# Chapter 3
# Industry 4.0 and Drivers for Socioeconomic Sustainability in the Construction Sector

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**Abstract** The construction industry is anticipating a plethora of transformative processes that will instill change and will require decisive actions from leaders to tackle the issues in the foreseeable future. The first tide of transformative processes envelopes the ongoing societal challenges like population collapse, environmental problems, and resilience, while the second is the emergence of Industry 4.0 that will be responsible to tackle and future-proof the construction industry from the ongoing social sustainability problems. The interaction between these two tides will decide how well the construction industry will be able to adapt, thrive, and meet the needs of society. For instance, the ongoing population trends are exhibiting a tectonic shift from population growth to population collapse, meaning that labor shortages will become more apparent and population aging is inevitable. Thus, digital automated technologies like 3D printing or semiautonomous robots will be vital to outweigh the human labor scarcity to have affordable housing. Emerging technologies like 3D construction-scale printers are already showing promising results in the reduction of $CO_2$ emissions in the building process, which requires less transportation, manpower and can open possibilities of bio-recyclable material use. The prefab building methods could help developers become more resilient not only from future pandemics, but also from any weather conditions since modular homes, or printing can be done in off-site locations. Therefore, the future of the construction industry depends on how well the Industry 4.0 technologies can be adopted to confront the upcoming social sustainability problems.

**Keywords** Urbanization challenges · Population forecasts · Industry 4.0 · Construction 4.0

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## 1 Introduction

Industry 4.0 emerges as a transformative process that alters the very fabric of our socioeconomic paradigm (Culot et al., 2020). Industry 4.0 was first introduced as the digital transformation of the manufacturing industry. It mainly involved implementing advanced digital and operations technology such as additive manufacturing, industrial robotics, artificial intelligence (AI), and data analytics and developing desirable conditions such as real-time capability and decentralization (Ghobakhloo, 2018). More recently, Industry 4.0 is regarded as the digital transformation of value-creating networks, involving various industrial sectors such as energy, transportation, distribution, and even health care (Tseng et al., 2018). Among many other industries, the construction industry is undergoing a significant transformation under the Industry 4.0 scenario (Oesterreich & Teuteberg, 2016). In reality, the construction industry is experiencing a significant paradigm shift concerning digitalization, commonly referred to as Construction 4.0 within the scientific literature (Dallasega et al., 2018; Maskuriy et al., 2019). It involves the application of most advanced digital technologies such as smart fabrication, 3D printing, robotics, smart sensors, high-performance computing (HPC), computer-aided design, and big data, all the way to the vertical and horizontal integration of information, knowledge, sub-systems, processes, and people across the construction supply chain (Newman et al., 2020; You & Feng, 2020). The digital transformation of the construction industry may offer valuable advantages such as product customization, time and cost efficiencies, smarter products, automation of hazardous jobs, transparent collaboration among stakeholders, and better decision making (Schiele et al., 2021, Tahmasebinia et al., 2020).

The construction sector is closely related to and exhibits a reciprocal relationship with society and economic pursuit. Thus, a foundational understanding of future trends in a socioeconomic dimension is vital for the construction sector to thrive in the Industry 4.0 era. First, the upcoming technological revolution bears many elements of uncertainty for the population forecast. The old theories of Malthusian that population will grow geometrically are being replaced by an alarming notion of population collapse, which has already taken place in most western countries. It appears that as the well-being of a society increases, the population loses interest in reproducing on a sustainable level, hence becomes dependent on donor countries for labor. The most recent example of China declaring that there might not be enough people on their mainland after pulling around 600 million people out of extreme poverty means that similar population evaporation trends will occur in India and Africa sometime in the future, thus eliminating all donor countries in the long run. Due to migration, some wealthier countries might sustain their economic activity, but construction sector in demographically decaying nations will need to rethink their strategic objectives. According to AHA (2007) by 2030, baby boomers will be managing at least one chronic condition which might require twice as many hospital admissions. This could require the construction industry to focus on building more healthcare facilities than kindergartens. Secondly, due to COVID-19, digitalization processes have accelerated immensely. The social media giant "Facebook" already predicts that 50% of its employees could be working remotely in the next decade. Consistently, urbanization rates might slow down or even reverse in some cases completely. Some of the largest metropolitan areas in the US have already experienced a decline in their residency, which, in turn, might create hardships to the office market but form the demand for housing space with dedicated workrooms further away from the central business sub-district. Experts even argue that office space might need to be converted to living space to help combat growing housing prices and address social inequality (Forbes, 2021; France24, 2021; Lewis, 2021).

Additionally, due to the COVID-19 outbreak, a consideration of prefab powered by digital technology might become more prevalent. The prefab factories assemble construction components in the factory, reducing traffic times of delivering materials back and forth, allowing better robotic automation, decreasing human interactions, and reducing the carbon footprint. It has been shown that the manufacturing component in a factory can reduce $CO_2$ emissions by 40%, and robotic automation will make the construction industry more resilient to future pandemics and market turbulence.

