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Framing Industry 4.0 as a Social Innovation

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Abstract. This article illustrates a social innovation perspective of Industry 4.0 by examining the literature around these concepts. Industry 4.0 refers to advanced technology adopted to automate and digitalise operations, and they are at the base of the fourth industrial revolution. So far, some studies show that Industry 4.0 adoption is oriented toward value maximisation for organisations. Against this backdrop, we show that Industry 4.0 technologies can be adopted to tackle social issues and improve the well-being of people in society. In particular, this study highlights three Industry 4.0 technology applications as social innovations: the socially sustainable factory, urban manufacturing and Fablabs.

Keywords: Industry 4.0, social innovation, Fablabs, socially sustainable factory, urban manufacturing.

1 Introduction

Industry 4.0 (I40) is becoming a popular topic among industrial, political, scientific, academic and maker communities [22]. I40 is an umbrella term embracing advanced digital technologies for production. These technologies are the basis of radical innovation for organisations because they can replace traditional technologies, providing extensive automation capability and, at the same time, digitalisation of the information flow of production [26]. For some authors, these technologies triggered the fourth industrial revolution, and their adoption is oriented to profit maximisation for organisations [30]. I40 adoption enhances production efficiency and enables mass customisation manufacturing, specifically the ability to make items with some alterations at a reduced price [22]. Against this backdrop, recent studies show that I40 technologies may tackle social issues by acting as social innovation (SI) [8]. For instance, I40 adoption may improve work conditions in production and create new job positions, or it can help the development of digital skills and creativity in future workers [25, 36]. Thus, this study posits that I40 adoption fosters SI, which aims to address social challenges [3,7]. Considering technology as the base for SI is not new in the scientific literature; this is the case for online learning, blockchain technologies, and information and communication technology [1, 8, 41]. For instance, one of their main social outcomes is the mitigation of organisational impact on the environment. This is possible through the use of information and communication technologies that allow the digitalisation of paper usage and consequently reduce its consumption [21].

However, despite the increasing need to improve the well-being of people, communities and society, the potential value of I40 as SI has not yet been fully ascertained and systematised. Since studies pinpointing I40 adoption as a SI are recent, the evidence on such novel perspectives remains fragmented in the literature.

Thus, this study fills this literature gap by framing I40 as SI through an extensive literature review, addressing the following research question: "What kind of I40 adoption is a social innovation?"

This article represents one of the first attempts to demonstrate that I40 adoption may be presented as a SI when the technologies are employed to establish a socially sustainable industry, urban manufacturing, and Fablabs. It also contributes to the literature by providing important implications for researchers and practitioners.

The article's remainder is as follows. Section 2 depicts the study's theoretical framework. Section 3 illustrates the research design. Section 4 presents the results of the I40 adoptions as SI, which are discussed in Section 5. Section 6 concludes the study.

2 Theoretical Framework

This section illustrates the two concepts of I40 and SI.

2.1 Social Innovation

Policymakers, researchers, and the citizen sector have given greater emphasis to SIs as a viable solution for tackling social problems [10]. Academic study on SI, on the other hand, is still scarce. Recent work has primarily been practice-oriented, and it has been published in the form of research reports from various organisations and foundations, as well as papers in publications such as the Stanford Social Innovation Review [9]. Some analysts consider SI not more than a buzzword or fad too imprecise to be usefully applied to academic scholarship [34]. Due to the uncertainty around the concept of SI, our study combines the CSR Europe definition [52], the ones provided by Pol & Ville (2009) and Morrar et al. (2017) and describes SI as follows:

"SI refers to any technological innovations (new or improved products or processes) or organisational innovations (changes to the firm's strategies, structures or routines) that have the potential to improve human welfare, resolve existing sustainability challenges and create new social collaborations between business sectors and stakeholders." The purpose of SI is not to offer breakthrough technologies or unique scientific advancements but rather to find solutions to social problems that will improve societal well-being while securing commercial, technological, organisational or scientific aims [10]. Given these features, SIs are increasingly seen as a sound business strategy to solve, on the one hand, some of society's most complex problems at local, regional, national, and global levels; on the other, they also aid in the proliferation and dissemination of several technological advancements [8].

Adopting such SI technologies is not free from challenges and barriers, especially in the initial implementation stage. They often require new skills, such as digital literacy, data analysis, and problem-solving, demanding a new workforce. However, SIs, by building on a more holistic view which considers all the stakeholders [11] during the innovation process, can play a significant positive role in organisation competitiveness, new revenue streams, customer satisfaction and overall organisational performance.

