Chapter 4

The Evolution of Industry 4.0 and its Impact on the Knowledge Base for the Circular Economy

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Chapter 4

The Evolution of Industry 4.0 and its Impact on the Knowledge Base for the Circular Economy

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1. Introduction

For decades, growth in wealth and well-being, especially in Europe, has been based on the increasing and unsustainable use of resources (Bringezu and Bleischwitz, 2009; EC, 2011). To address scarcities of supply and sustainability challenges, more efficient methods of turning waste into secondary resources are required. Such methods should avoid the common 'downcycling' of materials, in which the quality of the material is reduced with each cycle (Velis and Brunner, 2013).

Overcoming these unsustainable patterns of consumption and production will, among other things, require a radical transition of waste management towards an integrated element of the circular economy. For a long time, such concepts of keeping materials in closed circuits have been seen in local and national contexts only. Historically, waste policy has been considered as a responsibility of local governments or councils. Accordingly, the regulative framework that has emerged aims at preventing environmental burdens on-site (Kranert and Cord-Landwehr, 2010).

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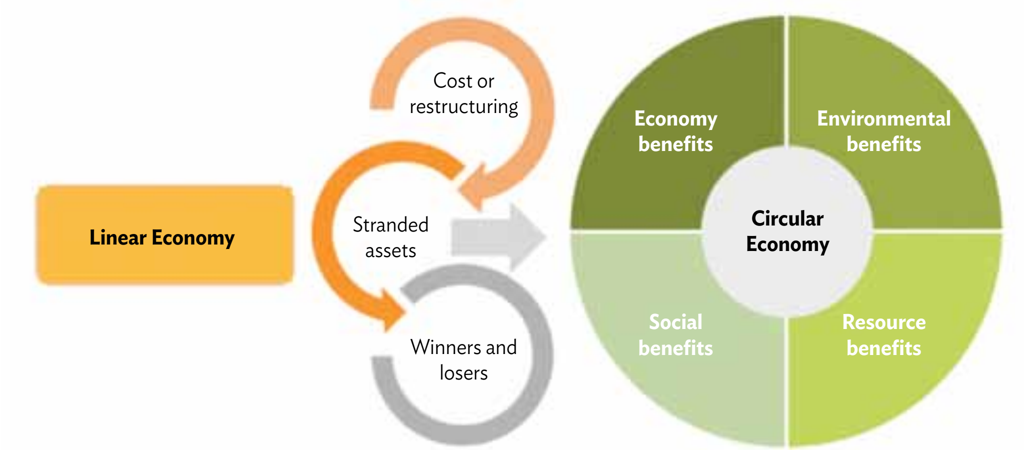
The concept of circular economy has recently gained attraction in European policymaking as a positive and solutions-based perspective for achieving economic development amid increasing environmental constraints (EEA, 2016; EASAC, 2015). The term is often very differently interpreted by the European Commission as an economy 'where the value of products, materials, and resources is maintained in the economy for as long as possible, and the generation of waste is minimised' (EC, 2015: 2). It is viewed as an essential contribution to the efforts of the European Union (EU) to develop a sustainable, low-carbon, resource-efficient, and, from an economic point of view, competitive economy. Figure 1 also shows the transition towards the circular economy concept applied in the EU. This is reflected, for example, in Europe's 7th Environment Action Programme, which identifies the need for a framework that gives appropriate signals to producers and consumers to promote resource efficiency and the circular economy. It is also increasingly seen as a business opportunity, for example, through the efforts of the Ellen MacArthur Foundation. Moreover, European countries increasingly indicate the circular economy as a political priority. In December 2015, the European Commission published its new strategy, 'Closing the loop – An EU action plan for the circular economy', which aims to support the transition to a circular economy in the EU (Wilts, 2016). The action plan sets out several initiatives that address all stages of the life cycle, combined with concrete targets on waste and the development of a monitoring framework.

Figure 1. The Transition Towards a Circular Economy



Source: European Environment Agency, 2016.

The current knowledge base, however, is rather fragmented. An improved 'transformative literacy' (Schneidewind, 2013) is needed, especially in terms of better insight into various aspects of system dynamics, such as production structures and functions, consumption dynamics, finance and fiscal mechanisms, and trigger pathways for technological and social innovations. This links to another new and dynamic policy field, the emergence of Industry 4.0, which is the comprehensive transformation of the whole sphere of industrial production through merging digital technology and the internet with conventional industry (European Parliament, 2015). In 2012, in response to this decline in the relative importance of industry, the European Commission set a target that manufacturing should represent 20% of the total value added in the EU by 2020. While some observers find this goal overly ambitious, many believe that we are on the brink of a new industrial revolution – Industry 4.0 – which could boost the productivity and value added of European industries and stimulate economic growth.