## 2 Population Forecasts and Urbanization Challenges Under Industry 4.0

Industry 4.0 is still in its embryonic stage but is believed that as digital technologies advance and AI matures, the impact of Industry 4.0 will exponentially alter the landscape of business and human being life by the next few decades (WEF, 2016). Overall, the emergence of the Industry 4.0 phenomenon comes at a fascinating time with regard to population progression, and the interaction between the two will have detrimental effects on the entire economy, including the construction sector. First, it is important to understand that the old Malthusian theory of exponential population growth that was created in 1789 is already being thrown out of the window and replaced by the population collapse theories (Bricker & Ibbitson, 2019; Burger, 2020). Malthus was partially correct to state that as higher agriculture technology improves and more food into the system is delivered, the population will increase. However, what he failed to consider was that the technology covariate does not work in solitude and other forces might completely outweigh its effect. Many researchers like Caldwell (1980), Castro and Juarez (1995), Skirbekk (2008), and Snopkowski et al. (2016) have documented that educational attainment for women has a negative effect on fertility rates, and in many developed countries, the educational attainment together with other factors has completely reversed the population growth trends below population replacement rates. Intuitively, this makes sense since in rural areas children are considered as investment, additional hands that can help out with farming activities, while in urban areas children are an expensive burden. For the latter mentioned reasons, the demographic transition model, which originally had four stages (high stationary, early expanding, late expanding, and low stationary), is nowadays being updated with five stages that might be called the "decline" or "depopulation" (Smeeding, 2014).

As shown in Fig. 1a, an exact inflection point has been delivered in 1970, when the population growth rate reached the peak and is now downward sloping. Still, the population is increasing in aggregate, but this will not last for long as the United Nations (UN) projects. Somewhere around 2100, the depopulation phenomenon should occur. However, some demographic experts say that the UN forecast is too optimistic. Wolfgang Lutz believes that the depopulation procedure will come as soon as 2040 since the rapid expansion of education, birth control, and women's rights is reaching the most distant corners around the world. It is hard to say, whether after the depopulation process, the world will simply maintain a sustainable level of population or an existential crisis will occur. As claimed by economist Elizabeth Brainerd, pro-natal policies have had a minor effect on post-soviet countries, while others like Sabotka et al. (2019) or Bonner and Dipanwita Sarkar (2020) found a positive effect, although emphasized that many other factors like education or future uncertainty were at play. Thus, artificially enhancing the depopulation might not be that simple.

Interestingly, as shown in Fig. 1b, the three-way highway is currently at play as different parts of the world are in different stages of the population cycle. The most developed regions of the world are already experiencing negative population growth, while the least and less developed regions are still growing. Surprisingly, the UN is projecting that by the end of 2100, the developed regions will bounce back to positive growth, primarily due to the migration from donor countries. In 2017, the largest five countries in terms of population size were China, India, USA, Indonesia, and Pakistan, with 1.4 billion, 1.38 billion, 325 million, 258 million, and 248 million, respectively. Nonetheless and in 2100, India, Nigeria, China, USA, and

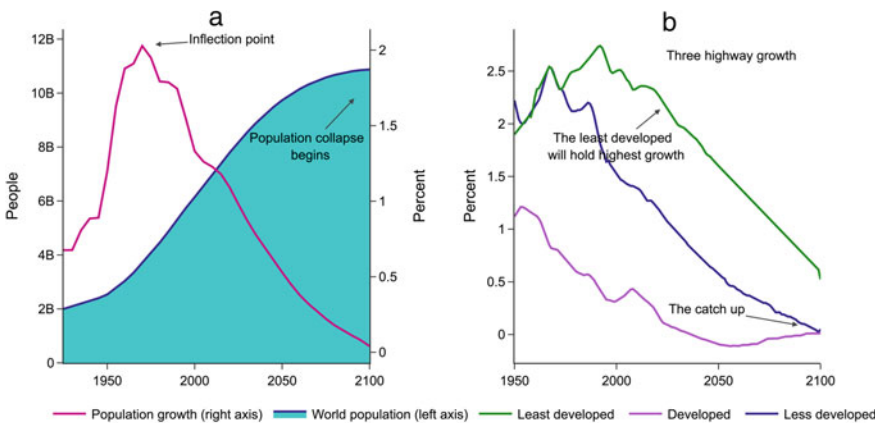


**Fig. 1** **a** Historical population growth rate and population aggregate size, and **b** Countries' growth rates classified by development (Authors original). Based on: *Source* **a**—UN Population Division and Our World in Data, **b**—UN Population Division (2019 Revision)

Pakistan, with. respectively, 1.09 billion, 791 million, 732 million, 336 million, and 248 million, will adjust their positions.

The urbanization trends will have substantial implications for urbanization processes, city planning, and the real estate and construction sectors. First, the UN projects that the total number of people living in urban areas from 2018 to 2050 will increase to 68% from 55%. This situation will intensify the construction activity immensely. According to the Statista database, in 2018, around 11,098 buildings were built daily worldwide. In 2050, however, this number will increase to 14,704, around 25% higher. Furthermore, the three-way highway phenomenon will split the urbanization trends in the near future. The least developed and less developed regions worldwide will continue to see cities massively expand, as shown in Fig. 2a. Megacities such as Lagos, Mumbai or Delhi, will have a massive population explosion, respectively, reaching 88 million, 67 million, and 57 million people. Because of such proliferation, cities will experience more poverty, overcrowding, terrible social and physical infrastructure and infrastructure decay, unaffordable housing, environmental pollution, slums, crime, and many more issues.

