0 has taken shape as a response to the challenges brought about by Industry 4.0, including unemployment, social inequality, and resistance to technological integration (Güdek, 2023). While Industry 4.0 primarily focused on production efficiency and digitalization, Industry 5.0 aims to establish production systems that are human-centric, sustainable, and resilient (Breque et al., 2021).

6.2 Human-Machine Collaboration and Value Proposition

One of the most distinctive features of Industry 5.0 is its emphasis on deeper collaboration between humans and advanced artificial intelligence systems (Nikolov, 2025). This collaboration aims to transform production processes into systems that are not only efficient, but also creative, fair, and capable of promoting long-term well-being (Huang et al., 2022). This vision involves the redesign of operations and supply chains based on principles of resilience, sustainability, and human-centricity (Grabowska et al., 2022; Ivanov, 2022).

6.3 Literature Analysis

As part of this study, a literature analysis was conducted on academic research related to Industry 5.0. A review of the annual distribution of studies reveals a notable increase in publications, particularly after 2020 (Figure 5).

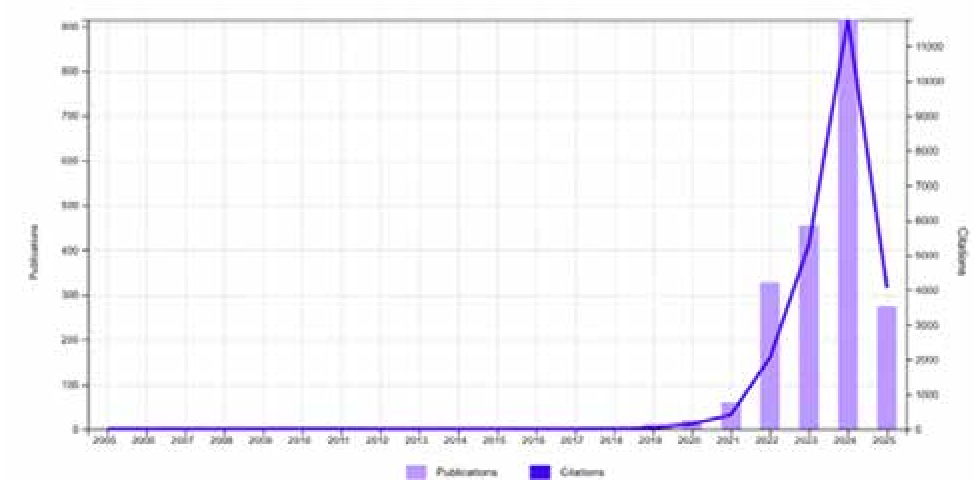

Figure 5 Distribution of Academic Studies on Industry 5.0 by Year (Obtained from Web of Science Data)

Keyword analysis highlights recurring themes such as smart manufacturing, sustainable development, digital transformation, Industry 4.0, and human-centricity (Figure 6).