This paper aims to analyse a few of the synergies and challenges that might occur at the interface of these radical innovation pathways, especially regarding the availability and provision of data, information, and knowledge as crucial aspects in both concepts. Given this, the paper asks how the emergence and evolution of the Industry 4.0 concept transforms the waste management sector, influences the transition towards a circular economy, and creates synergies with sustainable resource management. The evolution and key elements of Industry 4.0 are outlined in Section 2. Section 3 discusses the role of information that would be required to transform traditional waste management into a circular economy and thus develop the analytical framework for this paper. Section 4 analyses existing case studies on how Industry 4.0 might contribute. The final section draws conclusions regarding the further need for research and policy formulation.

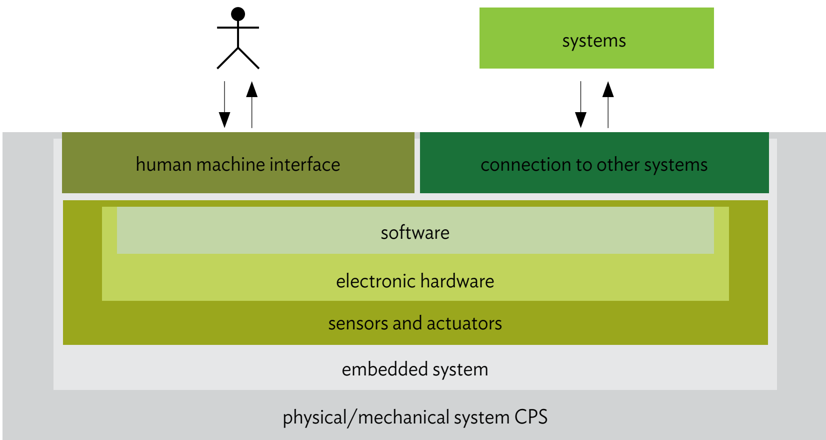
2. Evolution of the Industry 4.0 Concept

To understand the concept of Industry 4.0, it is helpful to analyse the evolution of previous industrial revolutions. All of them were triggered by technical innovations, such as the introduction of water- and steam-powered mechanical manufacturing at the end of the 18th century, the division of labour at the beginning of the 20th century, and the introduction of programmable logic controllers for automation purposes in manufacturing in the 1970s. According to Brettel et al. (2014), the upcoming industrial revolution will be triggered by the internet, which allows communication between humans and machines in large networks (Figure 2).

Alongside technological innovation, the organisational structure of industrial production has undergone several major shifts in the past to face the changing markets. Industrial production started with the transformation from craft production to mass production, with strict division of labour and standardisation. On a seller market with production as the major bottleneck, the organisational structure was focused on increasing outputs and productivity, disregarding variations in customer needs. As market saturation increased, markets transformed into buyers' markets and forced manufacturing companies towards product differentiation. To raise effectiveness at growing product varieties, lean production has become very popular as it allows eliminating waste along the value chain. The internet has been identified as a powerful instrument to manage distributed systems.

In future manufacturing, factories will have to cope with the need for rapid product development, flexible production, as well as complex environments. Within the factory of the future, also considered as a smart factory, new integrated systems will enable the communication between humans, machines, and products. As they can acquire and process data, they can self-control certain tasks and interact with humans via interfaces. In a smart manufacturing environment, intelligent and customised products comprise knowledge of their manufacturing process and consumer application, and independently lead their way through the supply chain. The resolution of the automation pyramid towards self-controlling systems leads to an extreme amount of data, which can be extracted, visualised, and used for end-to-end engineering. Individualised production, horizontal integration in collaborative networks, and end-to-end digital integration are key aspects of this transformative process that will radically change cyber-physical systems.

Figure 2. Interaction Between Humans and Machines via Cyber-Physical Systems



CPS = cyber-physical systems.
Source: Brettel et al., 2014.

According to an extensive survey conducted by the Laboratory for Machine Tools and Production Engineering in Aachen, over 90% of managers from the German manufacturing industry have high interest in resolving the dilemma between scale and scope (Brettel et al., 2014). The establishment of product families is seen to be the primary means to incorporate flexibility into mass production as product design and development usually represent only 5%–10% but determines more that 80% of the costs of a product. Hence, the desired flexibility of a product family must be determined at a very early stage. However, as the benefit of flexibility is difficult to quantify, it is generally not included in a classical investment analysis of new machinery. The lack of powerful information technology systems and their integration with each other, inadequate employee knowledge of production processes, and lack of change efforts within the company are key deficits that could be addressed and overcome by Industry 4.0 concepts. In the context of rapid manufacturing, industry experts see not only great potentials but also considerable obstacles to replace conventional production technologies.