On the other hand, the major metropolitans in the developed regions, as shown in Fig. 2b, are beginning to notice mass emigration. Cities like Los Angeles, Chicago, and New York are already in negative growth while others, although still growing, have a very strong and negative trend. Many reasons are behind the exodus, but the most popular narrative usually revolves around high taxes, unaffordable housing, unmanageable homelessness, overcrowding, eye-watering rents, and lower immigration. This raises doubts whether the original projections in Fig. 2a that the New York population will increase are valid. This trend of reduced growth is also happening in European cities like Paris, where the negative trajectory has been constant for almost ten years. According to the French national statistics agency, in 2006, only 68% of

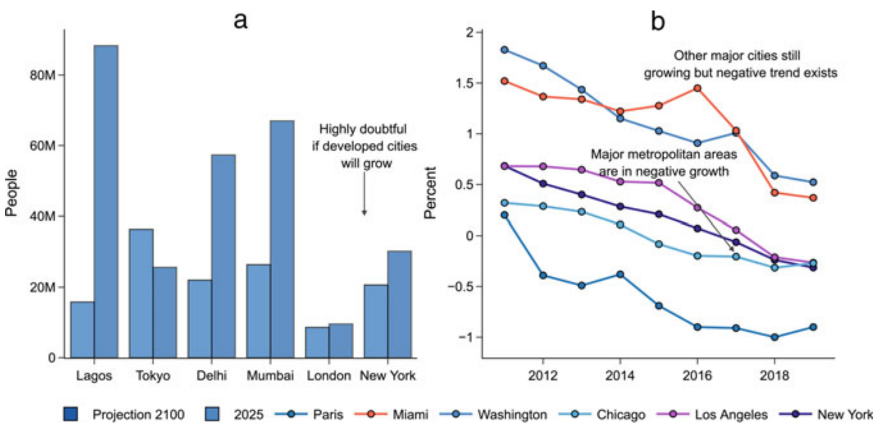


**Fig. 2** **a** Projections of the population for some of the world's largest cities in years 2025 and 2100 and **b** Cities' population growth rates. (Authors original), Based on: *Source* **a**—Ontario Tech (2021). University Population Data, **b**—Lnsee (2021) (France Population Census) and US Census Bureau

people born in Paris stayed during their lifetime. The latter processes should also raise questions on whether London will grow as projected before. In the 1960s and 1970s, statisticians underestimated London's decline, thus it would not be the first time where wrong predictions are made.

## 3 Construction 4.0 and Sustainable Development

Today, the social sustainability concept is at the core of many worlds institutions starting from the UN to the European Union. The understanding of sustainable development is straightforward: "it is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Edum-Fotwe, & Price, 2009). It holds three pillars:

(a) Economic implications pillar, including improved efficiency and growth by adopting new technologies that effectively allocate resources like labor and materials. Improved rate of return, net profit, and labor costs are examples of economic-productivity development indices;
(b) Social implication pillar that concerns the need of the population during the construction process and afterward. Social development indices are usually job displacement and creation, health issues, education, and training;
(c) Environmental implication pillar that reduces the damaging externalities to the environment. Energy consumption, recycled materials, $CO_2$ emissions, and waste are among the more crucial environmental sustainability metrics within the construction sector.

All of these issues have particular nuances. For instance, to solve the massive urbanization challenges, construction experts, urban planners, architects, and other parties involved will have to work together shoulder to shoulder to alleviate some of the burdens that cities, regions, and people are facing. Nevertheless, different regions will require different approaches from the construction industry for problem solving. As mentioned before, the developed cities are facing population shrinkage on their horizon. A crucial point to understand is that the negative growth in major metropolitan areas is not a COVID-19-induced situation as these trends started in 2018, but the COVID-19 impact might further exacerbate these processes. According to Bartik et al. (2020), more than one-third of firms that switched workers to remote work believe that distant work will remain common after the COVID-19 situation. Another paper by Dingel and Neiman (2020) examined how many jobs can be done remotely in the USA and other places, and most of the developed countries fell in the range between 30 and 50%. Since work can be done in the suburbs where traffic and taxes are lower, the negative growth in the major metropolitan areas might increase even more. This is especially true for such work as programming and software development that can retain similar productivity levels. Facebook CEO Mark Zuckerberg already claimed that within the next five to ten years, around 50% of employees would do work remotely (Bloomberg, 2021). It is reasonable to expect that other companies will follow this strategy since office rent costs can be reduced by holding virtual conference calls instead of physical ones. Construction activity outside the cities might rise, and homes with a dedicated workroom will become common. Some speculate that the COVID-19 virus might stay with society for the upcoming five years; thus, the remote work trend might be more prominent than at first was thought to be. If this is the case, it might help deal with the tremendous stress of urban density issues for policymakers and companies just shifting building activity from the city center to suburban areas. Nonetheless, remote work is much more common in industries with better educated and better-paid workers that can retain high productivity levels in distant environments. Thus, some portion of jobs will remain in the physical realm.

