Development of Industry 4.0: A Practical Case Study from the Netherlands

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Introduction

The Fourth Industrial Revolution (Industry 4.0) is a concept introduced in Germany around 2011, as result of a project to describe and understand the trends and developments in manufacturing industry in Germany (Rojko, 2017). The financial crisis of 2008 as well as the ever-ongoing process of outsourcing and offshoring of industrial activity brought forward the need of thinking about in which way the German industry could remain competitive worldwide, as being on the forefront of innovation. As Vannevar Bush (1945) argued, scientific and technological leadership is crucial in maintaining an important and influential position on the world-stage. After its inception, the concept was well received and gained worldwide attention, not just in the research community, but also in the industrial society (Oztemel & Gursev, 2018). Industry 4.0 is about smart factories, able to produce autonomously, as the manufacturing system is IT driven, without the need for (much) human intervention. The reason for the development of the industry in this direction is the ever-increasing demand of customers towards individual tailor-made products. At this moment, in the most advanced industrial economies in Europe, so-called "high mix low volume" production systems are rapidly becoming standard

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(Godinho Filho & Saes, 2013; Suri, 2020; Upton, 1995; Veza et al., 2015). This means that with this form of production rapid changes in products can be made, with probably less economies of scale, but relatively short delivery times. Such production systems allow for higher added values (Suri, 2020; Veza et al., 2015) giving industry a "raison d'être" in highly developed economies with high labour costs.

Often such "high mix low volume" products are assembled from different standardized components. At this moment such standardized industrial components are mostly outsourced to countries with lower wages and/or higher production capacities and because of the implementation of Enterprise Resource Management systems often delivered on an (almost) Just-In-Time basis (McLachlin, 1997). Industry 4.0 offers a promise for industry in more developed economies to (at least partly) take away the current cost price disadvantage (expensive labour) for production in the most developed economies as well as offering more balanced supply streams leading to less waste (Brozzi et al., 2020; Kovacs, 2018).

However, to this day Industry 4.0 remains largely a scientific concept without yet much adoption in practice (Oztemel & Gursev, 2018). Most of the available literature is also conceptual in nature and offers different types of frameworks, but rarely any examples of implementation of (near) Industry 4.0 projects (Zheng et al., 2021). This short chapter would like to do just that: to analyse the development of a proposed Industry 4.0 smart factory in the Netherlands, with the opportunities and challenges from a business perspective that this project has.

The aim of the study—to analyse the development of an Industry 4.0 smart factory in the Netherlands, with the opportunities, risks, challenges that this project has. The tasks of the work were defined: to provide a description of a highly innovative energy saving project in the housing sector; determine the prospects for the implementation of a project that is close to the requirements of Industry 4.0; specify the elements of the project that require improvement and full compliance with the requirements of Industry 4.0.

The object of research is a highly innovative INDU-ZERO project in the housing industry. This is a specific project that may lead to a smart factory close to Industry 4.0. The subject of the study is testing the project for compliance with the criteria of Industry 4.0. Conclusions are based on compliance with the list of Industry 4.0 criteria

The novelty of the study is as follows:

- A model of a smart factory close to Industry 4.0 has been developed.
- An interpretation of the energy neutrality model in the housing sector in the Netherlands, close to Industry 4.0, is presented.
- An analysis of the project's compliance with the criteria of Industry 4.0 is per-formed.
- The required investments are calculated, a business justification of the project's effectiveness is given.
- The problems, risks, and prospects of implementing projects close to Industry 4.0 are indicated.

Background

The materials for the study were scientific works that developed the concept of industrial revolutions. We will consider the background and context for the concept of Industry 4.0. The term "fourth industrial revolution" implies that there have been three previous industrial revolutions. The first industrial revolution is the mechanization of production from roughly the second half of the eighteenth century to the end of the nineteenth century. Toynbee (1884) introduced the concept of "Industrial Revolution" in the English language and placed the starting point for this industrial revolution around 1760, the time of the introduction of the "flying shuttle" in the weaving process and the subsequent introduction of the "spinning jenny", the first mechanized spinning machine. The textile industry is generally regarded as the first industry that industrialized, but many other sectors soon followed. The characteristic of this first industrial revolution is the use of coal to generate steam to power the machines. The start of the twentieth century gave rise to the second industrial revolution, the automated assembly line, and the further division of labour within the company. This second industrial revolution is usually linked to Frederick Winslow Tailor and Henry Ford, for respectively developing the first scientific theory on management and the application of the assembly line in automobile production leading to a large increase in production (Zheng et al., 2021). Characteristic of the second industrial revolution is the standardization of products as well as components to produce these products, with little attention for flexibility of the production process (Wang, 2018). Henry Ford's famous quote: "*You can choose any colour as long as it is black*" when talking about his T-ford, the first assembly line mass-produced automobile, quite accurately catches the concept of standardization belonging to Industry 2.0. The third industrial revolution came with the application of computers since the 1970s and digital computer aided design to produce more efficient and to use the digital techniques to allow for worldwide spanning supply chain networks (Oztemel & Gursev, 2018; Wang, 2018). Production in Industry 3.0 is more automated and sophisticated, offering much more flexibility in the production processes. The third industrial revolution saw the appearance of robots doing repetitive and/or risky tasks as replacement for human labour. As industry 3.0 comes with a lot of networking between firms, there is also increasing attention for cybersecurity, as such firms increasingly have to deal with risks of cyber-attacks (Wang, 2018). Still, even with automated production, necessary machine changeover times would significantly hinder further increases in flexibility of production. Human supervision and programming of machinery is still required, as well as in engineering customer orders to "producible" factory orders.