In the future, new forms of cooperation will allow businesses to flexibly allocate production capacity within a value chain. To do so, information needs to be accessible throughout collaborative networks, which has a lot of potential for conflicts. Companies usually refuse to disclose information about their production processes and cost structures to their partners to maintain a strong bargaining position. However, 45% of all German manufacturing enterprises adjust their capacity through outsourcing of jobs (Stich, Kompa, and Meier, 2011).

To overcome trust issues, dominant market forces like major original equipment manufacturers from the automotive industry need to structure entire value chains and urge suppliers to share information. An illustrative example is the electronic devices sector with a highly global supply chain where information about the specific raw material content is not passed on because it could allow competitors to draw conclusions on production and cost structures. But unless one party sees a direct benefit, exchange of information often fails due to a lack of willingness to bear costs, which others benefit from. The following section will illustrate this conceptual challenge using the example of the aspired transition towards a circular economy.

3. Information Requirements for the Circular Economy

The starting point for our consideration is the hypothesis that the lacking recovery of raw materials contained in end-of-life products in global material cycles is driven by knowledge problems and transaction costs (OECD, 2006; Wilts, 2016). On the one hand, recycling markets have failed to work properly because of asymmetrical distribution of information between recyclers and industry purchasing secondary raw materials, which has been impairing efficient agreements, e.g. plastic recycling rates are below economically optimal levels because it would be costly for buyers to confirm the quality of the product as stated by the seller, and even the smallest contamination could significantly lower the value of the material for the recycling process. On the other hand, governments also lack sufficient information that would be needed to correct the existing market failure in an optimal way through direct regulation.

Neither governments nor enterprises have the knowledge required to initiate and implement long-term changes towards sustainability. Thus, it is necessary to develop joint mechanisms, considering strategic interests and options for action (Bleischwitz, 2004; de Bruijn and Tukker, 2002; Grin, Rotmans, and Schot, 2010). Such integrated approaches for an 'industrial transformation go beyond the notion of eco-efficiency and beyond the domain of individual actors. It is about system innovation, both technological and institutional' (de Bruijn and Tukker, 2002: 8).

3.1. Conceptual Interlinkages Between Waste and Information Flows

On a conceptual level, the classification of specific products or materials as 'waste' is highly dependent on the availability of reliable information. Due to uncertainties regarding the quality of specific material flows, economic actors, based on their personal risk perception, can consider them as waste. Based on the analysis of international recycling markets, Johnstone and de Tilly have drawn conclusions on market inefficiencies that negatively influence recycling levels (OECD, 2006). Beyond traditional market failures like externalisation of environmental costs, information availability seems to play a crucial role. In contrast to primary resources, the quality of secondary resources is much more difficult, time-consuming, and costly to assess. Minimal contaminations can significantly change the value of metal scrap if it is no longer suitable for a recycling process, or it might even turn into hazardous waste.

In reality, waste management information on the material composition of products is almost non-existent or it gets lost alongside the recycling chain (Reuter et al., 2013).

Even if information regarding the quality of waste flows exists, it is asymmetrically distributed. Akerlof described how lack of information on end-of-life vehicles leads to a decreasing price level for such discarded products due to an adverse selection of market participants, which might eventually lead to a breakdown of the business model due to too high transaction costs for the confirmation of information (Akerlof, 1970).

It is striking that commercial waste streams lose a significant share of their value the moment they leave the company just because the available information become less reliable. Today, knowledge on waste quality and material composition of waste streams is mainly tacit, often bound to specific persons, and often not publicly available because it could allow competitors to gain insights into production technologies. This obviously leads to massive obstacles for closing material loops, e.g. the so-called industrial symbiosis concepts. The economic relevance of such transaction costs can be assessed based on price differences. Taking the example of plastic waste, it was shown that based on the availability of information, diverging price levels of up to a factor 10 have been reported (OECD, 2006). Thus, overcoming knowledge deficits becomes an independent regulatory objective – not as a sufficient but as a necessary precondition to improve market efficiency. Against this background, the Industry 4.0 concept of integrating information flows could be the cornerstone of a future circular economy that would contribute to innovation and competitiveness. Overcoming information-based market failures could increase the optimal level of material recycling, lead to additional investments into high-quality recycling technologies as well as research and development, and consequently support innovation capacities in this sector.