Furthermore, the developed regions will carry the agenda of sustainable development. European governments, as well as other countries, are doing all they can to popularize sustainable building practices that can contribute positively to the environment. The construction industry will need to be focused on net-zero building strategies that generate all energy required for consumption on-site and integrate innovative energy-saving technology. The general housing shortage problem might be reduced if more people start working from home and unused office space will be converted by construction companies into apartments or live work communities. Additionally, some architects are focusing on high-density future housing that is planned to accommodate around 4000 people per hectare in areas that today only accommodate 1500 people. The latter kind of structure will require construction companies to be more digitalized, flexible, and innovative to accommodate new building shapes. This might require using bent-active splines and textile membranes with tensioned bamboo nodes draped in fabric, which later can be cast in concrete and turned into single-family structures or shared housing. Smart or integrated homes are becoming more prevalent which allows controlling house energy use from a smartphone with ease. Other building configurations trends are focusing on conservation and sustainability as well. Houses are becoming more self-sufficient by using solar panels or being better integrated into the micro-grids.

Nevertheless, the sustainability agenda may fit the developed world, but for the least/less developed parts, problem solving should be done from a different angle. It is essential to understand that a compromise between net-zero buildings and a population increase of magnitudes like in Mumbai or Lagos must be achieved. Otherwise, climate catastrophes might arise in the future. It is calculated that every person emits two tons of $CO_2$ per year and on top of that construction industry is responsible for around 35–45% of $CO_2$ released into the atmosphere of which construction itself produces 11%, thus accommodating Mumbai or Lagos population increase without fighting $CO_2$ emissions is hardly an option (Muñoz et al., 2010; WEF, 2020). It is unreasonable to assume that less developed regions will have every single home equipped with solar panels in practice. Nevertheless, a prefabricated construction powered by digital technologies can help to create sustainable and high-quality housing at a speed that fits both the developed world and less/least developed regions and has immense AI adoption capabilities.

The idea of prefab is as follows: in contrast to traditional building methods that require massive labor force and material creation on-site, prefab apartments are assembled using different components (like the roof, walls), which are produced in a factory and transported to the construction site. The benefits of such production create a win–win situation for almost every party involved. First, as noted by Fluxus and Arcadis, companies can expect around 30% of net savings (WEF, 2020). In many cases, worker movement and accommodation are costly operations, thus having a permanent factory location helps workers and companies avoid unnecessary issues. More importantly, since most equipment parts are being made inside the factory, bad weather conditions are circumvented without interruption, leading to more predictable timings and higher overall efficiency.

Additionally, AI is the highlight of Industry 4.0, and so much product improvement and management can be achieved with big data. Companies that fail to adopt such tools might lose a competitive edge later on. In the prefab context, AI technology integrates smoothly with assembly lines or using data analytics to deliver insights for stakeholders. The material delivery using big data can be scheduled to minimize traffic or avoid peak times. Furthermore, simulation models at the factory level can help optimize, design, and test products, or even find new ways of making them. Additionally, if product standardization can be maintained, the speed at which the construction products are created can increase immensely. In general, a cheaper, faster, and more sustainable product, such as prebuilt construction material or smart housing equipment, could be delivered worldwide. Secondly, around a 90% reduction in construction waste can be achieved, and approximately 70% savings in $CO_2$ emissions can be expected (WEF, 2020). Heavy machinery transportations at low speed, constant worker arrival, and general material delivery are major problems that contribute to high $CO_2$ emissions, while prefab implications in the construction industry considerably reduce emissions and waste footprints. The factories can build most of the building components in the suburbs. This, in turn, can also create new jobs in new regions and reduce traffic. The speed, quality, and precision of prefab come from automated assembly lines, which human hand-built products cannot outpace. The latter is very important for less developed regions that will have to fight the population explosion (Howick, 2020).

Other alternatives for a more sustainable future are additive manufacturing or, more precisely, 3D printing technology. In layman's terms, using automated machinery, the building is built bottom-up, layer by layer. At first, it was considered a prototype building technology, but it is becoming an effective building tool in recent years. A project by the name of "Prvok" is the first 3D printed house in the Czech Republic. The project was estimated to complete in 48 h, and construction costs decreased up to 50%, while the $CO_2$ emissions were claimed to be reduced by 20% (PRVOK, 2020). Other engineers postulate that 3D printed concrete produces roughly 50% less emissions (All3dp, 2015; Malek et al., 2020). Although these numbers are smaller compared to prefab claims, both technologies are very young, and significant improvements can arise.