The fourth industrial revolution goes even further in terms of digitalization, it encompasses autonomous cyber-physical production systems and internet of things (Perales et al., 2018), cloud computing based on the usage of big data and the capability of machine learning where there is just minimal need for human intervention (Osterrieder et al., 2020; Wichmann et al., 2019). Industry 4.0 means that production systems in factories can operate on their own and make decisions for themselves about production batch sizes, specific types of products to produce as well as use machine learning to avoid previous mistakes and learn to adapt production towards better results in terms of customer needs. Such factories are also known as “smart factories”, “dark factories” or “lights-off factories” (Oztemel & Gursev, 2018). The ability of systems to learn from dealing with previous situations and from human interventions will determine the competitive advantages of individual businesses (Wang, 2018), as well as helping with waste reduction (Kamble et al., 2018). In practice, Industry 4.0 will reduce machine changeover times to almost zero, allowing “economies of scale” even with a batch size of one (Oztemel & Gursev, 2018). Such a new production system also comes with major changes to the factory management (Piccarozzi et al., 2018).

The methodology is presented by the theoretical provisions that became the basis for the classification of Sony and Naik (2019): full industry 4.0 factories of meet the following criteria:

- Integration of cyber-physical systems in the production process of the factory.
- Automated data-management within the factory.
- Optimization of resource utilization (less waste).
- Production error reduction by means of machine learning.
- Automated supply-chain, including automated vehicles for transport.
- Large attention for cyber-security of the IT systems.
- Organizational mission and vison related to the adaptation of Industry 4.0.
- General scientific methods were used: modeling, classification, generalization, logical method, concretization, as well as the method of economic analysis; among the empirical ones—description, survey, measurement, practical modeling, the method of expert assessments.

Practical Implementation of Industry 4.0

We will indicate the problems and risks of implementing projects close to Industry 4.0.

It is important to note that Industry 4.0 is still a largely scientific concept and therefore, in practice there are so far only laboratory scale “autonomous factories” available (Sony & Naik, 2019). Autonomous machine learning is still in its infancy and it is expected that it will take several more decades to become fully mainstream (Oztemel & Gursev, 2018; Sony & Naik, 2019). One of the reasons for the limited current application of the industry 4.0 standard is the immense data infrastructure that is required to harness the power of machine learning by having the ability to handle big data. Furthermore, the technology that is available and would be possible to use to create a near-Industry 4.0 production environment is (still) very costly and would require large investments with, due to the newness of the technology, still uncertain results, making such investments highly risky. Also, there may be significant barriers related to staff of manufacturing companies, as very different work competences are needed. Staff members may very well be reluctant to work on Industry 4.0 implementation for the fear of the loss of their jobs (Horváth & Szabó, 2019; Stentoft et al., 2019). Kovacs (2018) mentions that in the USA and Europe around 50% of all jobs may be lost by computerization. Horváth and Szabó (2019) identify another barrier, namely the influence of legislation: among others the uncertainty coming from tender procedures, of which many (larger) industrial firms are dependent on.

Nonetheless, there are clear drivers of Industry 4.0 adoption which can be found in many studies of the subject (see for an overview Oztemel & Gursev, 2018). Industry 4.0 drivers usually originate from higher management, with the promise of more production control, a reduction of waste, an increase of time to market, a reduction of operating costs and a general shortage of a qualified labour force (Horváth & Szabó, 2019; Stentoft et al., 2019). In general however, Stentoft et al. (2019) find in their study among Danish manufacturing companies low Industry 4.0 readiness and practice levels, even though Denmark is at the forefront of technological development. Similar findings have been reported for Sweden (Truvé et al., 2019) and Germany (Bittighofer et al., 2018). The manufacturing sector in Finland and the Netherlands appear to be a bit more Industry 4.0 ready than those in most other European countries (Castelo-Branco et al., 2019). The next part of this chapter is therefore a case study of one Industry project in The Netherlands.