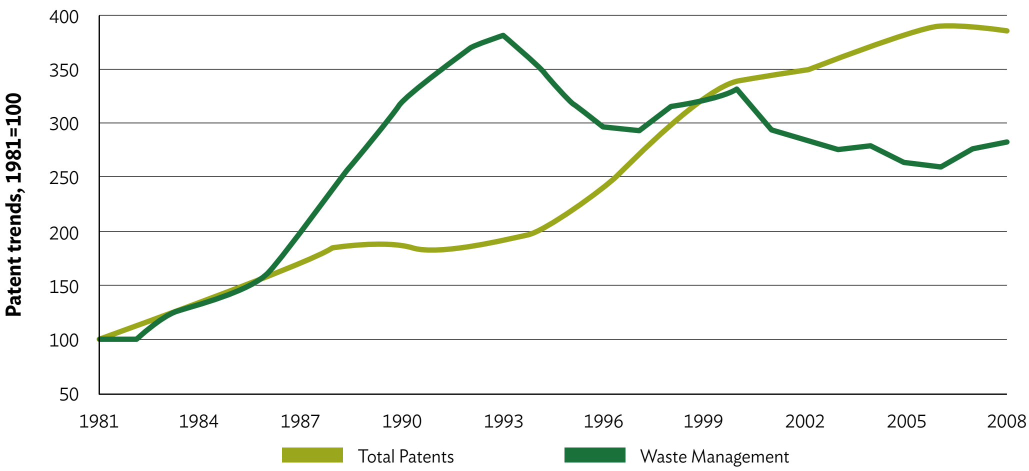
3.2. Reality of Waste Management

The necessity of such innovative concepts is highlighted by the reality of waste management in Europe. In contrast to the expressed political intention to transform Europe into a 'recycling society', the reality still shows a different picture. In 2011, total waste production in the EU amounted to about 2.5 billion tonnes. During the last 2 decades, solid waste streams have been massively diverted from landfill towards recycling and recovery. However, only 40% of waste generated in the EU had been recycled. The rest had been sent to landfills (37%) or incinerated (23%). About 500 million tonnes of materials could have been recycled or reused in the EU. The failure to recycle materials represents an environmental and possibly an economic loss (EC, 2015).

Innovation patterns in this sector have been analysed as part of a European research project on 'Environmental Macro Indicators for Innovation' coordinated by the

Wuppertal Institute, Climate and Energy. The outcomes highlight the importance of the integration of the circular economy and Industry 4.0. Extensive patent analysis in EU25 countries shows a clear decrease in waste-related innovations (see Figure 3). Innovation peaked in the 1990s when several new waste policies had been introduced. Similar policy-driven innovation patterns can be observed in the waste sector in Europe and worldwide. Due to increased level of data availability, improved quality of data, and reduced transaction costs for quality assessments, Industry 4.0 could be an important enabler to revive research and development in this sector, leading to a higher level of relevant eco-innovations for a circular economy.

Figure 3. Number of Patent Application Fields at the EPO by EU25 Countries Total Patents and Waste Patents, 3-year Moving Average (1981 = 100)



EPO = European Patent Office, EU = European Union.
Source: Wilts et al., 2015.

4. Industry 4.0 as an Enabler of a Circular Economy

The transition to a circular economy requires fundamental changes in many different areas of the current socio-economic system. Although it is a complex process that is difficult to predict, several crucial areas of change can be identified in technical, economic, and social domains, with a focus on the enabling factors that guide and accelerate the transition process. Industry 4.0 and the application of information and communications technology to digitise information and integrate systems at all stages of product creation and use (including logistics and supply), both inside companies and across company boundaries, can be considered as a key enabler for this development. Obviously, different factors need to act simultaneously to create reinforcing effects, and they all require the support of adequate policy frameworks and interventions (Wilts, 2016). The following section will give some concrete examples on how these elements will have to interact.

4.1. Industry 4.0-Based Business Models

One of the most powerful enablers of the circular economy are business model innovations based on web-based applications. Business models that successfully incorporate circular economy principles have a direct and lasting effect on the economic system. Most of these models relate to the functions of a product instead of its physical ownership (Ölundh and Ritzén, 2001; Mont, 2002). The following types can be distinguished: product-oriented services, which are centred on product sales, including additional services such as maintenance and take-back agreements; user-oriented services, which are based on product leases, rentals, sharing, and pooling; and result-oriented services, which provide specific outcomes, such as the creation of a pleasant climate in offices (Tukker and Tischner, 2006).

From an economic perspective, these models can improve customer loyalty, increase market share through product differentiation, scale up the value of used products leading to reduced costs, and bring new technologies to the market (Baines et al., 2007; EMF, 2013). In addition, service-based business models provide transparency for customers about the costs of the whole use phase, whereas uncertainties exist about costs of maintenance, repair, and replacement in purchase-based models. Nevertheless, these models may trigger negative economic and social impacts on traditional value chains, as they reduce the need for new materials and products. Environmental benefits can be observed in terms of reducing resource use and environmental impacts through the substitution of products with services. However, rebound effects, such as increased demand for a service because it costs less than ownership, could arise. Without the adaptation of policy frameworks, many innovative business models will not be able to compete with existing linear ones, or they might lose some or all their benefits when scaling up.