The beauty in 3D printing is that AI can create energy-efficient geometries that will consume less material (this process is sometimes called dematerialization) or even create new products that were never seen before. Simultaneously, any broken parts can be replaced on demand with no spare parts needed, thus creating less or no waste at all. Some authors like Sevenson (2015) or Van Wijk and Van Wijk (2015) even demonstrated 40–64% savings in materials that could be achieved. Another benefit is that limited logistic space is needed because products can be created on demand in any shape or form and are stored in a virtual warehouse. The latter benefit extends further to combat the tremendous energy usage in transportation, which according to the US energy information administration, around 28% of all energy was used for transportation alone in 2019. Since the production is local, less transportation is used, and even in the case of transportation, because material weighs less, energy is considerably saved. Additionally, 3D printing has immense capabilities for recycling. In many cases, plastic can be remelted and used again. Thus, the implication of additive manufacturing technology across the construction industry fits the concept of the digitally enabled circular economy perfectly. Lastly, 3D printing technologies reduce the need for labor, plant, or formwork.

At the moment, also some drawbacks exist with regard to 3D printing. Van Wijk and Van Wijk (2015) in their case study pointed out that the 3D technology impact on the environment comes mostly from electricity use. For a fused deposition printer, the heating element that heats up and melts the plastic consumes most of the energy. In the case of PLA (polylactic acid), the precise heat is between 1.5 and 2.0 kJ/kg for the temperature range of 50–200 °C, and in aggregate, the heating operations account for around 66–75% of total energy use. Furthermore, Van Wijk and Van Wijk (2015) created a case study where a hypothetical townhouse was built using 3D printing and conventional building methods. The size of the house was 100 $m^2$ of floor space, even roof, and was estimated to require around 50 $m^3$ (120 ton) of concrete conventionally, while for 3D operation, the PLA layers were used and around 5.4-ton PLA, 15 $m^3$ (36 ton) concrete, and 15 cubic meters of sand were needed. The final embodied energy and $CO_2$ emissions for the traditional building were at 133 GJ and 19.2 tons of $CO_2$, while for 3D printing, 186 GJ and 7.3 tons of $CO_2$. In this concrete example, it is evident that energy consumption is tremendous for 3D printing even though the $CO_2$ emission is slashed more than half. Consistently, having cleaner and preferably renewable energy input sources is indispensable for the industrial application of 3D printing technology in the construction sector. If the energy is generated sustainably, then the higher cost of energy consumption is not a problem. However, one must keep in mind that the case study by Van Wijk and Van Wijk (2015) had many limitations and assumptions about house building and insulation layers. Various other forms of bulk construction processes, like contour-crafting of walls, may not necessarily require such energy needs. Malek et al. (2020) have already noted that three-dimensional concrete printing has significantly reduced environmental outcomes in terms of global warming potential, acidification potential, eutrophication potential, smog formation potential, and fossil fuel depletion, thus, there are many nuances at play.

Another issue relating to construction, population, and Industry 4.0 is the labor force. Due to the declining labor force, it is difficult to tell if enough labor for the conventional building will exist in the future. Historically, a practice existed to allow emigration flows from donor states to compensate for population decline. However, due to tightening border control because of COVID-19 or changing government attitudes, it can be unreliable to expect a cheap labor force from abroad. This might disrupt building operations for some companies operating on small margins, meaning automation, simulation, continuous improvement, and the practical use of AI should be at the forefront of any company. An excellent example of how machine compensates worker shortage is a corporation in Japan called Shimzu. Due to aging population in Japan, three robots were developed to weld steel columns, install ceiling panels, and carry materials and were deployed to build a 24-story hotel in Osaka. The latter company claims to reduce its labor force up to 70–75%. In a prefab scenario, automated machinery requires less labor force as well (BBC, 2018; Shimz, 2017).

At the same time, another process from the opposite direction exists. Due to automation, many workers might be displaced from the construction sector. A research paper by Smith (2019) went into detail, claiming that around 2.7 million US construction workers will be displaced by 2057, the majority of them being blue-collar workers. According to Manzo et al. (2018), robots nowadays can lay bricks faster, build more yards per day, and construct buildings faster than human labor. It is estimated that around 49% of construction activities can be automated. Manzo et al. (2018) elaborate the automation potential is 35% for manual workers, 50% for carpenters, 42% for electricians, 50% for plumbers, and 88% for operating engineers.

For this reason, companies should work alongside the governments and begin thinking long term, since to have high-skilled labor that can use machine learning will not be easy to find. Thus, re-skilling current employees is a must. Some reports suggest conducting vocational training for current employees to work with the machines in the future. Also, government migration policies should be consulted with business community representatives. Otherwise, vast migration flows into the country might leave more people unemployed, thus increasing the homelessness problem. Smith (2019) also warns that sustainable development goals with companies, labor unions, or other governmental institutions will have to be unified. If not, an extreme redistribution scenario might occur, where robots will be taxed, or companies will be forced to pay stipends to workers for work displacement. As such, a sustainable approach is more beneficial for both companies and workers alike.

Finally, the workers' health in business has always been a priority in the social sustainability domain. The construction sector is one of the most dangerous fields to work in. As noted by the Occupational Safety and Health Administration (OSHA, 2020), one in five deaths annually occur in the construction sector. The governments have emphasized the "Fatal Four" primary causes of sector working fatalities, which are the following: falls, being struck by an object, electrocution, and being caught in something or between two objects. In essence and consistent with the technical assistance principle of Industry 4.0, the use of robotics and automation can reduce the majority of deaths relating to the latter situations, although still malfunction can exist, where assembly robot arm can accidentally harm a worker. Thus, robust and reliable systems have to be developed and implemented (ISO, 2016).