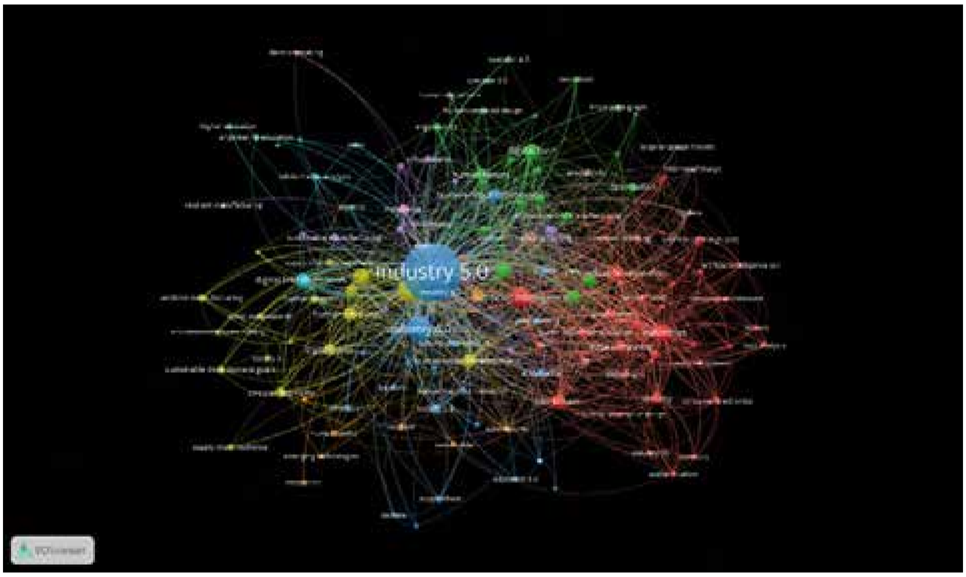

Figure 6 Distribution of Key Concepts Used in Studies on Industry 5.0 (Obtained from Web of Science)

When examining the relationship between these studies and the Sustainable Development Goals (SDGs), it is observed that the most commonly addressed goals are:
Goal 9: Industry, Innovation and Infrastructure
Goal 12: Responsible Consumption and Production
Goal 11: Sustainable Cities and Communities (Figure 7)

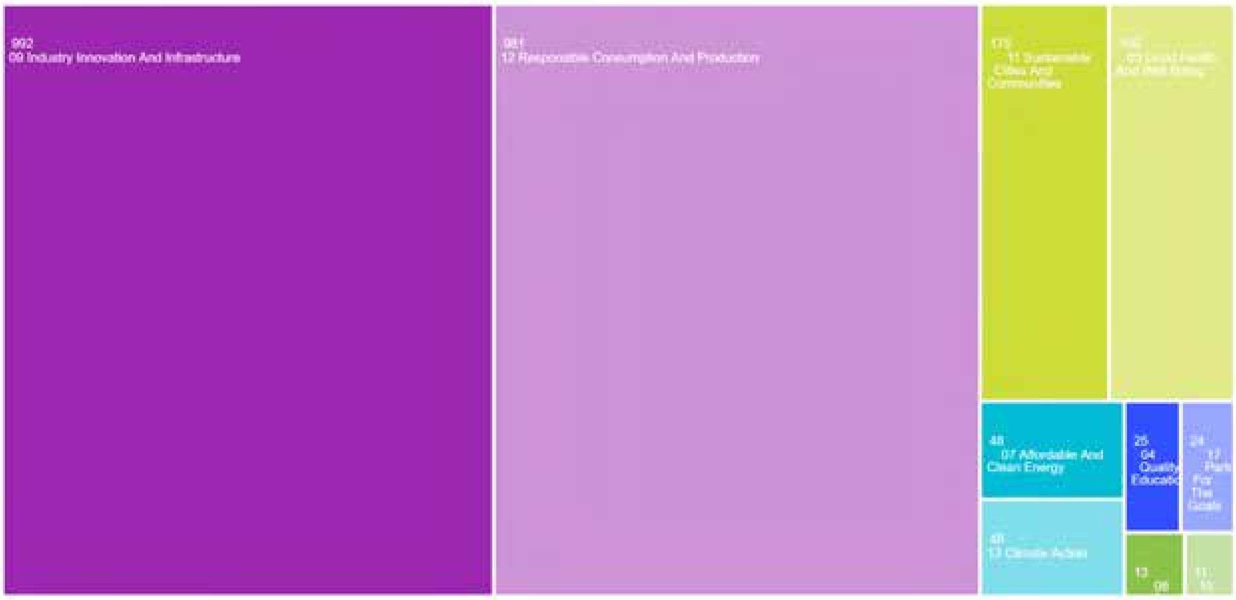

Figure 7 Sustainable Development Goals on Which Industry 5.0 Studies Concentrate (Obtained from Web of Science)

6.4 Relationship Between Industry 5.0 and Cities

The literature review revealed a lack of direct studies addressing the intersection of Industry 5.0 with urban planning and urban design. Therefore, the present study draws insights from existing research focusing on the core principles of Industry 5.0—human-centricity, resilience, and sustainability. Based on these principles, it can be argued that an Industry 5.0-oriented urban development model represents a paradigm shift from earlier urbanism approaches, emphasizing a form of urban circular symbiosis where industrial and urban systems are integrated.

