Computers & Industrial Engineering xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Urban production – A socially sustainable factory concept to overcome shortcomings of qualified workers in smart SMEs

Dominik T. Matt[a,b], Guido Orzes[a], Erwin Rauch[a,*], Patrick Dallasega[a]

[a] Faculty of Science and Technology, Industrial Engineering and Automation (IEA), Free University of Bozen-Bolzano, Piazza Università 5, 39100 Bolzano, Italy
[b] Fraunhofer Italia Research s.c.a.r.l., Innovation Engineering Center (IEC), via A. Volta 13a, Bolzano 39100, Italy

ARTICLE INFO

Keywords:
Urban production
Industry 4.0
Fourth industrial revolution
Small and medium sized enterprise
Smart factory
Socially sustainable production

ABSTRACT

Many of the Industry 4.0 approaches are of a technical nature, and by developing new intelligent technologies and adapting and transferring existing techniques, they will help increase productivity in industry. However, human resources will play a central role also in future factories, thus they are a key factor for implementing Industry 4.0. The role and job profile of employees in the smart factories will change in the future and it will be increasingly challenging for SMEs to compete with large corporations in the fight for skilled workers. In the smart city of tomorrow, production sites will be integrated in the sense of an 'urban production' in a city-friendly way becoming more interesting for talents and qualified work force. Thus, this paper discusses the imminent shortage of skilled workers with a focus on SMEs. The proposed concept of urban production gives an overview of measures to overcome the shortage of qualified workers. The paper aims to show that urban production is a concept to achieve a socially sustainable symbiosis between companies and the city of the future.

1. Introduction

After the mechanisation, electrification and computerisation, the introduction of a combination of advanced technologies and concepts, including cyber-physical systems (CPS), internet of things/services, big data, cloud computing, and additive manufacturing into the factory, announces what we call the 4th industrial revolution or Industry 4.0 (Kang et al., 2016; Oesterreich & Teuteberg, 2016). Thanks to an intelligent connectivity between manufacturing systems, logistics systems and products/services, Industry 4.0 allows for revolutionary new design, manufacturing, operation, and production systems (Brennan et al., 2015; Fawcett & Waller, 2014; Rüßmann et al., 2015). It is viewed as strategic initiative by many advanced countries as it might contribute to re-establish the sustainable competitive advantages of their firms that have been challenged by competition particularly from low-cost emerging economies, resulting in employment and wealth (Spath, Ganschar, Gerlach, Hämmerle, & Schlund, 2013).

Eight priority areas for action were outlined in the final report of the Industry 4.0 working group (Kagermann, Wahlster, & Helbig, 2013), one of the seminal and most cited contributions in the field: (1) to develop a set of common standards and a reference architecture to enable collaboration between companies (*standardisation and reference architecture*); (2) to develop appropriate planning and explanatory models to manage the increasing complexity of products and manufacturing systems (*managing complex systems*); (3) to create a reliable communication network to expand the broadband internet infrastructure (*comprehensive broadband infrastructure*); (4) to ensure that production facilities and products are not dangerous for people or the environment (*safety and security*); (5) to implement a socio-technical approach for work organisation which offers workers the opportunity to enjoy greater responsibility and enhance personal development (*work organisation and design*); (6) to adopt strategies to foster learning, enabling long life learning and workplace-based professional development (*training and continuing professional development*); (7) to adapt existing legislation to take account the new innovations (*regulatory framework*) and (8) to calculate the trade-offs between the additional resources needed and the potential savings generated in smart factories (*resource productivity and efficiency*).

Against the above mentioned priorities, most of previous Industry 4.0 studies deal with technological or infrastructural aspects, while surprisingly few of them focus on human resources and organisational aspects (priorities (2), (4), (5), (6)), legal aspects (priority (7)), or economic impacts (priority (8)) (see Section 2).

According to a study by the German Chamber of Industry and Commerce (DIHK, 2010), more than half of the executives surveyed see a future deficit of skilled employees. Today, many positions for skilled jobs remain already uncovered (Ras, Wild, Stahl, & Baudet, 2017).

* Corresponding author.
E-mail address: erwin.rauch@unibz.it (E. Rauch).

https://doi.org/10.1016/j.cie.2018.08.035

Moreover, considering the UK alone, currently one of four positions remain unfilled due to skills shortage (UKCESS, 2016).

In the Industry 4.0 era the role of the workforce will change from being production-centric to knowledge and data-driven (Ras et al., 2017). The share of operator's physical work will continue to fall and reach a minimum in future production systems. According to the Organisation for Economic Co-operation and Development (OECD) at least 9% of all jobs could be automated already today (Arntz, Gregory, & Zierahn, 2016). On the other hand, the share of dispositive work in terms of coordination and or organisation of production resources will still increases. Considering the skills type, a combination of deep professional skills (e.g. operating and maintaining machinery) with broad horizontal ones (e.g. time management, critical thinking or team leadership) is needed (UKCESS, 2016; World Economic Forum, 2016). According to Ras et al. (2017), tasks in the Industry 4.0 context will become more interdisciplinary, *"combining for example elements of mechatronics with data analytics and business administration*". Besides the Industry 4.0 related competences like the configuration of cyber physical systems, maintenance of sensor networks and knowledge about internet of things, other competences like creativity, social intelligence, innovation competence and complex problem solving will become even more important (Letmathe and Schinner, 2017).

One possible solution to address the skills shortage problem of SMEs is internal training. At the same time, it is however important to use the available potential in all areas of the labour market. This concerns, on the one hand, the employment of parents and thus the creation of the conditions for a better compromise of family and work. Another potential labour force is the reduction of the employment hurdles of older workers. A further point of the study deals with the targeted management of the immigration of qualified workers from abroad. On the political front, a reform of the education system is also needed in order to increase the proportion of the more highly qualified workers in form of specialists, not only at the level of academics, but also in the average level of qualification (DIHK, 2010). With a more targeted training, SMEs can increase their productivity by up to 30%. Machines take over standard tasks and employees undertake more complex multitasking activities (Schönauer, 2014). In addition to the use and internal qualification of the own workforce especially the struggle for new talents is becoming more and more important. An attractive and value-oriented employer image, strategic personnel marketing, school and university marketing, as well as the targeted recruitment of specialists play an important role (McKinsey, 2011). In the future, it will be particularly challenging for SMEs – which accounted in 2016 for slightly less than three fifths of European value added (European Commission, 2016) – to find and retain qualified employees. In small enterprises (with less than 50 employees) in average 23% of the advertised job positions remain vacant (Dietz et al., 2013). Considering medium sized enterprises (from 50 until 249 employees), this value is around 11% and in big companies (more than 250 employees) this value consists of around 2% (ibid.). Usually, SMEs are for jobseekers not the first choice. Especially, recent graduates favour big companies instead of SMEs to upgrade the own curriculum vitae. In addition, due to the fact that large companies perform professional human resources marketing, in future a high amount of available employees will be lured away from schools and universities. As a result, the competition between SMEs for the remaining young talents will increase drastically (Schütt, 2011). To compete for qualified employees SMEs are disadvantaged in comparison to large companies: usually, SMEs have fewer employees available for human resources policy and are less-known at an interregional level. Moreover, SMEs have been searching less frequent employees and therefore they lack of experience in successful recruiting strategies of staff members (BMWi, 2014).

Furthermore, the future urbanisation will lead to a growth of urban structures and at the same time to a concentration of potential consumers of goods as well as of potential workers (Niesing, 2012; United Nations, 2014). The problem of shortage of skilled workers will therefore be enhanced by the different location of workers and companies, posing significant challenges in terms of environmental and social sustainability. Let us think for example to the CO_2 generated in home-work commuting as well as to the time wasted during the aforementioned trips.

There are two basic research questions to be answered. The first is the impact of Industry 4.0 (and the related technologies) on the labour market. This task will be cleared by an accurate review of the literature on the topic. The second research question is about future measures and forms of socially sustainable factories to overcome the shortage of qualified workers in smart SMEs. To answer this research question, the known concept of Urban Production is analysed in detail in order to identify a set of measures for SMEs to achieve a higher attractiveness for qualified workers. The focus of this research lies on three main categories of people: (1) young talents, (2) mid agers and (3) best agers.