2.2 Industry 4.0

The label I40 was coined at the Hannover Messe in Germany in 2011, and currently, it is used as an umbrella term to embrace various advanced digital technologies for production [22]. There is no extensive list of such I40 technologies, and scholars present them with multiple frameworks [38]. This study uses the I40 technology framework by Frank et al. [13]. I40 front-end technologies are those adopted in production and enable the automation of operations and decision-making activities [23] and natively generate digital production data [22]. I40 front-end technologies are also equipped with control systems that enable interactions with workers [26] and can empower worker manual and cognitive activities [37]. Within this group, there are cobots which are robots designed to collaborate with workers [25]. Then, there are 3D printings that produce goods by adding material rather than mechanically removing material from a solid block [4]. 3D printings produce goods through light, ultrasonic vibration, laser, and electron beam and can follow computer-aided design (CAD) printable models for shaping the product [23]. Finally, the second group of I40 technologies are called I40 base technologies that retrieve, store and analyse data from front-end technologies from these technologies enabling continuous monitoring of process performance [23].

3 Methodology

We conducted an extensive literature review following the procedure proposed by [49] and [44]. The bibliographic databases employed for collecting relevant articles were Scopus and Scholar, widely recognised as the most comprehensive databases [17, 29].
Following our research interest, we considered all the relevant keywords related to "Social Innovation" AND "Industry 4.0" based on the keywords selected through a preliminary literature review and refined by expert recommendations. Given the novelty of the topic, we retrieved 17 articles, and the research team analysed each of the collected articles until May 2023 with the final aim of framing I40 from a SI perspective. The

following steps included a critical analysis of the articles to identify missing, incomplete, or poorly represented aspects in the literature. To ensure a relatively complete census of the relevant literature, by collecting and analysing selected studies (in the extracted sample), the authors applied the "*go backward*" and "*go forward"* approaches [47]. The first consisted of reviewing the citations of the article identified to include other relevant articles; the second consisted of identifying articles also reviewed some out-of-sample studies (cited by selected studies in the sample or selected through specific term search on Scopus and Scholar) to support the explanation of results (backward and forward search). The final sample was made of 27 articles due to a backwards and forward search of the articles.
The critical assessment of the papers by the authors has allowed the extraction of three main clusters of topics that have been presented in the following section.

4 Results

This section presents three perspectives of I40 that can be framed as a SI: the socially sustainable factory, urban manufacturing and Fablabs.

4.1 The socially sustainable factory

This research stream originates in juxtaposition with the traditional Smart Factory [23], which is designed to leverage the automation capability of I40 technologies and may disrupt several jobs in production. In contrast, the socially sustainable factory is designed with I40 technologies used as a work aid or that may collaborate with workers [36]. For instance, cobots can help workers assemble products, or augmented reality may help workers conduct complex cognitive activities [12]. Otherwise, I40 technologies with control systems may be adopted in production and managed by workers [33, 37]. In this way, I40 adoption is a SI because it creates new job positions: workers act as machine supervisors. Workers can also work as expert assembly operators, i.e., workers supported by I40 technologies that also help peer operations [26]. Beyond creating novel job positions, the socially sustainable factory provides qualitative benefits to the workers. I40 automation may be used to automate tasks that are harmful to workers and reduce the incidence of illness [42]. When I40 technologies measure time spent on operations by workers, they can monitor worker performance and detect those workers performing below standard. Thus, training can be provided to improve their skills [24].

Finally, workers should develop digital skills to operate in a socially sustainable factory. Thus, during the I40 adoption process, they are enrolled in several human resource practices, such as training, training on the job, and mentorship, to develop these skills [27, 47].

4.2 Urban Manufacturing

Urban manufacturing or urban factories are defined as centres of value generation located in cities [19]. This novel trend was triggered by I40 technologies enabling smaller, quieter, less polluting manufacturing processes that can be therefore moved in urban areas. In this case, additive manufacturing technologies – especially 3d printings – provide new avenues for social entrepreneurs. Indeed, urban manufacturing helps develop businesses that can be established close to the consumers [40]. Moreover, urban manufacturing helps circular economy practices in cities. Urban factories can use local supply chains to reduce transportation emissions, and urban manufacturers can utilise local waste flows as a resource [46].

Moreover, urban manufacturing reduces greenhouse gas emissions because it encourages suppliers to take more environmentally friendly actions [18]. Finally, urban manufacturing can integrate their production, enabling distributed manufacturing, i.e. a way of organising production to spread across many locations. An emblematic case was the massive production of the Charlotte valve to adapt a common mask for snorkelling as a life-saving respirator during COVID-19. The valve was designed in CAD and produced with 3d printings by an Italian company in a Northern city. Since this artefact may save several lives, the demand, at that time, was very high. Thus, the Italian company released the CAD project of the mask freely with the hope that further urban manufacturers may print the artefact. As a result, during the pandemic, the Italian company printed less than 100 thousand artefacts, but with the help of other firms worldwide, the valve was printed 186 thousand times [48].