## 4 Future-Proof Construction Industry: The Need for Crisis Resilience

To become resilient to future crises, a healthy and productive construction industry matters more than ever. From the emergency construction of hospitals in just a few days to addressing the prevailing housing crisis, the construction industry plays a critical role in responding to future challenges and prompt recoveries from crises. Unfortunately, the construction sector has been significantly hit by the COVID-19 pandemic (CHAS, 2020). The construction industry is generally much more volatile than other industrial sectors, given any economic disturbance, reduction of income, and lack of consumer purchasing power massively reduce the demand for commercial or industrial facilities. On top of that, supply chain disruptions, labor shortages, and operational restrictions are causing the extra suffering of the construction industry. These issues have negatively impacted the financial performance of construction companies worldwide.

It is vital for the construction sector to mitigate the risks of the current pandemic and to become resilient for any future issues that might arise. Some speculate that the COVID-19 virus might stay with us for up to five years or more. Indeed the building projects cannot stay in a frozen state until the virus is over as urbanization and many other problems await. Obviously, the construction sector is not a software development business that can easily be done from a distance, as it is in a physical realm that requires manual labor. However, and as previously mentioned, building methods like prefab and 3D printing fit nicely into the picture. First, as prefab can be done at any location, workers can avoid the hotspots of the city center, where the majority of people reside, and infection is more likely to occur. For most factories, it is more reasonable to be located in the suburbs and avoid high traffic. Second, as automation increases, more labor can be put into 3D modeling or programming fields. This would reduce person-to-person contact and the virus spread. Boston Dynamics has already presented "the spot" robot that can go to dangerous places to inspect structures or issues that occur during the construction process. Similarly, other remote monitoring devices like drones could be useful in managing risks.

Construction projects are generally complicated and slow, involving lengthy planning, piecemeal financing, cumbersome approval processes, detailed material and resource planning, and integrated execution phases. Under such circumstances, the disruptive force of the COVID-19 pandemic will manifest in the large-scale delivery disruption throughout the construction sector, whereas other industries may experience the disruption caused by the pandemic differently, such as swift and severe market disruptions within the airline industry or small-scale manufacturing interruptions across automobile sector. Therefore, the construction industry is expected to strongly feel the COVID-19 crisis's full disruptive impact within the next two to four years. It is important to note that the construction industry is the backbone of any economy, and the shrinking of this sector will negatively affect other industries in the near future. Thus, policymakers are expected to proactively address this crisis and come up with countermeasures such as strategically planned construction-economic stimulus programs that may prop up the construction industry. While devising the supportive strategies, either at the corporate or government levels, the development of digital progression and maturity strategies should be prioritized, given the construction industry is considerably lagging behind other industries in digital transformation. Interestingly, more digitally mature industrial sectors such as the automobile, distribution, or even energy industries have endured less during the COVID-19 crisis. The construction industry should ensure that digitalization investments and efforts are aligned with the strategic priorities to deliver the intended return on investment. Value chain integration is an integral part of the Industry 4.0 transformation, and identifying digitally mature partners and striving to develop the hyper-connected construction ecosystem should be equally emphasized, given this level of integration and collaboration is vital for construction companies seeking an adjustment to the new market realities and proactively reacting to disruptions.

2020 was an unfortunate year for many, including the construction industry. The COVID-19 crisis may have permanently changed the world, and many believe that the occurrence of unpredictable changes and crises would be accelerated in the future. The residential and non-residential construction outlook for the upcoming years seems to be volatile. Although mega constructors and industry leaders might be able to absorb the impact of market volatility better due to their unparallel absorptive capacity, construction companies with limited balanced portfolios, smaller companies particularly, are expected to face significant turbulence interacting with the market. Under such circumstances, digital and connected construction and application of advanced digital technologies present valuable opportunities for developing new business models and strategies that favor resiliency and adaptability. The communication and information sharing capabilities of digitalization would further allow construction companies to consider new business models such as digital alliancing or public–private partnerships that may improve their absorptive capacity and crisis resilience significantly. Looking at the micro-level implications, digitalization would also allow construction firms to deal with the restrictions caused by COVID-19 pandemic efficiently. The vertical integration of equipment, personnel, processes, and resource planning systems, facilitated by the organization-wide implication of sensors, Internet of things, networking infrastructure, and smart gadgets, would allow the virtual accessing of worksite whenever possible. Coupled with virtual meetings, remote mapping, and robotics, firm-level digitalization would minimize the physical interaction of human labor while maintaining productivity without sacrificing employment opportunities. More importantly, the rising construction material costs, as the side effect of the COVID-19 pandemic, can be significantly alleviated with benefits offered by digitalization to the construction operations, such as streamlined off-site and modular construction, the improved value proposition of smarter buildings, optimized construction management, resource management efficiency, informed decision making and project selection, better market sensing, and improved stakeholder collaboration.