2. Background

2.1. Industry 4.0 and its impact on the labour market

The fourth industrial revolution or Industry 4.0 refers to the increasing digitisation and automation of the manufacturing environment as well as the creation of a digital value chain to enable the communication between products and their environment and business partners (Oesterreich and Teuteberg, 2016). As Liao, Deschamps, Loures, and Ramos (2017) point out in their systematic review on Industry 4.0, most papers focus on technological or infrastructural aspects, proposing for instance architectures for cyber physical manufacturing systems (e.g., Lee, Bagheri, & Kao, 2015; Yue, Cai, Yan, Zou, & Zhou, 2015), developing planning models (e.g., Zhan et al., 2015; Ivanov, Dolgui, Sokolov, Werner, & Ivanova, 2016), discussing the machine-machine and human-machine interactions (e.g., Weyrich, Schmidt, & Ebert, 2014), or proposing architectures for internet of things (e.g., Yao, Lian, Yang, Zhang, & Jin, 2014; Savazzi, Rampa, & Spagnolini, 2014). This is supported by the fact that the majority of the papers are published in mechanical, electronics, and computer sciences journals. A significant debate has however started to emerge in the last few years: how Industry 4.0 (and the related technologies) will affect the labour market and, more specifically, the skills and jobs required. We frame and summarise this debate below.

A *first cluster of studies* have focused on the overall impact of digitisation and automation on the job demand at different levels (such as low skill, medium skill and high skill jobs). Authors have analysed the easiness/difficulty to computerise/automate different tasks and consequently different jobs (Autor, Levy, & Murnane, 2003; Blien & Dauth, 2016). *Routine tasks* (i.e., fully codified and usually performed by medium-skilled workers) have been argued to be easy to computerise/automate (Gregory et al., 2016); *abstract tasks* (i.e., requiring problem-solving capabilities, intuition, creativity, and persuasion and usually performed by highly educated workers) and *manual tasks* (i.e., requiring situational adaptability, visual and language recognition, and in-person interactions and usually performed by low-skilled workers) have instead been shown to be rather difficult to computerise/automate (Autor et al., 2003). Based on such analysis, Goos and Manning (2007) highlighted a significant increase in the number of high-skills (high-paid) jobs and a probable increase in the number of low-paid service jobs due to automation/computerisation, both at the expense of middle-skills jobs, and labelled this phenomenon "job polarisation". This polarisation has been empirically supported by several studies on a wide set of countries (e.g., Autor & Dorn 2013; Michaels, Natraj, & Van Reenen, 2014; Goos, Manning, & Salomons, 2014). Considering that our paper is focused on the manufacturing industry, the main effect of automation/computerisation is the increase in demand for high-skills (high-paid) jobs (the raise in low-paid jobs in the service industry could be disregarded). Such effect is supported by more studies (Akerman, Gaarder, & Mogstad, 2015; Berger & Frey, 2016; Blien & Dauth, 2016; Hirsch-

Kreinsen, 2016). Berger and Frey (2016) documented for instance the raise of jobs with a high content of abstract skills through an analysis of new job titles reported in the Dictionary of Occupational Titles (DOTs) and in the Alphabetical Index of Occupations. Akerman et al. (2015) show that the broadband internet technology increase both productivity and demand of skilled workers (since it complements them in executing non-routine abstract tasks) and decrease the demand of unskilled workers (since it substitutes such workers in performing routine tasks). Finally, Blien and Dauth (2016) analyse the labour market in Germany and find that demand for high skill employees grows, demand for medium skill employees shrinks, and demand for low skill employees is constant.

Other authors are instead more sceptical on overall/net effect of automation/computerisation on the number of job places. Frey and Osborne (2017) estimate for instance the probability of computerisation for 702 detailed occupations and forecast that 47% of total US employment is at high risk. Similarly, Berger and Frey (2016) foresee a productivity increase in the future due to automation and called for appropriate policy responses to widely share its benefits and do not determine a decrease in the employment rate.

A *second cluster of studies* have instead shed light on how the workers/employees role has changed (and will change) and how the required specific skills/competences have changed (will change) accordingly. Romero, Bernus, Noran, Stahre, and Fast-Berglund (2016) present different evolution stages of the operator throughout the first until the fourth industrial revolution. In Operator 1.0, the human performs manual work and is supported by manually operated machine tools (1700–1960). The Operator 2.0 generation is supported by CAx tools, NC operating systems and enterprise information systems (1960–1970). The Operator 3.0 generation performs cooperative work with robots, machines and computer tools, which is also referred to as human-robot collaboration (1970–2000). Ultimately, the Operator 4.0 generation is characterised by operating in a human-automation symbiosis for enhancing workforce capabilities. In Romero, Noran, Stahre, Bernus, and Fast-Berglund (2015) the authors present three scenarios depicting how adaptive automation can help to achieve human-automation-symbiosis. (1) Senior Operators (Aging Challenge) – here, assistance systems could support the operator in the field of physical as well as cognitive tasks. Considering the latter one, cognitive aid systems could also be used to transfer knowledge from experienced workers to younger ones. (2) Operator with a Disability (Inclusiveness Challenge) – physical and cognitive aid systems could support operators with disabilities to compensate subjective hindrances. (3) Apprentice Operator (Inclusiveness Challenge) – in this case cognitive aid systems could support the worker in improving his learning curve that the operator is able to learn operations faster and perform them with fewer errors. Lorentz et al. (2015) highlight how Industry 4.0 will modify the job profiles and the skills required by companies. They show the changes to the job profile of the automotive assembly line worker, of the mobile service technician, and of the machine operator and they shed light to some “new” jobs that will arise, i.e., the industrial data scientist and the robot coordinator. They also argue that the following skills will be increasingly important in the Industry 4.0 context: techniques for working with robots, basic IT competences (using spreadsheets and accessing interfaces), advance IT competences (programming and analytics), as well as soft skills (openness to change, flexibility to adapt to new environments and roles, problem solving). Spath et al. (2013) explain the change in the role of workers in the production of the future as follows: “In the production work of the future people are more the conductors and coordinators of the factory. The hard muscle work and also a part of the cognitive work take over the machines”. Smith and Anderson (2014) collect a set of experts’ opinions on the future advances in robotics and artificial intelligence and their impact on jobs and employment, highlighting several changes that may occur, among which the reduction of repetitive tasks and consequently of the working hours. The “simple” employee at the machine will not only have to fulfil operational production tasks but have also to assume more complex tasks requiring new skills. Already in the context of the introduction of holistic production systems according to the Lean Toyota principle, the work spectrum of the employees has changed considerably in production. They have in fact been increasingly involved in decision-making and tasks scheduling, for material control or for quality assurance. Smith and Anderson (2014) also alert us that the current educational systems are not adequately preparing students for the work of the future.

In sum, the worker profile of the future will be much more complex, since the employee must increasingly do also knowledge work changing via mobile terminals programs on machines and controlling the machines in real-time with the help of new software systems. Whereas in the past the employee used and controlled the machine (role of machine operator), in the future the machine itself – at least partly – will obtain cognitive abilities. Consequently, in the factory of the future the workers/employees need a higher qualification than today. Thus, many companies, and especially SMEs, will face the challenge to find highly skilled and qualified staff.

2.2. Socially sustainable factories and workplaces

European research activities, like the “SO SMART” project, have investigated how a successful integration of social sustainability aspects into the European manufacturing industry should be pursued to reach a balance between the needs and capabilities of individual workers, the industry and the society as a whole (Berlin et al., 2016). Based on a survey on 971 employees from 15 European countries, four dimensions of social sustainability corporate culture have been identified: (1) sustainability strategy and leadership; (2) mission, communication and learning; (3) social care and work life; and (4) loyalty and identification (Berlin et al., 2016). Moreover, according to the project “SO SMART” more than 40% of a company’s success can be explained by the impacts of the four previously mentioned dimensions of social sustainability (Berlin et al., 2016). Results of the previously mentioned project confirmed that, in socially sustainable factories of the future, improving the well-being and performance of operators can be achieved without negatively affecting the performance and success of a company (Berlin et al., 2016). Although unemployment is a big concern in Europe, manufacturing companies have difficulties in finding appropriate workforces and fill vacant jobs (Eurostat Statistics, 2017; World Economic Forum, 2014). As such, attracting skilled workers is becoming one of the main priorities of European (and US) manufacturing companies (Accenture, 2014; World Economic Forum, 2014). Moreover, the main objectives of the strategic multi-annual research roadmap elaborated by the European Factory of the Future Research Association is the creation of socially sustainable, safe and appealing workplaces (EFFRA, 2012).