4.3 FabLabs

Fabrication labs, more commonly known as FabLabs, represent a further facet of I40 as a social innovation. FabLabs are collaborative spaces where individuals have free access to technologies, especially 3d printings, and learn new knowledge and skills [7, 16]. Everyone in FabLab can use shared tools and technologies to acquire knowledge and enrich their cultural background by transforming their ideas into real prototypes [16].

Gershenfeld and colleagues at MIT in Boston were the first to create FabLabs in 2001, designing it as standardised laboratories equipped with tools and equipment. Specifically, Gerstenfeld's basic idea of Fablabs is a common space where individuals or groups can share tools like 3d printings, laser cutters and equipment [45, 50].

Subsequently, the model developed at MIT spread rapidly around the world [15, 28] thanks to the nature of the FabLab as a community space, where users share both designs and instructions for using the machines with the international community [39]. Today, the expansion of the FabLab movement has increased the number of such collaborative spaces to an estimated 1,750 FabLabs in 100 countries (see https://fabfoundation.org/).

FabLabs are places where individuals can collaborate and exchange experiences among members. Indeed, they are known as an accelerator of ideas and creativity among users, who can create (individually) or co-create (collectively) physical and digital products [3, 51]. Knowledge created and shared in fabrication workshops refers to "all kinds of understanding acquired through experience or study" [20]. Thus, the resources shared in such places are tangible (machines and prototyping tools) and intangible, such as new knowledge, professional networks, and training [7]. Therefore, the interaction between people with different skills and characteristics, combined with training and the use of equipment, helps create a creative and stimulating environment. FabLabs can be considered tools for promoting economic and technological progress, as they foster social inclusion and participation [5, 14] and promote science education and entrepreneurship [6, 14, 43]. Ultimately, FabLabs are places of exchange and learning, and most importantly, are spaces where the creation and sharing of knowledge is a community resource that is fundamental to the success of such a place [32].

5 Discussion

Table 1 illustrates the study's results. Thus, we contribute to the literature by summarising three SI perspectives of I40.

I40 adoptions as SIs	**Social Benefits**
• Socially Sustainable factory	New job positions Safety Workplace Digital skills for workers Efficiency
• Urban Manufacturing	Nurturing social entrepreneurs Reduction transportation emissions Local supply chains Encouraging environmentally friendly actions Encouraging circular economy practices
• Fablabs	Learning fabrication activities for everyone Knowledge sharing Fostering social inclusion and participation Supporting idea generations Co-working

Table 1 Industry 4.0 as social innovations and the consequent benefits

Unlike the traditional vision of I40 adoption, which is centred on value maximisation for the organisation [23], we have identified two distinct SI perspectives for profit organisations that may yield varying societal values and one for non-profit organisations.

The socially sustainable factory and urban manufacturing are forms of SI for-profit organisations. To achieve these forms of SI, I40 technologies are designed for collaborating with people [25]. The interaction between I40 technologies and people leads to positive changes in how they work, learn, communicate, and live. This is because the two have a mutual influence, resulting in a beneficial socio-technical transformation. Therefore, we extend the technological capability literature for SI, reporting that the digitalisation of information communication technologies is at the basis of SI because it can decouple raw material consumption [21], by showing that automation can also support SI when used collaboratively and oriented towards workers' needs.

Regarding the potential I40 technologies at the basis of a SI, we found that such technology selection differs from the traditional I40 adoption. Unlike the traditional I40 adoption for value maximisation, where a variety of I40 technologies can be used, we found SI with I40 technologies can be achieved with few I40 technologies, especially cobots and 3d printings. The latter is pivotal for urban manufacturing and FabLabs. Urban manufacturing can nurture entrepreneurship, and therefore, it can mitigate unemployment in times of crisis. On the other hand, FabLabs is an engine to foster social development because it allows interaction among different actors (individuals, companies, associations, public authorities, etc.) and their exchange of ideas. Thus, the intellectual and cultural diversity of the users makes possible the development of knowledge for everyone and on all projects by making this new knowledge free for the FabLab community [32].

Moreover, the literature reports that technology may be the basis of singular SI [1, 8, 41]. This reflection may change for I40 technologies because all these technologies can be integrated, and their purpose is similar: goods production [22]. Therefore, we believe that these three SI perspectives of I40 should not be considered singly but in conjunction (see Figure 1). Indeed, the development of FabLabs may help entrepreneurs to develop idea products and prototype them with CAD projects printable with 3d printings. At this point, urban manufacturing may be opened, or the product idea and CAD file can be sold or simply produced in a socially sustainable factory. On the flip side, the socially sustainable factory or urban manufacturing can maintain job positions and invest in FabLabs to help future entrepreneurs or makers create new product ideas. Further, urban manufacturing and socially sustainable factories can create synergies for sustainable productions: productions can be delocalised close to consumers to reduce CO2 emissions from trasportations.