Another option with a clear role for solutions based on information and communications technology within Industry 4.0 is collaborative consumption, which is based on sharing, swapping, bartering, trading, or leasing products and other assets such as land or time (Botsman and Rogers, 2010). While such peer-to-peer interactions have long been practised on a local scale, they have developed into a different dimension through online sharing marketplaces where the demand for certain assets, products, or services is matched with their supply, usually through consumer-to-consumer channels.

Some involve fees for individual transactions while others are only open to registered fee-paying members, and some, typically smaller and often local schemes, are cost-free for users. One example is the hugely successful Airbnb model, which allows people to rent rooms and apartments. A 2014 global online survey showed that 54% of European respondents were willing to share or rent out their possessions for money, while 44% were happy to rent goods and services from others (Nielsen, 2014). This suggests that this model has considerable potential.

Positive economic effects include consumer access to a broader selection of products and services without incurring the liabilities and risks associated with ownership. While outcomes for citizens are generally positive, traditional businesses could experience losses in the form of lower sales, while governments might have to re-examine fiscal rules to guard against diminishing tax revenues.

Environmental benefits include a decrease in the use of natural resources, energy, and emissions throughout production and consumption cycles based on longer or more intensive use of existing products. Annual economic benefits of increased reuse have been estimated at about €360 billion for Europe alone (EMF/McKinsey, 2015). This, however, might trigger negative environmental impacts by promoting the longer use of inefficient appliances, or an increase in mobility (Leismann et al., 2013) through, for example, car sharing or low-price access to holiday accommodation.

Social effects can be measured through enhanced social interaction and cohesion as well as job creation. While the net effect on the creation of new jobs is unknown, companies organising collaborative consumption stimulate micro-entrepreneurship among the public (Dervojeda et al., 2013). The rapid growth of some internet-based consumer-to-consumer platforms has sparked discussion about fair competition, safety, risk allocation, and workers' rights, triggering the creation of specific legislative frameworks. Issues of concern that might require regulation when collaborative consumption is scaled up include taxation, property rights, avoiding the creation of informal sectors in the economy, and insurance.

Uptake of collaborative consumption is also influenced by cultural factors (e.g. historic experiences of forced collectivisation) and increased personal wealth (more assets to share), although interest in sharing might, for economic reasons, be higher in less well-off regions of Europe. Overall, the effects of collaborative consumption business models depend on the exact set-up of the model, including whether they are oriented towards profit or non-profit.

4.2. Industry 4.0 as an Enabler of an Actual Circular Economy

Despite the current emphasis on recycling, the concept has limits and is just a means to achieve higher level targets; it is not a goal in itself (Velis and Brunner, 2013). The main benefit of recycling is environmental protection, decreasing the need to mine and produce virgin materials, and reducing energy requirements and large-scale emissions. Against this background, there is an urgent need to measure recycling on a more sustainable basis. The integration of value chains and material flows with Industry 4.0 provides the option to measure progress towards a circular economy.

A recycling metric must be based on clear definitions of inputs and outputs, considering the time axis and material stocks along this time axis. Furthermore, the different qualities and constituents of materials must be considered. Plastics and metals are composed of numerous additives and alloying metals. When recycling targets are defined, these mixtures require individual attention to yield optimum and balanced economic, environmental, and resource solutions. The recent United Nations Environment Programme International Resource Panel Report on metal recycling has taken a similar perspective by pointing out the limits of a material-centric approach that worked in the past for base metals but increasingly fails for complex products, production processes, and value chains. The report says: 'However, thanks to the increasingly sustainability enabling technological advancement of the 21st century, products have become increasingly complex, mixing almost any imaginable metal or other material. Recycling these products became increasingly difficult as trying to recover one material would often destroy or scatter another, and it became clear that we needed a product-centric approach' (Reuter et al., 2013: 23). Embedded system production technologies and smart production processes, as part of Industry 4.0, will pave the way to a new technological age, which will radically transform industry and production value chains and enable completely new options to maintain the embedded value of materials and components in products – inter alia by remanufacturing, high-quality recycling, or dematerialisation (GTAI, 2015).

4.3. Experiences with Industry 4.0 in the Circular Economy

Despite the practical and conceptual challenges outlined above, several innovative entrepreneurs and pioneers have initiated start-ups and business models that aim to link Industry 4.0 and the circular economy. The examples presented below – waste electrical and electronic equipment (WEEE), construction and demolition waste, and household waste – are three of the fastest growing waste streams.