To increase manufacturing performances in terms of flexibility, agility and competitiveness, work demands have to be adapted to the physical and cognitive capabilities of workers especially for older and disabled operators (EFFRA, 2012). Here, Human-Centric manufacturing Workplaces (HCMW) play an important role because they leverage the full potential and experience of each individual operator (Fantini, Pinzone, Taisch, & Altesa, 2016). The main objective of HCMWs is to take in consideration the needs of employees to balance collaboration, privacy and work objectives (Lee and Brand, 2005). More in detail, in the design of HCMWs, inter-individual differences (e.g. anthropometrics, gender) and intra-individual characteristics (psychological and physiological) are taken in consideration instead of just referring to static data of a population of employees (Parsons, 2000). Fantini et al. (2016) present an application case of a HCMW taken from the train manufacturing industry where equipment needed for performing the vertical wiring mock-up is adjustable according to the morphologic characteristics of each individual worker allowing to improve ergonomic aspects.

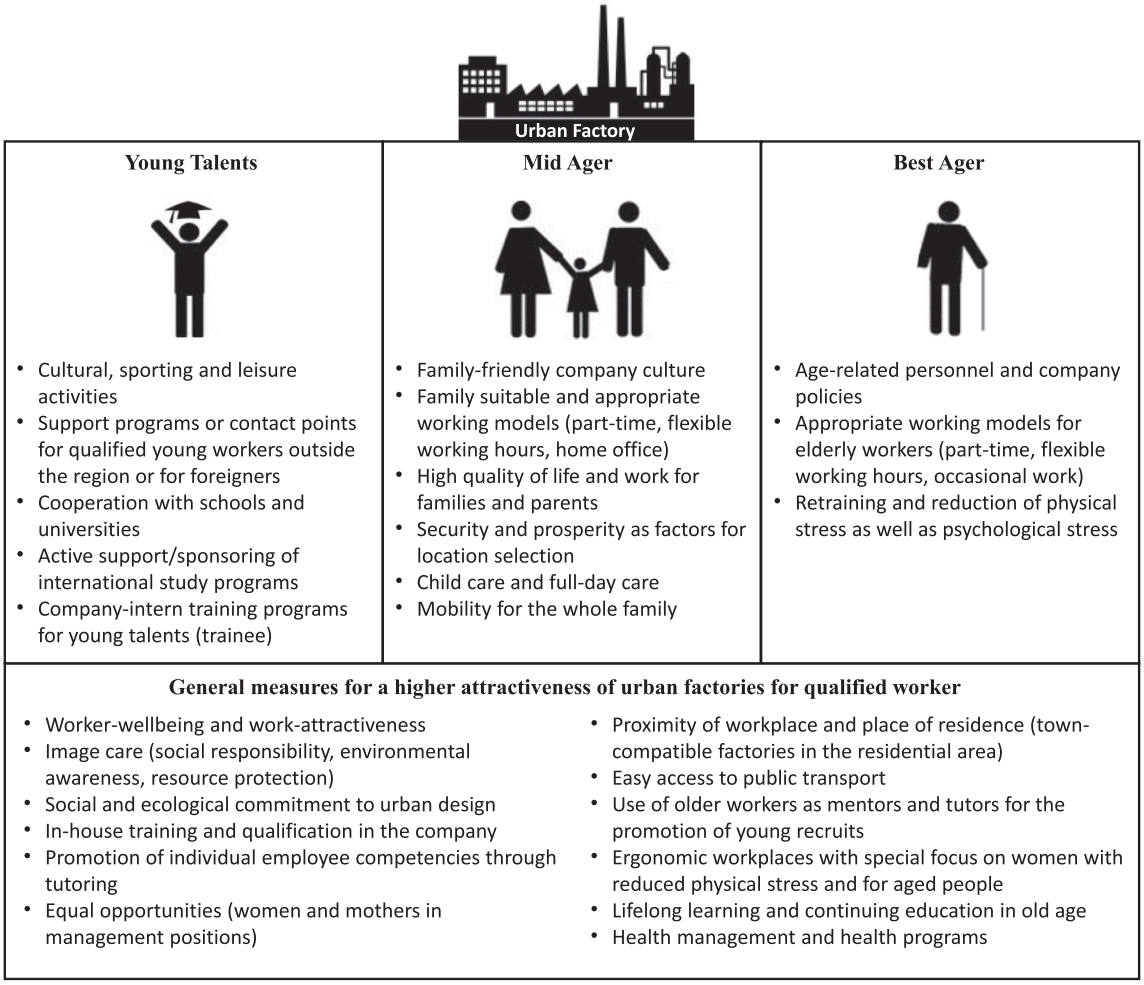

Fig. 1. Measures for a higher attractiveness of urban factories for qualified worker.

The fourth industrial revolution will allow new forms of interaction between humans, machines and software systems named as the industrial Internet of Things, Services and People (IoTSP). Here, by interconnecting humans, things and services via the Internet, data analysis will be improved, operations will be optimised, productivity and flexibility will be increased, reliability will be enhanced and as a result costs will be reduced in social and smart factory environments (Romero, Wuest, Stahre, & Gorecky, 2017). According to Kassner et al. (2017), in a social sustainable factory, operators, machines and software systems are interconnected and the data created within this network is actively used, resulting in a smart production environment. As such, in a social factory, information is provided at the right time and place to the right person, machine and/or software (Kassner et al. 2017). Moreover, operators are supported under any working conditions and humans are engaged to contribute actively to new knowledge creation (Kassner et al., 2017). Romero et al. (2017) present a high-level Social Factory Architecture (SFA) which is based on an adaptive, collaborative and intelligent multi-agent system that interconnects and allows interoperability among multiple agents fostering collaboration and leveraging expertise and capabilities usually spread across an enterprise. In future factories, employees will be involved in job design and task balancing processes by considering social aspects in terms of skills, experience and worker's features (May et al., 2014). In May et al. (2014), researchers present a worker-centric job allocator tool in which human factors like abilities, preferences, restrictions and needs are considered in job allocation. Traditionally, algorithms for job allocation are used in a static way, which means that the worker's evolution is not taken into account. However, in a human-centric factory the evolution/improvement of worker's skills (thanks to experience and training) is considered in production planning (May et al., 2014).

3. Socially sustainable urban factories and measures for talent attractiveness

3.1. The city of tomorrow and the concept of urban production

The Fraunhofer Gesellschaft has studied the concept of the city of tomorrow (*'Morgenstadt'*) and argued that it should be adapted to the climate change and consider the vision for the realisation of a CO_2-neutral, energy-efficient and climate-adjusted city of the future. The "city of the future" faces numerous challenges in order to achieve the status of a sustainable, and future-oriented city (Fraunhofer, 2012). Seven fields of research have been defined for the realisation of the *'Morgenstadt'*: (1) Energy; (2) Building; (3) Information and Communication; (4) Mobility and Traffic; (5) Urban Processes and Organisation; (6) Security and Protection; and (7) Production and Logistics (7) (Fraunhofer, 2012). The research field "Production and Logistics" should provide innovative processes in the transport and handling of goods, in retail, services and production, as well as the supply of food and other goods for the residents (Matt, Spath, Braun, Schlund, & Krause, 2013).

The future economic, ecological and social development of the cities leads to a reorientation and redesign of production in the form of urban production sites. In the *'Morgenstadt'* production sites will be integrated in the sense of an "urban production" in a city-friendly manner. Production is returning to the city and has to make the production sites

Table 1
Set of measures for a socially sustainable urban factory attracting qualified workers.