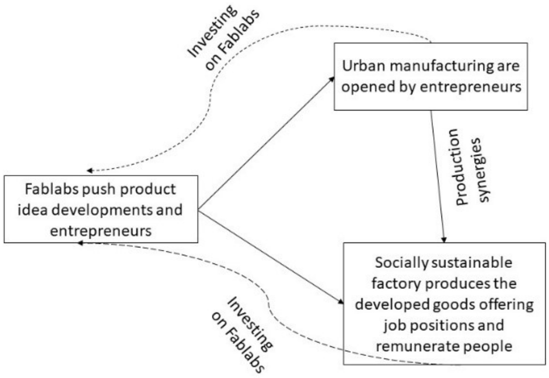

Figure 1 Social Innovation process thanks to Industry 4.0

To conclude, our study shows that I40 as SI provides both quantitative and qualitative benefits. Although quantitative benefits, such as novel job positions, novel business creation thanks to social entrepreneurs or numbers of Fablabs, are easy to capture [31], we propose a set of qualitative outcomes that should enter SI perspectives such as learning process, knowledge sharing and new skills for people.

5.1 Implications for researchers, future research avenues and limitations

In the field of Human Resource Management, I40 requires businesses to train and develop skilled professionals who can work with these new technologies. To do this effectively, managers need to reorient employees' competencies and skills to the new demands of I40. Therefore, employee training as one of the critical success factors of I40 implementation [35] represents a crucial point, and future research may be conducted to better understand the use of different training methods such as simulations and virtual reality.

Monitoring the impact of addressing social challenges represents another interesting research avenue. It is still not clear how to effectively measure the actual effectiveness of the new approach adopted by businesses while engaging in SI.

Finally, in the age of I40, SI can enable firms to forge more robust and long-lasting relationships across value chains. As a result, to establish sustainable and lucrative firms, managers must embrace SI and adopt new methods of thinking. Researchers are invited to investigate the organisational impact of I40 through the lenses of SI.

This study is not free from limitations. The results are a consequence of the keywords' selection process and authors' interpretation; therefore, different keywords could have determined different results. However, we tried to include all the most relevant keywords for the scope of the study and through the application of the backward and forward approaches, we aimed to overcome this limitation. Then, we focus on academic journal papers in English, and thus, we have excluded papers in other languages.

5.2 Implications for practitioners

I40 adoptions as SI have several managerial consequences that may be observed at various organisational levels. Individually, I40 adoptions as SI may be defined as a mentality or attitude that enables employees to think creatively and be more attentive to community and societal issues. Employee engagement, job satisfaction, and overall motivation can all benefit from employees feeling more connected to the purpose and meaning of their work. As employees work together to tackle difficult societal challenges, SI may lead to increased cooperation and cross-functional teamwork. This has ramifications for communication and leadership since managers may need to embrace new ways of team management and motivation to build a new culture around SI.

At the organisational level, these I40 adoptions may substantially influence corporate strategy as corporations continue to emphasise social and environmental consequences alongside financial rewards. This can result in new business models, alliances, and innovation ecosystems that promote social impact. It can also have ramifications for stakeholder management, as corporations need to connect with a larger spectrum of stakeholders to understand and respond to societal concerns.

Overall, the managerial implications of I40 adoptions as SI require a new set of skills, strategies, and mindsets that are grounded in a deep understanding of social and environmental issues. This necessitates a constant commitment to learning which involves the whole organisation [2] and growth, as well as a willingness to experiment and take risks in pursuit of real social impact.

6 Conclusion

This study represents one of the first attempts to provide a SI perspective of I40 by showing which type of I40 implementation qualifies as a SI. The literature around these concepts of SI and I40 has been critically analysed, and a synthesis of the new knowledge on the topic has been provided.

Although various studies show that I40 technologies are used for value maximisation for organisations, we show that these technologies tackle societal issues. We report that the adoption of I40 technologies can be considered SI for developing a socially sustainable factory, urban manufacturing, and FabLabs. The socially sustainable factory leverages an interplay between workers and I40 technologies to produce goods and improve work conditions. Urban manufacturing is smaller and quieter manufacturing based on 3d printing in cities that offer novel opportunities for social entrepreneurs and enable circular economy practices. Finally, FabLabs are spaces where people can use shared tools and technologies to produce goods. They accelerate idea creation encouraging learning and knowledge sharing among people.

Finally, considering the limitations and advantages of our study, we acknowledge the usual limitations that apply to any literature review (such as the extent of coverage in Scopus and Scholar, appropriate keywords, and inclusion/exclusion criteria). Nevertheless, given the novelty of the subject matter, we are confident that our analysis has produced noteworthy findings and aided us in developing a more definitive and organised portrayal of the topic.

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