Industry 4.0 Case Study in the Netherlands

The experience of developing a specific model of energy neutrality in the housing sector, close to Industry 4.0, in the Netherlands will be presented.

Even though factories fully compliant to the industry 4.0 standard are perhaps still non-existent, this part is a case study on a specific project that may very well lead to a near-Industry 4.0 factory. Firstly, some background on the project will be provided, followed by the design choices and business model selection of this proposed smart factory. Secondly, the proposed factory with its design will be tested against the before mentioned criteria of Industry 4.0.

The project leading to the proposed smart factory is a project based on the Paris Agreement against climate change. If the goal of a significant reduction in carbon emissions is to be reached, the annual emissions have to be reduced tremendously during the next decades, given the situation that in 2021 an almost all time high amount of CO_2 equivalents was emitted (IEA, 2021). One of the key aspects of the policy plans of European countries in the North-Sea Area to reach the necessary reduction, is to retrofit the entire housing stock of these countries towards energy neutrality. This means that the net energy use of these houses should be zero, meaning that the houses themselves would provide all necessary energy for domestic appliances, heating, hot tap water etc. It is very well possible to build new houses and renovate existing houses towards this situation of energy neutrality: It is a combination of decentralised energy generation, usually by means of solar PV panels on the one hand, and energy saving, by adding extra insulation to the house on the other hand. Newly built houses and apartment blocks have to meet strict rules for energy usage in North Sea Region countries, and since these new houses are designed and developed basically from scratch, it is relatively easy to implement such energy requirements in the design itself (Smit, 2017).

However, the situation is very different for existing houses and apartment buildings. There is a huge diversity in size, and layout of different houses and apartments. To energetically retrofit the existing housing stock, houses must be measured individually to provide them later with an outer layer of insulation material, as well as the correct dimensions of solar PV panels on the roof. It is therefore evident that the energetic retrofitting of existing residential buildings is currently a very labour intensive and costly affair. Not only costs are problematic, given the current shortage of labour (which is not likely to end soon, given among others the demographic situation), but the speed of these necessary renovations is also too low as well. In the North Sea region alone, around 22 million residential buildings are in need of energetic retrofitting before 2050 (INDU-ZERO, 2021). With the current costs and speed of operation, this goal is unattainable.

Therefore, a consortium of university partners, governments and business has come together in a triple helix setting to tackle this issue, by focusing on finding a solution which both cuts the costs of renovations per dwelling by half and allows for a very significant increase of the speed of production of energetic retrofitting packages. The consortium named the project INDU-ZERO. The solution decided upon by the consortium was to develop a blueprint for a near Industry 4.0 “smart factory”. This triple helix-based consortium was a very effective way to tackle the issue at hand, as seen in the previous section of the chapter, barriers of Industry 4.0 implementation can be found on legislative issues (government), technology and knowledge issues (university) as well as on business model/investment readiness issues (business).

Within the INDU-ZERO project, a fully automated digital driven production system has been designed, with three production lines, together able to produce renovation packages for 15,000 residential units in total yearly. Since every house and/or apartment is different, and labour saving is one of the main goals, each house must receive tailor made renovation packages to be placed as a shell around the house or apartment, by a team of four workers in 3 days. This means that work activities on site should be kept at a bare minimum: The factory should be able to produce unique and exactly fitting panels for every single dwelling which can be mounted to the dwelling within minutes (see for visual materials INDU-ZERO, 2021). Solar PV panels come integrated with the roof panels, taking away the need to mount them. Even original roof tiles don’t have to be removed, the roof panels can be mounted right over them. Only existing chimneys must be taken away. Since there will be no wood or gas usage in the new situation, any existing chimney will be obsolete and can be taken off the roof in minutes with a special crane.

The factory itself, must be extremely flexible in terms of production: the market requires batch sizes of 1 (unique renovation packages for each single home or apartment). Therefore, the factory will be developed as an Industry 4.0 fully automated smart factory. Key to the development of such a factory is the development of the data stream, which would be the red thread throughout the production process. The starting point is the measurement of the dwelling, to find out the dimensions the renovation package needs to have, as well as the places where the windows and doors should appear. Traditionally this is done by manually measuring the distances and allowing for some slack space that can be made to measure during the final assembly of the insulation material. INDU-ZERO uses building scanners that produce a data point cloud, which is uploaded to the factory and translated to a digital twin of the building. With minimal engineering time (for example for adding extra visual attractiveness of the outside of the panels if so desired by the client), such digital twins are automatically used by the production system to produce the elements with the exact, millimetre accurate, dimensions. The overarching Enterprise Resource Planning (ERP) system automatically selects the necessary materials from the factory warehouse and orders additional materials whenever the inventory is below a certain safety level. Incoming trucks (an estimated 70 per day) are offloaded automatically by Automated Guided Vehicles (AGVs). Since every renovation package is unique, the ready-made product is picked up by a truck to be transported to the exact dwelling it was produced for. The on-site mounting process of the package, consisting of several panels for each side of the house, as well as the roof should be able to be mounted in the shortest possible time with the lowest possible amount of required labour. After the mounting process, the new installations must be connected and installed (the heat pump for heating and hot water and the solar PV panels, including inverters for providing energy). This takes up the bulk of the still necessary worktime for the on-site assembly of the renovation packages.