No	Measures	Young Talents	Mid Ager	Best Ager	Literature References
1	Offer of cultural, sporting and leisure activities (cinema, theatre, bars, pubs, fitness center)	✓			Florida (2014) and Baker (2016)
2	Support programs or contact points for qualified young workers outside the region or for foreigners	✓			Beckers and Boschman (2013) and Docquier and Machado (2016)
3	Cooperation with schools, and universities	✓			Mellander and Florida (2006), Schiller and Revilla Diez (2012) and Reiner et al. (2017)
4	Active support/sponsoring of international study programs through study projects, internships or fellowships	✓			Altbach and Teichler (2001) and Betz et al. (2016)
5	Company-intern training programs for young talents (trainee)	✓			Thom and Nesemann (2011) and Kwon and Thom (2017)
6	Family-friendly company culture		✓		Stoynova and Gourova (2017)
7	Family suitable and appropriate working models (part-time, flexible working hours, home office)		✓		Merisalo et al. (2013) and Stoynova and Gourova (2017)
8	High quality of life and work for families and parents		✓		Niedomysl and Hansen (2010), Martin-Brelot et al. (2010) and Bontje et al. (2017)
9	Security and prosperity as factors for location selection		✓		Marans (2003), Kloosterman and Trip (2011) and Arntz et al. (2014). Esmaeilpoorarabi et al. (2016)
10	Child care and full-day care		✓		McNulty and Hutchings (2016) and Verhoef et al. (2016)
11	Mobility for the whole family		✓		Gardner (2016); Patton and Doherty (2017)
12	Age-related personnel and company policies			✓	Grima (2011) and Fabisiak and Prokurat (2012)
13	Appropriate working models for elderly workers (part-time, flexible working hours, occasional work)			✓	McNair et al. (2004) and Fuertes et al. (2013)
14	Retraining and reduction of physical stress as well as psychological stress			✓	Ilmarinen (2006), Grima (2011) and Kraiger (2017)
15	Worker well-being and work attractiveness	✓	✓	✓	ElMaraghy (2005), Fantini et al. (2018), Radziwon et al., (2014) and Ras et al. (2017)
16	Image care (social responsibility, environmental awareness, resource protection)	✓	✓	✓	Tai and Chuang (2014) and Bhattacharya et al. (2008)
17	Social and ecological commitment to urban design	✓	✓	✓	Erbstößer (2016) and Esmaeilpoorarabi, et al. (2016)
18	In-house training and qualification in the company	✓	✓	✓	Cappelli (2008) and Koc-Menard (2009)
19	Promotion of individual employee competencies through tutoring	✓	✓	✓	Stoynova and Gourova (2017)
20	Equal opportunities (women and mothers in management positions)	✓	✓	✓	Kinnunen et al. (2005) and Lewis (2006)
21	Proximity of workplace and place of residence (town-compatible factories in the residential area)	✓	✓	✓	Eriksson et al. (2008) and Boussauw et al. (2012)
22	Easy access to public transport	✓	✓	✓	Florida (2014), Baker (2016) and Bontje et al. (2017)
23	Use of older workers as mentors and tutors for the promotion of young recruits	✓		✓	Griffiths (2007) and Stevens-Roseman (2009)
24	Ergonomic workplaces with special focus on women with reduced physical stress and for aged people		✓	✓	Johnston et al. (2008) and Perry (2010)
25	Lifelong learning and continuing education in old age		✓	✓	Betz et al. (2016)
26	Health management and health programs		✓	✓	McDermott et al. (2010)

suitable for the city. At the same time, production and resource-conserving production processes and production technologies are used in urban production to minimise pollution and noise emissions for residents. Urban production will be based on a symbiosis between companies and urban populations.

The inhabitants of the *'Morgenstadt'* should be able to combine their individual way of life with their work, since the environmentally friendly production sites are located in the immediate vicinity of residential areas and are therefore easily accessible on foot or by bicycle. The decentralised distribution of production sites within the city ensures the supply of raw materials and energy to the production sites via intelligent logistics and energy cycles. Within the framework of urban production, the following five assumptions about the sustainable design of urban production are presented by Fraunhofer (2012) and Matt et al. (2013):

- *Integration of market and customer:* Local proximity to the market allows new forms of customer-integrated product development. For a variety of products, new individual solutions can be developed by being close to potential customers. Through adaptable factory structures and processes, small batches can also be produced for the fluctuating demand of the market.
- *24/7 production of new ideas:* Urban production leads to the formation of numerous decentralised "Micro Fabs" (laboratories with additive manufacturing technologies), which are connected with one another and offer the possibility to produce individual products in the shortest possible time. Thanks to these new advanced additive manufacturing technologies, products can be manufactured in a 24/7 principle. This also requires a faster transfer of product development concepts into production parameters.
- *Flexible working hours - a stable future:* The local availability of qualified workers enables a very flexible response to constantly changing environmental conditions. Idle time can be reduced and added value can be increased. However, this requires a high degree of flexibility from the employees. In this context, flexible employment is no longer viewed as a negative point, but as an opportunity for higher employment security.
- *I work where I live:* The immediate proximity to the employee's living environment makes patchwork relationships possible, which allow employees to work in several companies at the same time. As a result, rigid working hours and fixed jobs will increasingly be replaced by flexible models. New technologies and methods allow workers to decide when and where they work in urban production. Information is distributed decentralised and via mobile devices, thus gaining time. This time can be used by employees for other interests such as voluntary work, childcare or leisure. Through the cooperative networking in work planning, a productive combination of work and life in the urban environment becomes possible.
- *Age-appropriate work in the city of tomorrow:* The proximity to the employer as well as to all the facilities of the private environment makes it possible to work in an age-appropriate manner. Shorter paths between the home and the workplace as well as a well-functioning public transport network allow short-time work, part-time work and occasional work. Older employees can freely allocate their working hours and cover certain hours in the company, which can be used for young workers and families to manage work and leisure time, or work and family life. These circumstances allow older workers to bring their skills and knowledge into the company.

The concept of urban production bears in our view a big potential to solve the problem of a medium- and long-term deficiency of skilled labour force, in particular of SMEs. Attractive production facilities localised in urban areas will in fact have a competitive advantage to gather highly skilled labour forces. The city of the future will provide a creative medium for innovative ideas, inventions and new business models. The prerequisite for future growth of the industry is the availability of skilled employees, industry-related services as well as the proximity to research institutions. These requirements will be provided in urban areas (Stiftung neue Verantwortung, 2012).

By providing short routes to workplaces, SMEs will hold better cards for the recruiting of highly qualified employees. Working in urban areas will not only be attractive for young engineers but also the offer of highly qualified part-time workers is in the proximity of metropolitan areas considerably greater. Furthermore, urban production will facilitate the integration of older population who are still able to work. Therefore, measures for young, mid, and ager talent attractiveness in urban factories will be discussed in the next paragraphs.

3.2. Measures for young talent attractiveness in urban factories

The concept of urban production is especially attractive for young talents with a university education or qualified apprenticeships, due to a high density of higher education in cities. Especially SMEs, which are located in peripheral regions have great difficulties to recruit young employees whose centre of life is in the city. Usually they do not want to perform long distances to reach their workplace. As a result, locating factories in municipal areas will increase drastically the offer of highly qualified labour forces to SMEs. However, what makes SMEs attractive for young employees? In the following we propose and explain some hypotheses. Measures for being attractive for young people could be an active promotion of recreational activities and facilities by a strength collaboration with entities offering cultural programs as well as entertainment possibilities (e.g., fitness centres, bars, pubs, cinemas, theatres) (Baker, 2016; Florida, 2014). Today, the living space "city" is currently going through a renaissance and it attracts not only domestic talents but also young qualified persons from abroad. Thus, the urban factory of tomorrow will collaborate actively with public entities to establish contact points and funding programs to attract highly qualified employees from foreign countries (Beckers & Boschman, 2013; Docquier & Machado, 2016). More in detail, the urban factory of tomorrow will engage actively in the collaboration with university and schools (Mellander & Florida, 2006; Reiner, Meyer, & Sardadvar, 2017; Schiller & Revilla Diez, 2012) as well as the establishment of international study programs to attract future potential employees through internships, study projects or sponsored fellowships (Altbach & Teichler, 2001; Betz, Partridge, & Fallah, 2016). Although, production in urban areas will be not only favourable for getting young talents from abroad, but it will also support in-house training programs to encourage young employees in increasing their qualification (Kwon & Thom, 2017; Thom & Nesemann, 2011).

3.3. Better compatibility of family and work for mid agers in urban factories

Not only young talents represent a potential to increase the supply of skilled workers. Skilled employees settle down in attractive locations and start a family (Stiftung neue Verantwortung, 2012). In many cases, the father, mother or single-parents are highly qualified but due to family/work conflicts they are dropped out from the professional life. Here, especially the politics should establish family suitable and appropriate working models (Merisalo, Makkonen, & Inkinen, 2013; Stoynova & Gourova, 2017). However, this bears also high potential to increase the attractiveness of SMEs in establishing family-friendly urban factories. Especially, SMEs should focus on building up a family-friendly business culture by breaking up old thinking patterns and considering families and especially mothers as important social entities (Stoynova and Gourova, 2017). As a practical example, equal opportunities for men and women where leadership positions could also be covered by working mothers could be mentioned (Kinnunen, Mauno, Geurts, & Dikkers, 2005; Lewis, 2006). In the view of a family-friendly company culture (Bontje, Musterd, & Sleutjes, 2017; Martin-Brelot, Grossetti, Eckert, Gritsai, & Kovacs, 2010; Niedomysl & Hansen, 2010), the location of the factory as well as its environment play an important

role. Families chose their residence according to two important aspects: security and economic welfare (Arntz, Gregory, & Lehmer, 2014; Esmaeilpoorarabi, Yigitcanlar, & Guaralda, 2016; Kloosterman & Trip, 2011; Marans, 2003). Is the factory located in urban areas with a certain wealth and a low crime rate this increases the probability of the company to gather highly educated employees from local families. This means that family-friendly working time models, in terms of part-time, home-office or teleworking have to be implemented as important prerequisites to hire highly qualified parents being able to combine work and family in a successful way (Merisalo et al., 2013; Stoynova & Gourova, 2017). Modern factories of the future should be town compatible, located in the near of residential areas and should have a good connection/accessibility to public transport (Baker, 2016; Bontje et al., 2017; Florida, 2014). If this is not the case, companies can support or promote the mobility of families and professionals by additional concepts (Gardner, 2016; Patton & Doherty, 2017). An important aspect which has to be considered in the strategy to promote the work/family balance is to provide children's crèche and all-day schools near to the factory (McNulty & Hutchings, 2016; Verhoef, Roeters, & van der Lippe, 2016).