This symbiotic approach particularly refers to the use of urban by-products (e.g., waste) as alternative raw materials or energy sources in industrial activities (Van Berkel et al., 2009). Through such an Industry 5.0-driven urban metabolism, the integration of residential, work, and industrial spaces is encouraged. This integrated model aims to regulate the transition between land uses, promote circularity and supply chain diversification enabled by new technologies, facilitate worker well-being in alignment with the principle of human-centricity, and foster spaces for social interaction (Eraydın, 2022).

In this context, the re-emergence of production activities within cities is gaining traction in novel forms such as maker spaces, innovation districts, vertical urban factories, and fab labs—highlighting emerging patterns of contemporary and future urban production (Lane & Rappaport, 2020). Historically, zoning regulations confined industrial activities to designated areas. However, Industry 5.0-compatible production activities—like 3D printing, laser cutting, small-scale prototyping, and media or film production—are not always compatible with traditional land-use regulations (Lane & Rappaport, 2020).

Therefore, the development of new planning and design strategies is required for spaces where Industry 5.0-based production can occur. These spaces should support fine-grained, mixed-use activities, maximize face-to-face interaction, and creatively resolve challenges related to material flow and building functionality (Lane & Rappaport, 2020). The identified urban design principles for such areas include:

• Street designs should support both the movement of goods and diverse modes of interaction between producers and non-producers.

• Open spaces should be flexible, vibrant, and active throughout the day.

• Edges of the zones should be well-defined yet permeable.

• Spatial configurations should accommodate new living-working relationships, ensuring gradual transitions between factories and adjacent neighborhoods in terms of scale and land use (Lane & Rappaport, 2020).

Elements of urban form—such as street and block networks, public spaces, edges, and adjacency of uses—play a crucial role in shaping the complex and flexible ecology of production (Lane & Rappaport, 2020). The design of Industry 5.0 production areas should ensure access to public transport, dining, and gathering facilities, thereby enhancing the quality of life for workers and realizing the human-centric vision (Lane, 2020).

In terms of resilience, such spaces should be conceptualized as ecosystems with diverse and interconnected supply chains. In times of crisis, flexible and adaptable production capacities can enhance systemic resilience (Ivanov, 2020; Kılıç, 2023). Furthermore, the transformation of production relations and urban systems through Industry 5.0—particularly aligned with the concept of urban symbiosis—points toward the development of circular systems that reuse, repurpose, and maximize resource efficiency, thus contributing directly to the principle of sustainability (Xu et al., 2021).

7. Conclusion

"The world has changed.
I see it in the water.
I feel it in the Earth.
I smell it in the air.

This passage from the beginning of Tolkien's The Lord of the Rings symbolically reflects the paradigm shift we are currently experiencing. Today, one of the most significant driving forces behind this transformation is the increasing frequency and severity of crises and disasters. Cities have become the primary sites where the most devastating impacts of these crises are felt. The fact that more than half of the world's population now lives in urban areas further complicates the issue. This study explores the potential of Industry 5.0 as a tool to enhance the resilience of cities against such crises, and examines the transformations it may bring to urban space. Within the framework of Industry 5.0's three core principles—human-centricity, sustainability, and resilience—it is anticipated that the resulting urban landscape will be more compact, mixed-use, and cyclical in nature.

Industry 5.0 seeks to merge technologies such as artificial intelligence and robotics with human creativity. Unlike previous industrial revolutions, it represents a shift toward placing not only economic growth but also social goals and a non-extractive view of nature at the center of production.Accordingly, in cities shaped by Industry 5.0, the reorganization of living, working, and production spaces is expected to integrate circularity and diversity into everyday life—thereby increasing urban resilience in the face of future crises.

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