4.3.1. Radio frequency identification in WEEE

Despite the increased political focus on WEEE, the recovery, especially of critical raw materials, is still surprisingly low (EC, 2015). Major inefficiencies in the collection and treatment of WEEE stem from product-specific information gaps, leading to inadequate recovery or recycling of valuable materials. Radio frequency identification is an auto-identification system that could enhance potential benefits due to higher recovery rates for resource intensive materials in the current waste management system. Within the framework of smart product labelling, specific WEEE and their components are marked with transponders and individual identification numbers. This allows a product's identification throughout the entire life cycle without necessarily touching or seeing it. By being connected to a database, further information about material compositions, whether they are toxic or hazardous, and components are made available. The implementation of this technology allows a transparent identification of heterogeneous waste streams like WEEE by enabling adequate process optimisation of treatment, making it more flexible and product-specific. It also offers producer-specific cost analysis that sets incentives for a better product design (Löhle, 2013). The radio frequency identification technology therefore contributes to a more circular economy by offering the following potentials (Löhle and Urban, 2011):

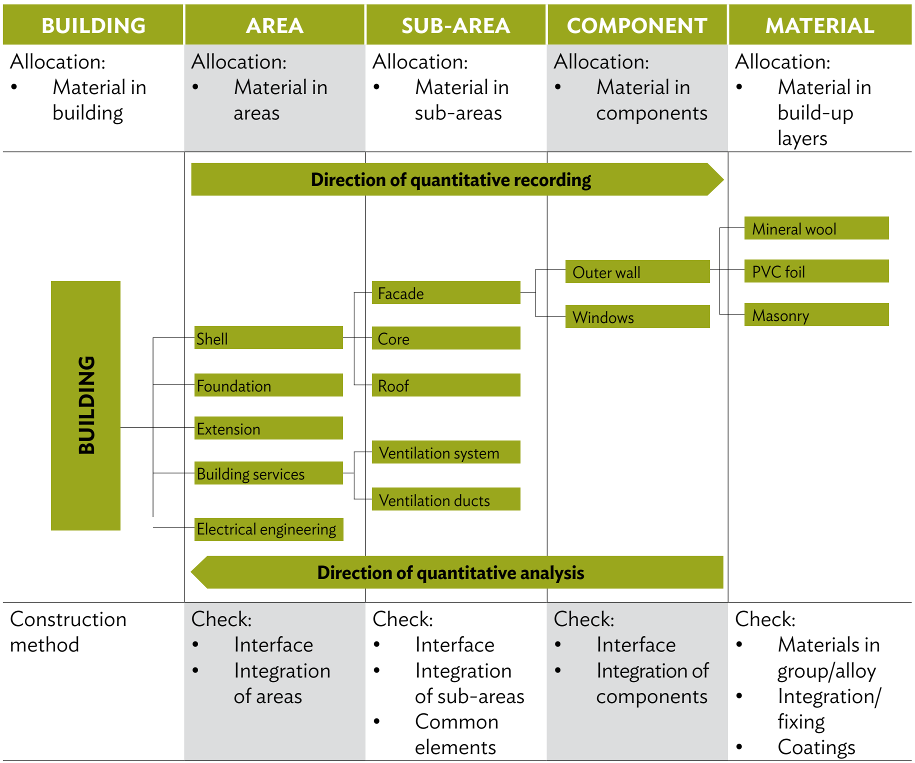
- categorisation of end-of-life products regarding materials, toxic components, environmental risks, or recyclable materials;
- provision of information about age, type, and requirements for reuse;
- provision of information about economically feasible dismantling or recycling strategies;
- provision of information about waste characteristics regarding treatment;
- provision of information and visualisation of dismantling instructions;
- data collection for material quantities and accounting; and
- support for deposit and leasing systems.

4.3.2. Building pass

A second potential field of application of Industry 4.0 solutions could be 'urban mining', the increased use of secondary raw materials, especially from buildings and infrastructures. Due to high uncertainties about future generation and demand, and especially information-related transaction costs for raw material contents and qualities, the construction and demolition waste sector is mainly characterised by down-cycling processes. Several actors, especially in Austria and Belgium, aim to address this issue by web-based 'building passes', an information system about the material characteristics of a building, containing necessary information about optimum low-waste management of building materials throughout the whole life cycle. It should document building activities, used materials, and technical equipment, e.g. heating, water, or electricity systems; and recommended maintenance measures. It is also a basis for the ecological evaluation of the building and provides an optimisation of deconstruction at the end of its life.