3.4. Age management – potential of qualified best agers in urban factories

Beyond the recruiting of young talents and working parents, the labour group of elderly persons bears a high potential/opportunity for companies looking for skilled employees. Such working groups possess a vast experience as well as extensive expertise. Today, many companies shy away from employing elderly workforces, nonetheless they are usually characterised by a high loyalty and diligence in day-to-day work. By means of appropriate measures of the so-called “Age Management”, SMEs located in the near of urban areas are able to make good use of this unseen potential.

Companies are attractive for elderly people if the staff culture and company policy is able to satisfy their specific requirements as well as if potential for conflict between old and young is discussed transparently and solved in collaboration (Fabisiak & Prokurat, 2012; Grima, 2011). In the context of “Age Management” new models for part-time retirement, short-time work, flexible and occasional work should be developed (Fuertes, Egdell, & McQuaid, 2013; McNair, Flynn, Owen, Humphreys, & Woodfield, 2004). As a result, older employees could bring into the company expertise as well as support younger colleges in their professional development. However, because of the age-related performance reduction future workplaces should consider the specific requirements of a constantly ageing society. This encompasses the ergonomic design of the workplace as well as the age appropriate lighting or the reduction of great physical effort (Grima, 2011; Ilmarinen, 2006). In addition to the workplace design, an appropriate job design will play an important role in the future. As practical example, frequent breaks with the aim to reduce the level of stress at work can be mentioned (Grima, 2011; Ilmarinen, 2006). A further aspect concerns the alignment of the occupational health management of a company to support the wellbeing of elderly employees (McDermott, Kazi, Munir, & Haslam, 2010). Furthermore, occupational re-training as well as specific educational programs will enable elderly workers to acquire appropriate skills to perform stress reduced activities (Kraiger, 2017). As practical examples, advanced training courses for computer or modern software systems can be mentioned.

3.5. General measures for a higher attractiveness of urban factories for qualified workers

SMEs should use the opportunity to design and organize the work in the factory itself in such a way, that it would attract skilled workers, or would make the workers more skilled in the factory. Worker well-being and work attractiveness could be increased, in the context of Industry 4.0 or in the work place in various ways, such as by adaptive production processes (Radziwon, Bilberg, Bogers, & Madsen, 2014), user modeling (ElMaraghy, 2005), adaptation of job profiles and work-life-balance (Ras et al., 2017) and by placing the operator in the center (Fantini, Pinzone, & Taisch, 2018). Due to an increasing awareness of sustainability more and more employees show a sensible relationship to the strategy and behaviour of a company. Based on the ongoing climate change, employees relate to the strategy of a company, if the latter one engages respectful with the environment and uses resources carefully (Bhattacharya, Sen, & Korschun, 2008; Tai & Chuang, 2014). As a result, the image branding of SMEs becomes increasingly important. As a practical example, the aim of a CO_2-neutral factory should persist not only within documents but it should be actively implemented by the company. However, these actions should not only be followed inside a single SME but at an intercompany level. As a practical example, an active contribution of different companies in the urban design leads to a positive image and at the same time it increases the attractiveness as successful employers of tomorrow (Erbstößer, 2016; Esmaeilpoorarabi et al., 2016). In addition a culture of equal opportunities for women and mothers, especially in management positions, is important to attract also higher qualified female workers (Kinnunen et al., 2005; Lewis, 2006). Further tutor programs should be developed to promote individual employee competencies (Stoynova and Gourova, 2017) or to identify need for internal training and qualification programs (Cappelli, 2008; Koc-Menard, 2009). In such cases, particularly older and experienced tutors should be engaged to transfer their knowledge and experience to younger colleagues (Griffiths, 2007; Stevens-Roseman, 2009). For mid ager as well as for best ager lifelong learning becomes important to remain up to date regarding technologies and new or innovative methods. Therefore continuous education is important for a high qualification of workers (Betz et al., 2016). For both people groups also health management programs become more and more important (McDermott et al., 2010). Especially, those SMEs will most benefit which implement ergonomic working places. By using automation as well as ergonomic sciences the physical load on workplaces can be drastically reduced to reach a comfortable working environment especially for female or older employees (Johnston, Souvlis, Jimmieson, & Jull, 2008; Perry, 2010). This can be realised by using appropriate manipulators as well as lifting aids specifically conceived for the requirements of female or elderly workers. In general the proximity of workplace and place of residence (Boussauw, Neutens, & Witlox, 2012; Eriksson, Friman, & Gärling, 2008) as well as an easy access to public transport are important factors for employees (Baker, 2016; Bontje et al., 2017; Florida, 2014).

In Fig. 1 the proposed measures for a higher attractiveness of urban factories for qualified workers are summarised.

4. Discussion and future research directions

This conceptual paper has sought to address the shortcoming of skilled workers in particular for SMEs, that will occur in the near future due to technological and demographic trends such as Industry 4.0 (e.g., Oesterreich & Teuteberg, 2016; Hirsch-Kreinsen, 2016), the increasing average age of the population (Boston Consulting Group, 2014), and the urbanisation (United Nations, 2014). These trends have been analysed in detail coming to the conclusion, that Industry 4.0 needs more qualified workers. Thus, the trend towards urbanisation and the concept of urban production seem to be interesting opportunities for SMEs to recruit qualified staff.

According to the second research question we have discussed more in detail the concept of urban production and proposed some measures for young, mid, and ager talent attractiveness in urban factories as well as some further general/common measures. This opens up significant future research directions (RD), which will be discussed below.

Despite the few significant attempts to highlight the new role of the worker in the context of Industry 4.0 (Hirsch-Kreinsen, 2016; Romero et al., 2015, 2016), further research is needed to better highlight the

changes to the organisational structures (e.g., division of labour, responsibilities, reporting lines) and business processes (e.g., logistics, information processing, accounting, auditing) required for the implementation of Industry 4.0 and the consequent different needs in term of technical and soft skills of employees (e.g., leadership, critical thinking, project management) and qualification. This might in turn also suggest some adaptation in study programs at high schools and university levels. We therefore propose the following research direction:

RD1: To identify through conceptual as well as empirical analyses the changes to the organisational structures and business processes required for the implementation of Industry 4.0 and the consequent different needs in term of employee's skills and qualification.

Various attempts have been made to forecast the labour market developments, considering future labour demand and supply. In light of other demographic and technological trends, such as the aforementioned Industry 4.0 and the increasing urbanisation, a prominent need however exists to refine these analyses at more specific/detailed levels from a geographical point of view as well as from a skills/qualifications point of view. Such analyses could for instance shed light on the shortcomings of workers/employees in specific areas (such as industrial parks located far from cities) and perhaps an over availability in other areas (such as megacities). They might also highlight that employees with some skills/qualifications will be easy to find while other will be much more difficult to recruit. We therefore propose the following research direction:

RD2: To determine the labour demand and offer of Industry 4.0 workers in different geographical areas.

We showed in our paper that people – in particular young people – prefer to live in cities and argued that urban production might therefore significantly contribute to solve the problem of the shortage of skilled workers, which is much more critical for SMEs. This needs however to be further verified through empirical analyses, such as survey focused on the housing/living preferences of people, as well as through scenario analyses about their housing distribution.

RD3: To empirically verify and quantify the impact of urban production on the availability of skilled workers.