## 5 Conclusions

The construction industry is in the middle of a radical change. The present chapter explained how the dramatic shifts in the population growth and dispersal patterns and the resulting turbulence in the housing market, along with the global crises such as the COVID-19 pandemic and the ongoing digital transformation known as Industry 4.0, are reshaping the future of the construction industry. Overall, changes in the market and technological environment are introducing major disruption into the construction industry. Fluctuating housing demand, ever-shrinking employee pool, supply and delivery chain disruptions, and the emerging social trends have made it even more challenging for the construction industry to meet the quality, time, safety, and budget limitations of construction projects. The chapter explained how interactions between these disrupting forces have dramatically pushed the modernization of the entire construction industry. Under the Industry 4.0 scenario, the construction industry needs to shift toward automation and digitalization and draw on disruptive technologies such as additive manufacturing, AI, smart wearables, autonomous vehicles, robots, the Internet of things, extended reality, big data, and smart materials to streamline the constructions operations, improve communications across project stakeholders, facilitate modular construction, increase the safety of operations, and enhance the flexibility and sustainability of construction operations. The modernization of the construction sector demands industry leaders and policymakers to recognize the enabling role of Industry 4.0 technologies in navigating through the ongoing crises and responding to the emerging social trends.

## References


AHA (American Hospital Association). (2007). When I'm 64: How boomers will change health care. Chicago, IL.

All3dp. (2015). 50% reduction in $CO_2$ emissions with 3D printed concrete. Accessed https://all3dp.com/50-reduction-in-co2-emissions-with-3d-printed-concrete/

Bartik, W. A., Cullen, Z. B., Glaeser, E. L., Christopher, M. L., & Stanton, T. (2020). What jobs are being done at home during the covid-19 crisis? Evidence from firm-level surveys. NBER working paper series. Working Paper 27344, Available http://www.nber.org/papers/w27344

BBC. (2018). Why robots will build the cities of the future. Accessed https://www.bbc.com/news/business-46034469

Bloomberg. (2021). Facebook says it will expand remote work to all employees. Accessed https://www.bloomberg.com/news/articles/2021-06-09/facebook-says-it-will-expand-remote-work-to-allemployees#:~:text=Facebook%20CEO%20Mark%20Zuckerberg%20said,%2C%E2%80%9D%20Zuckerberg%20told%20employees%20Wednesday.

Bonner, S., & Dipanwita Sarkar, D. (2020). Who responds to fertility-boosting incentives? Evidence from pro-natal policies in Australia. *Demographic Research, 42*(18), 513–548.

Bricker, D., & Ibbitson, J. (2019). *Empty planet: The shock of global population decline hardcover—International edition.* Crown.

Burger, J. R. (2020). *Encyclopedia of evolutionary psychological science* (pp. 1–10). Springer.

Caldwell, J. C. (1980). Mass education as a determinant of the timing of fertility decline. *Population and Development Review, 6*, 225–255.

Castro, M., & Juárez, F. (1995). The impact of women's education on fertility in Latin America: Searching for explanations. *International Family Planning Perspectives, 21*, 52–57.
CHAS. (2020). The impact of COVID-19 on the construction industry (according to business owners). Accessed https://www.chas.co.uk/blog/covid-impact-on-construction-industry/
Culot, G., Nassimbeni, G., Orzes, G., & Sartor, M. (2020). Behind the definition of Industry 4.0: Analysis and open questions. *International Journal of Production Economics*, 107617.
Dallasega, P., Rauch, E., & Linder, C. (2018). Industry 4.0 as an enabler of proximity for construction supply chains: A systematic literature review. *Computers in Industry, 99*, 205–225.
Dingel, J. I., & Neiman, B. (2020). How many jobs can be done at home? Working Paper 26948. Available http://www.nber.org/papers/w26948
Edum-Fotwe, F., & Price, A. (2009). A social ontology for appraising sustainability of construction projects and developments. *International Journal of Project Management, 27*(4), 313–322.
Forbes. (2021). Accessed https://www.forbes.com/sites/palashghosh/2021/04/27/empty-offices-to-homes-london-like-nyc-plans-converting-work-spaces-after-covid-exodus/?sh=420be652301d
France24. (2021). Accessed https://www.france24.com/en/live-news/20210221-covid-19-could-empty-office-buildings-help-solve-france-s-housing-crisis
Ghobakhloo, M. (2018). The future of manufacturing industry: a strategic roadmap toward Industry 4.0. *Journal of Manufacturing Technology Management*, *29*(6), 910–936.
Howick. (2020). Waste reduction potential of offsite volumetric construction. Accessed https://www.howickltd.com/asset/327.pdf
ISO. (2016). Robots and robotic devices—Collaborative robots. Accessed https://www.iso.org/standard/62996.html
Lewis, R. K. (2021). https://www.washingtonpost.com/gdpr-consent/?next_url=https%3a%2f%2fwww.washingtonpost.com%2frealestate%2ffollowing-pandemic-converting-office-buildings-into-housing-may-become-new-normal%2f2021%2f03%2f31%2f2fec400e-8820-11eb-8a8b-5cf82c3dffe4_story.html
Lnsee. (2021). France population database. Accessed https://www.insee.fr/en/metadonnees/source/serie/s1321
Malek, M. Masad, E. & Al-Ghamdi, S. G. (2020). 3D concrete printing sustainability: A comparative life cycle assessment of four construction method scenarios. *Buildings, 10*(12), 245. https://doi.org/10.3390/buildings10120245
Manzo, J., Manzo, F. & Bruno, R. (2018). The potential economic consequences of a highly automated construction industry. Available at https://midwestepi.files.wordpress.com/2018/01/the-economic-consequences-of-a-highly-automated-construction-industry-final.pdf
Maskuriy, R., Selamat, A., Ali, K. N., Maresova, P., & Krejcar, O. (2019). Industry 4.0 for the construction industry—How ready is the industry? *Applied Sciences*, *9*(14), 2819.
Muñoz, I., Canals, L. M., & Fernández-Alba, A. R. (2010). Life cycle assessment of the average Spanish diet including human excretion. *The International Journal of Life Cycle Assessment*.https://doi.org/10.1007/s11367-010-0188-z
Newman, C., Edwards, D., Martek, I., Lai, J., Thwala, W. D., & Rillie, I. (2020). Industry 4.0 deployment in the construction industry: A bibliometric literature review and UK-based case study. *Smart and Sustainable Built Environment* (ahead-of-print). https://doi.org/10.1108/SASBE-02-2020-0016
Occupational Health and Safety. (2020). Commonly used statistics. Accessed https://www.osha.gov/data/commonstats
Oesterreich, T. D., & Teuteberg, F. (2016). Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Computers in Industry, 83*, 121–139.
Ontario Tech University. (2021). City population 2025–2100. Accessed https://sites.ontariotechu.ca/sustainabilitytoday/urban-and-energy-systems/Worlds-largestcities/population-projections/city-population-2100.php