All in all, there are still 440 workplaces needed in the smart factory, for producing the 15,000 renovation packages yearly. This is a strong reduction from the current labour-intensive production situation (takt time of each produced panel is expected to be around 2 min), but still, it means that the proposed factory is not yet a fully Industry 4.0 “lights-off factory”. The workforce is mainly occupied with quality supervision and solving machine breakdowns, as well as—as is expected—in some cases with rework of quality control rejected panels. A complete Industry 4.0 factory would also have machines automatically controlling the final quality of the produced panels. Even though there is certainly a good amount of quality control done automatically, still a final visual overall inspection has to be done by humans. In the blueprint, there is yet no machine learning tool foreseen, which can automate the final quality control. Consequently, also the rework section will require human workers to do any necessary rework activities. In a truly automated Industry 4.0 environment this would also be done by cyber physical systems with the capability of machine learning.

In terms of business model and required investment, the total amount of the investment is but is going to be more than 200 million Euro, which certainly is a considerable sum of money. Still, the business case allows for a relatively speedy return on investment, given the fact that the sales volume is forecasted at 15,000 units yearly (based on the demand from larger Dutch & German housing associations). In the city of Enschede, The Netherlands, three showcase houses have been

Fig. 1 Testcase houses of the INDU-ZERO project in Enschede, The Netherlands under redevelopment. Photo: Jacob Cornelis Bazen

completed with the help of the new on-site assembly process, designed in the project (Hellegers, 2021), see also Fig. 1.

Now of writing, the smart factory blueprint is in its final stages of preparation and upon delivery of the blueprint, with the development of the machines, the design of the factory and the design of the process of on-site assembly, the smart factory will be investor ready. When all goes according to plan and enough investors are willing to contribute, within 2–3 years the blueprint can be developed into a complete and working Industry 4.0 factory.

Conclusion

When testing the proposed blueprint against the Industry 4.0 criteria list (see section "Background" of this chapter), the factory scores as follows:

1. **Integration of cyber-physical systems in the production process of the factory**: The factory functions almost autonomously. The only human intervention in the normal production process is the final optical quality check of the panels, quality checks of different components are done automatically. When quality issues are detected, the panel is moved to the rework section of the factory, which

runs with physical labour. Therefore, one can argue that the blueprint is 90% Industry 4.0 ready.

2. **Automated data-management within the factory**: The factory is fully dependent on an automatic DataStream based on the point cloud scan of the dwelling. Some human interference can occur in terms of the design when customers would like to add patterns or other decorative elements to the panels. But, in principle, on this aspect the proposed factory fully meets the Industry 4.0 standard.
3. **Optimization of resource utilization (less waste)**: Feedback loops in the production are foreseen, to reuse cut-offs. It is currently untested, to which extent this will lead to optimization of resource use. Exact compliance with Industry 4.0 standards cannot be given at this point.
4. **Production error reduction by means of machine learning**: Currently, no machine learning tool is included in the design of the factory. Therefore, the proposed factory does not meet this part of the Industry 4.0 standards.
5. **Automated supply-chain, including automated vehicles for transport**: All in-house logistics are completely automated and will run without human intervention. This includes automatic unloading of supply trucks. The loading of the trucks with the readymade panels still must be done manually by the truck driver. Therefore, in terms of logistics, the proposed factory meets around 90% of the Industry 4.0 standards.
6. **Large attention for cyber-security of the IT systems**: There is a strong attention on cyber security, a relatively large part of the proposed workforce is foreseen as IT specialists, focusing on digital safety. For as much as can be seen now, on this aspect the factory will meet Industry 4.0 criteria.
7. **Organizational mission and vison related to the adaptation of industry 4.0**: Since the organisation is new, and the project team has focused on the design of a smart factory from the beginning, it could be safely assumed that in organizational sense, the factory will be Industry 4.0 ready.

Therefore, given the scores on seven important aspects of Industry 4.0, it can be concluded that even this highly innovative INDU-ZERO project, with its design of ground-breaking cyber-physical production systems does not fully meet the most important Industry 4.0 requirements. Even though this factory has many aspects of a "dark factory", it is still not fully running autonomously. Industry 4.0 is still a standard that needs significantly more time to become mainstream in production environments.

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