The "city of tomorrow" has appeared to be potentially able to significantly contribute towards the achievement of the sustainability goals (economic, environmental, and social). This concept – as well as the related concept of urban production – deserves however further research from a technological (e.g., pollution-free production systems, small footprint production systems), a logistics (e.g., transportation of material, components, and products in the urban area), an organisational (e.g., flexible working hours, staff exchange between different companies and production units), and a business ecosystems (e.g., ties/relationships with schools, university and research centres, connections with the local community) point of view. Further empirical studies are needed to better estimate the impact of the 'factory of the future' and the urban production on economic (e.g., lower transportation costs for home-work commuting, lower travelling time wasted), environmental (e.g., lower carbon emission), and social (e.g., more time for family care) sustainability goals. The different (sometimes conflicting) interests of all the different stakeholders – such as the employees, the companies' shareholders, the managers, the government and local institutions, and the community – would need to be considered in such analysis, perhaps leading to controversial conclusions. We therefore propose the following research direction:

RD4: To better define the 'factory of the future' and the urban production concepts and shed empirical light on their impact on the achievement of sustainability goals (economic, environmental, and social), considering all the different stakeholders.

Finally, we have proposed in this study a set of measures for young, mid, and ager talent attractiveness in urban factories as well as some further general/common measures. Table 1 summarises these measures highlighting employee/people groups (young, mid, and/or ager) that are affected and providing some supporting references.

The future needs/preferences of young, mid, and/or ager employee/people deserve to be further investigated, also to empirically estimate the importance of the measures proposed in our study. This could provide significant guidelines to smart companies, in particular SMEs, to attract and retain the needed talents, this way fostering growth and competitiveness. We therefore propose the following research direction:

RD5: To empirically highlight the future needs/preferences of young, mid, and/or ager employee/people and highlight the importance of the different measures for talent attractiveness in urban factories (see Table 1) for the aforementioned three groups of people.

5. Conclusion

This article highlights the human resources as an important aspect of Industry 4.0 implementation. Although the introduction of automation, digitisation and CPS, the humans remain an important constituent part for planning, designing and implementing modern production systems and factories. A scarcity of skilled labour forces will be experienced by many industrial sectors. Especially, SMEs have great difficulties in finding highly educated employees.

By using the concept of urban production, this article proposes a solution for SMEs to gather highly educated employees. In future, production systems should be designed for a problem-free integration in the urban environment. According to various reasons this is quite difficult for SMEs: insufficient and inadequate production areas, high land prices in comparison to peripheral areas, inherited liabilities and the lack of acceptance of local residents hinder the localisation of industrial companies in urban areas (Stiftung neue Verantwortung, 2012). However, considering the increasing trend of urbanisation, factories close to metropolitan areas bear enormous advantages. One of these advantages is to address the lack of qualified labour-forces. The article proposes measures suitable for SMEs located in urban areas to recruit young talents, to retain families in terms of working parents (father and/or mother) and to occupy the increasing amount of elder employees by means of an appropriate Age Management program.

Declaration of interest

Conflicts of interest: none.

The authors disclose any financial and personal relationships with other people or organizations that could inappropriately influence (bias) their work.

Acknowledgments

This work was supported by the Open Access Publishing Fund provided by the Free University of Bozen-Bolzano.

References

Accenture (2014). Accenture 2014 manufacturing skills and training study – out of inventory skills shortage threatens growth for US manufacturing. http://www.themanufacturinginstitute.org/Research/Skills-and-Training-Study/~/media/70965D0C4A944329894C96E0316DF336.ashx (accessed 22.10.2017).

Akerman, A., Gaarder, I., & Mogstad, M. (2015). The skill complementarity of broadband internet. *The Quarterly Journal of Economics, 130*(4), 1781–1824.

Altbach, P. G., & Teichler, U. (2001). Internationalization and exchanges in a globalized university. *Journal of Studies in International Education, 5*(1), 5–25.

Arntz, M., Gregory, T., & Lehmer, F. (2014). Can regional employment disparities explain the allocation of human capital across space? *Regional Studies, 48*(10), 1719–1738.

Arntz, M., Gregory, T., & Zierahn, U. (2016). The Risk of Automation for jobs in OECD countries. *OECD SEM Working Papers, 189*.

Autor, D. H., & Dorn, D. (2013). The growth of low-skill service jobs and the polarization of the US labor market. *The American Economic Review, 103*(5), 1553–1597.

Autor, D. H., Levy, F., & Murnane, R. J. (2003). The skill content of recent technological change: An empirical exploration. *The Quarterly Journal of Economics, 118*(4), 1279–1333.

Baker, E. S. (2016). The lure of big cities for the highly educated. *Monthly Labor Review, 2016*, 1–2.

Beckers, P., & Boschman, S. (2013). A place called home: Residential choices of highly skilled migrants in the Netherlands and the role of local amenities. *Proceedings of 7th international conference of population geographies (ICPG). Groningen, Netherlands*(pp. 25–28).

Berger, T., & Frey, C. B. (2016). Structural transformation in the OECD: Digitalisation, deindustrialisation and the future of work. OECD Social, Employment and Migration Working Papers, No. 193. Paris: OECD Publishing. https://doi.org/10.1787/5jlr068802f7-en (accessed 22.10.2017).

Berlin, C., Barletta, I., Fantini, P., Georgoulias, K., Hanisch, C., Lanz, M., Latokartano, J., ... Tuokko, R. (2016). Prerequisites and conditions for socially sustainable manufacturing in Europe's future factories—Results overview from the SO SMART project. In T. S. Schlick (Ed.). *Advances in Ergonomics of Manufacturing: Managing the Enterprise of the Future. Advances in Intelligent Systems and Computing*(pp. 319–330). Cham: Springer.

Betz, M. R., Partridge, M. D., & Fallah, B. (2016). Smart cities and attracting knowledge workers: Which cities attract highly-educated workers in the 21st century? *Papers in Regional Science, 95*(4), 819–841.

Bhattacharya, C. B., Sen, S., & Korschun, D. (2008). Using corporate social responsibility to win the war for talent. *MIT Sloan Management Review, 49*(2), 37–44.

Blien, U., & Dauth, W. (2016). Job polarization on local labor markets? *ERSA conference papers (No. ersa16p114)*.

BMWi (2014). Fachkräftesituation in KMU: Kleine und mittlere Unternehmen sind besonders betroffen. Bundesministerium für Wirtschaft und Energie (BMWi). http://www.kompetenzzentrum-fachkraeftesicherung.de/daten-und-fakten/fachkraeftesituation-im-mittelstand/fachkraeftesituation-in-kmu/ (accessed 12.04.17).

Bontje, M., Musterd, S., & Sleutjes, B. (2017). Skills and cities: Knowledge workers in Northwest-European cities. *International Journal of Knowledge-Based Development, 8*(2), 135–153.

Boston Consulting Group (2014). The global workforce crisis: $10 trillion at risk. https://www.bcg.com/publications/2014/people-organization-human-resources-global-workforce-crisis.aspx (accessed 31.08.18).

Boussauw, K., Neutens, T., & Witlox, F. (2012). Relationship between spatial proximity and travel-to-work distance: The effect of the compact city. *Regional Studies, 46*(6), 687–706.

Brennan, L., Ferdows, K., Godsell, J., Golini, R., Keegan, R., Kinkel, S., ... Taylor, M. (2015). Manufacturing in the world: Where next? *International Journal of Operations & Production Management, 3 5(9)*, 1253–1274.

Cappelli, P. (2008). Talent management for the twenty-first century. *Harvard business review, 86*(3), 74.

Dietz, M., Kubis, A., Leber, U., Müller, A., & Stegmaier, J. (2013). Personalsuche in Deutschland: Kleine und mittlere Betriebe im Wettbewerb um Fachkräfte (in German: Search for personnel in Germany: Small and medium-sized enterprises in the competition for skilled workers). In Institut für Arbeitsmarkt- und Berufsforschung IAB (Ed.), IAB Kurzbericht -Aktuelle Analysen aus dem Institut für Arbeitsmarkt- und Berufsforschung (pp. 1–8). Regensburg: Vormals Manzsche Buchdruckerei und Verlag.

DIHK – Deutsche Industrie- und Handelskammertag (2010). *Mitarbeiter dringend gesucht! Fachkräftesicherung – Herausforderung der Zukunft (in German: Staff urgently wanted! Safeguarding the future – The challenge of the future)*. Berlin: DIHK.

Docquier, F., & Machado, J. (2016). Global competition for attracting talents and the world economy. *The World Economy, 39*(4), 530–542.

EFFRA (2012). Factories of the Future PPP – FoF20220 Roadmap – Consultation document. Bruxelles.

ElMaraghy, H. A. (2005). Flexible and reconfigurable manufacturing systems paradigms. *International Journal of Flexible Manufacturing Systems, 17*(4), 261–276.

Erbstößer, A. C. (2016). *Produktion in der Stadt. Berliner Mischung, 2.0.* Berlin: Technologiestiftung Berlin.

Eriksson, L., Friman, M., & Gärling, T. (2008). Stated reasons for reducing work-commute by car. *Transportation Research Part F: Traffic Psychology and Behaviour, 11*(6), 427–433.