PRVOK (2020). 3D-printed floating house will be built in 48 hours in Czech Republic. Accessed at https://www.designboom.com/technology/prvok-3d-printed-floating-house-48-hours-czech-republic-05-27-2020/

Schiele, H., Bos-Nehles, A., Delke, V., Stegmaier, P., & Torn, R. J. (2021). Interpreting the industry 4.0 future: Technology, business, society and people. *Journal of Business Strategy* (ahead-of-print). https://doi.org/10.1108/JBS-08-2020-0181

Sevenson, B. (2015). Shanghai-based WinSun 3D prints 6-story apartment building and an incredible home. Accessed October 4, 2016.

Shimz. (2017). Collaboration between people and robots equipped with the latest technology at construction job sites. Accessed https://www.shimz.co.jp/en/company/about/news-release/2017/2017011.html

Skirbekk, V. (2008). Fertility trends by social status. *Demographic Research, 18*(5), 145–180. https://doi.org/10.4054/demres.2008.18.5

Smeeding, T. M. (2014). Adjusting to the fertility bust. *Science, 346*(6206), 163–164. https://doi.org/10.1126/science.1260504

Smith, D. (2019). The robots are coming: Probing the impact of automation on construction and society. *Construction Research and Innovation, 10*(1), 2–6. https://doi.org/10.1080/20450249.2019.1582938

Snopkowski, K., Towner, M. C., Shenk, M. K., & Colleran, H. (2016). Pathways from education to fertility decline: a multi-site comparative study. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 371*(1692), 20150156. https://doi.org/10.1098/rstb.2015.0156

Sobotka, T., Matysiak, A., & Brzozowska, Z. (2019). Policy responses to low fertility: How effective are they? Working Paper No. 1 May 2019. Available at https://www.unfpa.org/sites/default/files/pubpdf/Policy_responses_low_fertility_UNFPA_WP_Final_corrections_7Feb2020_CLEAN.pdf

Tahmasebinia, F., Sepasgozar, S. M., Shirowzhan, S., Niemela, M., Tripp, A., Nagabhyrava, S., & Alonso-Marroquin, F. (2020). Criteria development for sustainable construction manufacturing in construction industry 4.0. *Construction Innovation*, *20*(3), 379–400

Tseng, M. L., Tan, R. R., Chiu, A. S., Chien, C. F., & Kuo, T. C. (2018). Circular economy meets industry 4.0: Can big data drive industrial symbiosis? *Resources, Conservation and Recycling, 131*, 146–147.

UN Report. (2020). Global status report for buildings and construction. Accessed https://wedocs.unep.org/bitstream/handle/20.500.11822/34572/GSR_ES.pdf?sequence=3&isAllowed=y

USA census Bureau database. Accessed https://www.census.gov/

Van Wijk, A., & Van Wijk, I. (2015). 3D printing with biomaterials: Towards a sustainable and circular economy. IOS Press and Delft University Press

WEF. (2016). Fourth industrial revolution what it means and how to respond. Accessed https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/

WEF. (2020). Here's how smart construction could transform home-building after COVID-19. Accessed https://www.weforum.org/agenda/2020/08/here-s-how-smart-construction-could-transform-home-building-after-covid-19/

You, Z., & Feng, L. (2020). Integration of industry 4.0 related technologies in construction industry: A framework of cyber-physical system. *IEEE Access, 8*, 122908–122922.