A building pass can help inform new building owners about the distribution of (hazardous) components within the building, facilitate detection of hazardous materials, simplify the planning of demolition, and create the preconditions for an efficient deconstruction process with high recovery and recycling rates. Furthermore, it provides a base for careful election of eco-friendly, recyclable building materials. Therefore, a building pass is especially valuable for demolition companies. Regarding the waste stream of construction and demolition, a building pass could increase the recycling rate for construction waste, improve the recycling quality, extend the useful life of a building, and substantially reduce waste generation of non-metallic minerals and metals (Reisinger et al., 2014). Web-based cadastres offer the possibility of identifying, quantifying, evaluating, and visualising relevant anthropogenic deposits with urban mining potential.

Figure 4. Example of a Building Pass



PVC = polyvinyl chloride.

Source: Adapted from Markova et al., 2010.

As can be seen in Figure 4, a building pass encompasses all building levels from the broader area to the individual materials. The aim is not to assess buildings or materials, but to receive qualitative and quantitative information about materials in any building. The focus therefore is on the location in the building, potential interfaces, material type, and how it is connected to other components (glued, screwed, and the like). The main parameters include structural elements (areas, sub-areas, components, and materials) and their relevant interactions that are crucial for recording, assigning, and evaluating information. Documentation is divided into two phases: quantitative recording, which is top-down; and quantitative analysis, which is bottom-up (Markova et al., 2010).

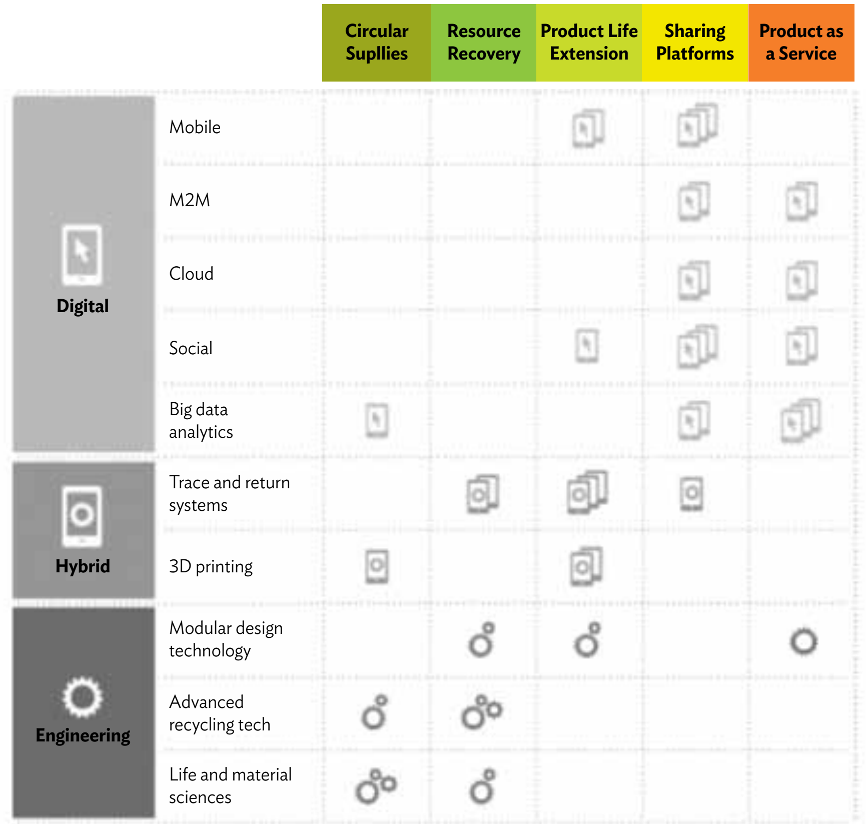
4.3.3. Rubicon Global: cloud-based waste management

A key driver for Industry 4.0 will be the emergence of lucrative business models. One example is Rubicon Global in the United States, a provider of a cloud-based waste management platform. On this platform, customers can manage and track waste and recycling metrics to monitor the progress towards environmental sustainability. The company does not provide treatment services itself but offers haulers the opportunity to connect their businesses on a national scale. First, companies sign up with the network, which enables haulers to compete for the business. Rubicon informs the winning bidder, who then provides the fleet for waste pickup. Through the global positioning system tracking within Rubicon's application, the waste's route is tracked from pickup to final drop-off where waste is processed into recycled materials, which are then sold on the cloud-powered auction site. The application also automatically organises all payments between haulers, customers, processors, and buyers. According to Rubicon, this system should help save costs, keep waste from being sent to landfills, and achieve sustainability goals within corporations (Rubicon, 2018). Five years after receiving US$5 million seed funding, the company is now estimated to be worth about US$1 billion.