Esmaeilpoorarabi, N., Yigitcanlar, T., & Guaralda, M. (2016). Towards an urban quality framework: Determining critical measures for different geographical scales to attract and retain talent in cities. *International Journal of Knowledge-Based Development, 7*(3), 290–312.

European Commission (2016). Annual report on european SMEs 2015–2016. http://ec.europa.eu/growth/smes/business-friendly-environment/performance-review-2016_it (accessed 26.04.17).

Eurostat Statistics (2017). Explained – Unemployment statistics. http://ec.europa.eu/eurostat/statistics-explained/index.php/Unemployment_statistics (accessed 12.11.17).

Fabisiak, J., & Prokurat, S. (2012). Age management as a tool for the demographic decline in the 21st century: An overview of its characteristics. *Journal of Enterpreneurship, Management and Innovation, 8*(4), 83–96.

Fantini, P., Pinzone, M., & Taisch, M. (2018). Placing the operator at the centre of Industry 4.0 design: Modelling and assessing human activities within cyber-physical systems. *Computers & Industrial Engineering* (in press).

Fantini, P., Pinzone, M., Taisch, M., & Altesa, J. (2016). Human-centric manufacturing workplaces: Aiming at increasing attractiveness and user experience. In I. Nääs, O. Vendrametto, J. Mendes, R. Gonçalves, M. Terra, G. von Cieminski, & D. Kiritsis (Eds.). *Advances in production management systems. Initiatives for a sustainable world* (pp. 363–370). Cham: Springer.

Fawcett, S. E., & Waller, M. A. (2014). Can we stay ahead of the obsolescence curve? On inflection points, proactive preemption, and the future of supply chain management. *Journal of Business Logistics, 35*(1), 17–22.

Florida, R. (2014). *The rise of the creative class – Revisited: Revised and expanded.* New York: Basic Books.

Fraunhofer (2012Fraunhofer,, 2012Fraunhofer,, 2012). *Die Stadt von Morgen – die Morgenstadt (in German: The city of tomorrow – The Morgenstadt)*. Stuttgart: Fraunhofer-Gesellschaft.

Frey, C. B., & Osborne, M. A. (2017). The future of employment: How susceptible are jobs to computerisation? *Technological Forecasting and Social Change, 114*, 254–280.

Fuertes, V., Egdell, V., & McQuaid, R. (2013). Extending working lives: Age management in SMEs. *Employee Relations, 35*(3), 272–293.

Gardner, G. (2016). Imagining a sustainable city. In G. Gardner (Ed.). *State of the World* (pp. 3–9). Washington, DC: Island Press.

Goos, M., & Manning, A. (2007). Lousy and lovely jobs: The rising polarization of work in Britain. *The Review of Economics and Statistics, 89*(1), 118–133.

Goos, M., Manning, A., & Salomons, A. (2014). Explaining job polarization: Routine-biased technological change and offshoring. *The American Economic Review, 104*(8), 2509–2526.

Gregory, T., Salomons, A., & Zierahn, U. (2016). Racing with or against the machine? Evidence from Europe, ZEV Discussion Paper No. 16-053. http://ftp.zew.de/pub/zew-docs/dp/dp16053.pdf (accessed 22.11.17).

Griffiths, A. (2007). Healthy work for older workers: Work design and management factors: The future for older workers. *New Perspectives, 1*, 121–138.

Grima, F. (2011). The influence of age management policies on older employee work relationships with their company. *The International Journal of Human Resource Management, 22*(06), 1312–1332.

Hirsch-Kreinsen, H. (2016). Digitization of industrial work: Development paths and prospects. *Journal for Labour Market Research, 49*(1), 1–14.

Ilmarinen, J. (2006). The ageing workforce—Challenges for occupational health. *Occupational Medicine, 56*(6), 362–364.

Ivanov, D., Dolgui, A., Sokolov, B., Werner, F., & Ivanova, M. (2016). A dynamic model and an algorithm for short-term supply chain scheduling in the smart factory Industry 4.0. *International Journal of Production Research, 54*(2), 386–402.

Johnston, V., Souvlis, T., Jimmieson, N. L., & Jull, G. (2008). Associations between individual and workplace risk factors for self-reported neck pain and disability among female office workers. *Applied Ergonomics, 39*(2), 171–182.

Kagermann, H., Wahlster, W., & Helbig, J. (2013). Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0. Abschlussbericht des Arbeitskreises Industrie (in German: Implementation recommendations for the project Industry 4.0. Final report), 4(5).

Kang, H. S., Lee, J. Y., Choi, S., Kim, H., Park, J. H., Son, J. Y., ... Do Noh, S. (2016). Smart manufacturing: Past research, present findings, and future directions. *International Journal of Precision Engineering and Manufacturing-Green Technology, 3*(1), 111–128.

Kassner, L., Hirmer, P., Wieland, M., Steimle, F., Königsberger, J., & Mitschang, B. (2017). The social factory: Connecting people, machines and data in manufacturing for context-aware exception escalation. *Proceedings of the 50th Hawaii international conference on system sciences, Waikoloa, Hawaii*(pp. 1673–1682).

Kinnunen, U., Mauno, S., Geurts, S., & Dikkers, J. (2005). Work-family culture in organizations: theoretical and empirical approaches. Work and family. *An International Research Perspective,* 87–120.

Kloosterman, R. C., & Trip, J. J. (2011). Planning for quality? Assessing the role of quality of place in current Dutch planning practice. *Journal of Urban Design, 16*(4), 455–470.

Koc-Menard, S. (2009). Training strategies for an aging workforce. *Industrial and Commercial Training, 41*(6), 334–338.

Kraiger, K. (2017). Designing effective training for older workers. In E. Parry, & J. McCarthy (Eds.). *The Palgrave handbook of age diversity and work*(pp. 639–667). Basingstoke, UK: Palgrave Macmillan.

Kwon, J. H., & Thom, N. (2017). Talent management through trainee programmes in german-speaking companies and its implications for Korean companies. *Koreanische Zeitschrift für Wirtschaftswissenschaften, 35*(2).

Lee, J., Bagheri, B., & Kao, H. A. (2015). A cyber-physical systems architecture for industry 4.0-based manufacturing systems. *Manufacturing Letters, 3*, 18–23.

Lee, S. Y., & Brand, J. (2005). Effects of control over office workspace on perceptions of the work environment and work outcome. *Journal of Environmental Psychology, 25*(3), 323–333.

Letmathe, P., & Schinner, M. (2017). *Competence management in the age of cyber physical systems. In Industrial Internet of Things.* Cham: Springer595–614.

Lewis, J. (2006). Work/family reconciliation, equal opportunities and social policies: The interpretation of policy trajectories at the EU level and the meaning of gender equality. *Journal of European Public Policy, 13*(3), 420–437.

Liao, Y., Deschamps, F., Loures, E. D. F. R., & Ramos, L. F. P. (2017). Past, present and future of Industry 4.0-a systematic literature review and research agenda proposal. *International Journal of Production Research, 55*(12), 3609–3629.

Lorentz, M., Rüsmann, M., Strack, R., Lueth, K. L., & Bolle, M. (2015). Man and machine in Industry 4.0: How will technology transform the industrial workforce through 2025? The Boston Consulting Group. https://www. bcgperspectives. com/content/articles/technology-business-transformationengineered-products-infrastructure-man-machine-industry-4 (accessed 22.11.17).

Marans, R. W. (2003). Understanding environmental quality through quality of life studies: The 2001 DAS and its use of subjective and objective indicators. *Landscape and Urban Planning, 65*(1), 73–83.

Martin-Brelot, H., Grossetti, M., Eckert, D., Gritsai, O., & Kovacs, Z. (2010). The spatial

mobility of the 'creative class': A European perspective. *International Journal of Urban and Regional Research, 34*(4), 854–870.
Matt, D. T., Spath, D., Braun, S., Schlund, S., & Krause, D. (2013). Morgenstadt: Urban production in the city of the future. In M. F. Zäh (Ed.). *Proceedings of 5th International Conference on Changeable, Agile, Reconfigurable and Virtual Production (CARV 2013), Munich, Germany*. (pp. 13–16).
May, G., Maghazei, O., Taisch, M., Bettoni, A., Cinus, M., & Matarazzo, A. (2014). Toward human-centric factories: Requirements and design aspects of a worker-centric job allocator. In B. Grabot, B. Vallespir, G. Samuel, A. Bouras, & D. Kiritsis (Eds.). *Advances in production management systems: Innovative and knowledge-based production management in a global-local world* (pp. 417–424). Berlin Heidelberg: Springer.
McDermott, H. J., Kazi, A., Munir, F., & Haslam, C. (2010). Developing occupational health services for active age management. *Occupational Medicine, 60*(3), 193–204.
McKinsey (2011). *Wettbewerbsfaktor Fachkräfte: Strategien für Deutschlands Unternehmen.* Berlin: McKinsey.
McNair, S., Flynn, M., Owen, L., Humphreys, C., & Woodfield, S. (2004). *Changing work in later life: A study of job transitions.* Centre for Research into the Older Workforce, University of Surrey93.
McNulty, Y., & Hutchings, K. (2016). Looking for global talent in all the right places: A critical literature review of non-traditional expatriates. *The International Journal of Human Resource Management, 27*(7), 699–728.
Mellander, C., & Florida, R. (2006). The creative class or human capital. Explaining Regional Development in Sweden. *Electronic Working Paper Series, Nr*, 79.
Merisalo, M., Makkonen, T., & Inkinen, T. (2013). Creative and knowledge-intensive teleworkers' relation to e-capital in the Helsinki metropolitan area. *International Journal of Knowledge-Based Development, 4*(3), 204–221.
Michaels, G., Natraj, A., & Van Reenen, J. (2014). Has ICT polarized skill demand? Evidence from eleven countries over twenty-five years. *Review of Economics and Statistics, 96*(1), 60–77.
Niedomysl, T., & Hansen, H. K. (2010). What matters more for the decision to move: Jobs versus amenities. *Environment and Planning A, 42*(7), 1636–1649.
Niesing, B. (2012). Die Zukunft der Stadt (in German: the future of the city). *Fraunhofer magazin ,weiter.vorn, 4*(12), 8–13.
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.
Parsons, K. (2000). Environmental ergonomics: A review of principles, methods and models. *Applied Ergonomics, 31*(6), 581–594.
Patton, W., & Doherty, C. (2017). Career, family, and workforce mobility: An inter-disciplinary conversation. *Journal of Career Development* 0894845317731157.
Perry, L. S. (2010). The aging workforce: Using ergonomics to improve workplace design. *Professional Safety, 55*(04), 22–28.
Radziwon, A., Bilberg, A., Bogers, M., & Madsen, E. S. (2014). The Smart Factory: Exploring adaptive and flexible manufacturing solutions. *Procedia Engineering, 69*, 1184–1190.
Ras, E., Wild, F., Stahl, C., & Baudet, A. (2017). Bridging the skills gap of workers in industry 4.0 by human performance augmentation tools: Challenges and roadmap. *Proceedings of the 10th international conference on PErvasive technologies related to assistive environments, Rhodos, Greece*(pp. 428–432).
Reiner, C., Meyer, S., & Sardadvar, S. (2017). Urban attraction policies for international academic talent: Munich and Vienna in comparison. *Cities, 61*, 27–35.
Romero, D., Bernus, P., Noran, O., Stahre, J., & Fast-Berglund, Å. (2016). The operator 4.0: Human cyber-physical systems and adaptive automation towards human-automation symbiosis work systems. In I. Nääs (Ed.). *Advances in production management systems. Initiatives for a sustainable world. APMS 2016*(pp. 1–11). IFIP Advances in Information and Communication Technology: Springer.
Romero, D., Noran, O., Stahre, J., Bernus, P., & Fast-Berglund, Å. (2015). Towards a human-centered reference architecture for next generation balanced automation systems: Human-automation symbiosis. In S. Umeda, M. Nakano, H. Mizuyama, & H., Hibino, D. Kiritsis and G. von Cieminski, (Eds.). *Advances in production management systems: Innovative production management towards sustainable growth*(pp. 556–566). Cham: Springer.
Romero, D., Wuest, T., Stahre, J., & Gorecky, D. (2017). Social factory architecture: Social networking services and production scenarios through the social internet of things, services and people for the social operator 4.0. In H. Lödding, R. Riedel, K.-. D. Thoben, G. von Cieminski, & D. Kiritsis (Eds.). *Advances in production management systems. The path to intelligent, collaborative and sustainable manufacturing* (pp. 265–273). Cham: Springer.
Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., & Harnisch, M. (2015). *Industry 4.0: The future of productivity and growth in manufacturing industries.* Boston Consulting Group.
Savazzi, S., Rampa, V., & Spagnolini, U. (2014). Wireless cloud networks for the factory of things: Connectivity modeling and layout design. *IEEE Internet of Things Journal, 1*(2), 180–195.
Schiller, D., & Revilla Diez, J. (2012). The impact of academic mobility on the creation of localized intangible assets. *Regional Studies, 46*, 1319–1332.
Schönauer, I. (2014). *Industrie 4.0 – Die vierte Industrielle Revolution (in German: Industry 4.0 – the fourth industrial revolution).* Berlin: Reflex Verlag.
Schütt, P. (2011). *Fachkräftesicherung in kleinen und mittelständischen Unternehmen. Betriebliche Handlungsstrategien und Haltefaktoren (in German: Skilled workers in small and medium-sized enterprises. Operational action strategies and holding factors).* München: Institut für Sozialwissenschaftliche Forschung e.V.
Smith, A., & Anderson, J. (2014). AI, robotics, and the future of jobs. *Pew Research Center, 6* http://www.pewinternet.org/2014/08/06/future-of-jobs/ (accessed 31.08.18).
Spath, D., Ganschar, O., Gerlach, S., Hämmerle, T. K., & Schlund, S. (2013). *Produktionsarbeit der Zukunft – Industrie 4.0 (in German: Production work of the Future - Industry 4.0).* Stuttgart: Fraunhofer Verlag.
Stevens-Roseman, E. S. (2009). Older mentors for newer workers: Impact of a worker-driven intervention on later life satisfaction. *Journal of Workplace Behavioral Health, 24*(4), 419–426.
Stiftung neue Verantwortung (2012). *Future Urban Industries – Produktion, Industrie, Stadtzukunft, Wachstum. Wie können wir den Herausforderungen begegnen? (in German: Future Urban Industries - production, industry, urban development, growth. How can we meet the challenges).* Policy Brief 11/12Berlin: Stiftung neue Verantwortung e.V.
Stoynova, N., & Gourova, E. (2017). Attracting and preserving talents. *VikingPLoP, 2017* 11 pages.
Tai, F. M., & Chuang, S. H. (2014). Corporate social responsibility. *Ibusiness, 6*(03), 117.
Thom, N., & Nesemann, K. (2011). Talententwicklung durch Trainee-Programme. In A. Ritz, & N. Thom (Eds.). *Talent Management* (pp. 25–38). Wiesbaden: Gabler.
UKCESS (2016). The UK Commission's employer skills survey 2015. https://www.trainingjournal.com/articles/news/one-four-jobs-go-unfilled-due-skills-shortage-reveals-ukces (accessed 13.02.18).
United Nations, 2014. United Nations world urbanisation prospects – The 2014 revision. https://esa.un.org/unpd/wup/publications/files/wup2014-report.pdf (accessed 06.05.17).
Verhoef, M., Roeters, A., & van der Lippe, T. (2016). Couples' work schedules and child-care use in the Netherlands. *Journal of Child and Family Studies, 25*(4), 1119–1130.
Weyrich, M., Schmidt, J. P., & Ebert, C. (2014). Machine-to-machine communication. *IEEE Software, 31*(4), 19–23.
World Economic Forum (2014). Matching skills and labour market needs – Building social partnerships for better skills and better jobs. https://www.weforum.org/reports/matching-skills-and-labour-market-needs-building-social-partnerships-better-skills-and-better-jobs (accessed 12.11.17).
World Economic Forum (2016). The global competitiveness report 2016–2017. http://www3.weforum.org/docs/GCR2016-2017/05FullReport/TheGlobalCompetitivenessReport2016-2017_FINAL.pdf (accessed 13.02.18).
Yao, X., Lian, Z., Yang, Y., Zhang, Y., & Jin, H. (2014). Wisdom manufacturing: New humans-computers-things collaborative manufacturing model. *Computer Integrated Manufacturing Systems, 20*(6), 1490–1498.
Yue, X., Cai, H., Yan, H., Zou, C., & Zhou, K. (2015). Cloud-assisted industrial cyber-physical systems: An insight. *Microprocessors and Microsystems, 39*(8), 1262–1270.
Zhan, Z. H., Liu, X. F., Gong, Y. J., Zhang, J., Chung, H. S. H., & Li, Y. (2015). Cloud computing resource scheduling and a survey of its evolutionary approaches. *ACM Computing Surveys (CSUR), 47*(4), 63.