4.4. Industry 4.0 Models for the Circular Economy

New business models offer companies powerful options for embracing the circular economy. Almost all of them would not be possible without the support of innovative new technologies, especially Industry 4.0-based digital ones such as social, mobile, analytics, cloud, and machine-to-machine technologies (e.g. the wirelessly connected internet of things, not just people). Designing value chains to embed circular business models all the way through to the customer's use and return is a major new frontier for the digital world, which revolutionises levels of service and flexibility as the physical and digital worlds merge and products start to flow between users, markets, and life cycles at very low transaction costs. Figure 5 identifies 10 disruptive technologies commonly used by the leading circular economy companies. These technologies fall into three categories: digital (information technology), engineering (physical technology), and a hybrid of the two.

Figure 5. Disruptive Technologies Used by Pioneers to Launch and Operate Circular Business Models with Speed and Scale



3D = three-dimensional, M2M = machine-to-machine.

Source: de Boer, 2015.

5. Conclusion and Outlook

The three examples highlight the market and eco-innovation potentials that could be generated by Industry 4.0 applications in the waste sector, especially in an integrated circular economy. They underline the issue of information requirements that can be the main entry point for web-based solutions if they manage to link. So far, the production and consumption phases are completely disconnected with the end-of-life phase of materials and products. This issue can be of specific importance for the ASEAN countries that face steeply increasing levels of waste generation and a direct link between economic development and the amount of wasted resources.

Forward-looking governments and business organisations are increasingly analysing policy options and their potential impacts, aiming to create favourable conditions for a circular economy (De Groene Zaak, 2015; EMF, 2015). At the EU level, the European Commission's recent circular economy package (EC, 2015) and the European innovation partnership on raw materials (EC, 2012) both aim to enable circular economy approaches, while the EU's Horizon 2020 research and innovation programme is set to invest around €941 million throughout 2018–2020 into the EU industry, with the aim of supporting circular economy approaches (EC, 2017). At the same time, several EU member states sponsor Industry 4.0-related initiatives, including Germany, Italy, France, and the United Kingdom, which represent the largest industrial sectors by value added in the EU. Since 2010, the German government has contributed €200 million to the 'Industrie 4.0' initiative (one of the 10 projects in the German High-Tech Strategy 2020 Action Plan) to encourage the development of smart factories (European Parliament, 2015). Unfortunately, these initiatives are rather decoupled from attempts to support the transition towards a circular economy. Against this background, the Economic Research Institute for ASEAN and East Asia initiative to look for potential synergies and trade-offs between Industry 4.0 and the circular economy is of special importance, especially regarding the alignment of national/regional strategies, research and development, and financing structures in both areas.

As outlined in a recent study on ASEAN countries and companies operating in the region with their specific development challenges, particularly vulnerable ecosystems, increasing demand for higher living standards, and rapidly growing population, the resource shortage is more pressing and a circular economy approach is urgently needed (de Boer, 2015). The study describes how these challenges in the next two decades could translate into, on a global scale, trillion-dollar losses for companies and countries whose growth remains tied to the use of scarce and virgin natural resources (de Boer, 2015). Without further action, the ASEAN countries would have to bear a big proportion. At the same time, infrastructure in several regions is yet to develop, making it challenging on the one hand but also possible to leverage latest technological progress to leapfrog the old development models on the other hand. It is crucial for ASEAN to look beyond the old 'take, make, and waste' models and to adopt alternative models of growth to ensure long-term sustainability.

Another important factor in this analysis is the global perspective of material and information flows. Decreased dependence on imports of strategic resources may be an explicit objective of the circular economy, but European as well as ASEAN production-consumption systems depend on such imports and will not operate in isolation. It is crucial to understand the environmental pressures that arise along the value chain where these pressures will be critically felt and how a transition to a circular economy may influence those pressures. Only then can policy efforts be targeted at resources and actors where the economic, environmental, and social benefits of circular economy approaches are greatest. So far, European policies are mostly targeted at impacts that occur within Europe at the production and end-of-life stages of systems. For ASEAN countries, this offers significant potentials for innovative and integrated strategies. As international trade laws limit intervention options, policy generally relies on consumption-oriented approaches, such as eco-labels, to influence the impacts of production abroad.

ASEAN and global businesses increasingly work towards sustainable value chains. Obviously, Industry 4.0 can neither be a national nor just a European or an ASEAN project. Considering global interdependencies alongside global supply chains, completely new governance approaches will be necessary to link these fields on different spatial levels. A closer coordination of circular economy and Industry 4.0 strategies between the ASEAN countries and the EU could be beneficial. A second aspect with clear benefits for ASEAN countries would be a strengthened focus on Industry 4.0 linked to the circular economy in financial cooperation schemes as well as access to finance for inter-company cooperation.

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