Part II
Tools and Methods

Innovation Management with an Emphasis on Co-creation

Dominic Hurni and Stefan N. Grösser

Abstract Innovation management is a means of supporting an understanding of an organisation's operating environment and enables the organisation to create and manage innovations more systematically throughout a system's life-cycle. This chapter introduces innovation management and co-creation in general, and details the methods of design thinking and business model canvas, thereby enabling organisations to professionalise their collaboration with customers and manage complex supply chains. Through co-creation organisations potentially improve their ability to innovate, optimise processes, adapt products and services to customer's actual needs, encourage stronger customer buy-in, hence creating a more sustainable market position through a more flexible organisational culture

Keywords Innovation management · Co-creation · Design thinking · Business model canvas · Open innovation · Management tools

1 Introduction

Innovation management is about rapidly transforming good ideas and inventions into innovative products or services. It is this commercialisation which the German Federal Ministry of Education and Research seeks to promote in its high-tech strategy for European industry published in 2015 (Bundesministerium für Bildung und Forschung 2015a). Although industry in Europe faces new technology such as "Industry 4.0" (Bundesministerium für Bildung und Forschung 2015b) and more intense global competition (Lusch and Vargo 2015), even more challenging seems to be enabling employees to remain agile in fast-changing business environments.

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According to the report "Fast Forward 2030" (Fast Forward 2030 2014), 50% of current occupations in corporations will fundamentally change in the next ten years. It is possible that European industry with its "zero-defects principle" finds itself locked-in this culture, focusing exclusively on optimizing existing products and thereby missing these other changes (Divernich 2007). Executives in Europe are aware that different approaches to innovation management are required. Often companies set up innovation projects free from the constraints of normal production to speed up the innovation process (Assink 2006). However, this separation fosters the creation of sub-cultures in the company and has to be avoided. Another crucial requirement to run projects successfully is user involvement (CHAOS Manifesto 2013 2013). Companies which have a rapid in- and outflow of relevant knowledge have a higher internal innovation rate (Chesbrough et al. 2005). But the implementation of open structures in companies appears to be challenging. Innovation management in general, and co-creation in particular, are approaches to address these.

Such challenges are also addressed by the Use-it-Wisely (UIW) project (see Reyes, Chapter "The Challenge", and Granholm and Groesser, Chapter "The Use-It-Wisely (UIW) Approach" in this book). In this chapter, we detail several approaches to innovation management and thereby offer a rich source for practitioners and researchers to innovate process, products, services, and subsequently business models.

This chapter is structured as follows: Sect. 2 provides both a definition of innovation management and a generic overview. Then, Sect. 3 details the general approach of co-creation and examines in detail "design thinking" methodology and the method "business model canvas". Section 4 discusses and concludes the chapter.

2 Generic Overview of Innovation Management

This section provides an overview of innovation management and includes discussions of various definitions that have been proposed within the field. This section aims to provide a theoretical foundation for the subsequent section on co-creation and design thinking in practice.

2.1 Definition of Innovation Management

Innovation management has arisen as a logical consequence of Schumpeter's (1934) concept of creative destruction. Innovation management is the process of handling the development of a product or service including successful market launch. Invention represents the creative act of developing a product or service and is the logical first step of an innovation. There are multiple definitions of innovation management; for example Edison's et al.'s (2013) literature review found more than

40 definitions of the term and declared Crossan's and Apaydin's (2010, p. 1155) as the most complete: "Innovation is: production or adoption, assimilation, and exploitation of a value-added novelty in economic and social spheres; renewal and enlargement of products, services, and markets; development of new methods of production; and establishment of new management systems. It is both a process and an outcome." Therefore, innovation refers not only to product, service or market development, but also to organisational development. Consequently, innovation management is the discipline of planning, executing, steering, and controlling a systemic process (Bergmann and Daub 2008; Hauschildt and Salomo 2011; Müller-Prothmann and Dörr 2009; Vahs and Burmester 2005) in an interdisciplinary team (Bergmann and Daub 2008; Hauschildt and Salomo 2011; von der Oelsnitz 2009) to create innovation.

2.2 *Management of Innovation*

According to Gassmann and Sutter (2011), innovations and technologies have to be managed at the normative (Fig. 1—blue rectangle), strategic (Fig. 1—white rectangle), and operational level (Fig. 1—development funnel) which are indicated in Fig. 1. Simply supervising technology development is not sufficient for innovation management. On the normative level, for instance, values and cultural norms of society influence the vision and mission statement of an organisation as well as the market and technology development in general. One normative question is: How should we use and control "artificial intelligence" in our organisation? It has to be answered congruently with the internal and external self-image of the organisation otherwise its credibility and also the trust in its strategy suffers.

From the perspective of strategy, innovation is both a strong source for short-term reduction of costs and for long-term sustainable competitive advantage. When technology is a source of an organisation's core competences, the protection

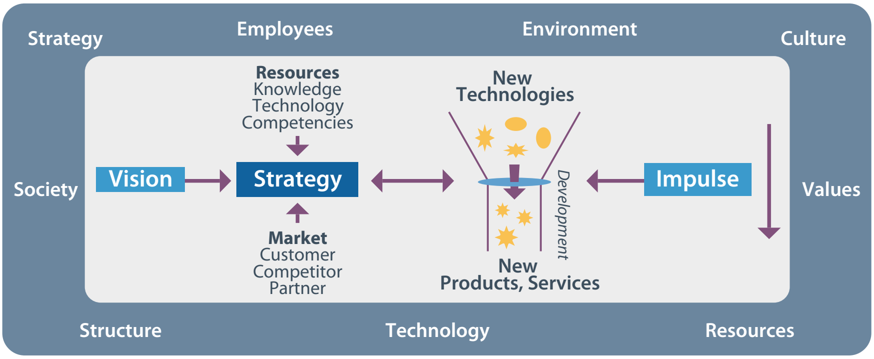

Fig. 1 Innovation management (taken from Gassmann and Sutter 2011, p. 8)

of intellectual property (IP) rights becomes crucial. From an R&D perspective, the issue of the protection of IP rights becomes especially critical in countries where legal frameworks are unsupportive. The strategic-level of innovation management builds the link between more abstract normative-level and highly detailed operational-level management. Moreover, the strategic-level has to position the company internally with regards to employees as well as externally with regards to customers and partners (Fig. 1). Operational-level management focuses on innovation processes which use methods and tools to control performance, quality, costs, and time.

2.2.1 Objects and Degrees of Innovation

Often it is recommended to use innovation portfolio tools to obtain an overview of current innovation projects. Tidd et al. (2001) provide one example of such an innovation portfolio tool. They distinguish four potential innovation objects and three degrees of innovations. The object is the thing being innovated and is categorised as a process, product, service, or business model (Table 1).

Degrees of innovation can be understood in several ways (Crossan and Apaydin 2010; Edison et al. 2013) and a scale of innovation degrees which fits our purposes here stems from Damanpour (1991). Incremental innovation represents variation in existing routines and practices. Radical innovation induces fundamental changes and is a clear change of existing organisational practices. Disruptive innovation changes not only organisational practices, but whole markets by creating new market opportunities as well as value networks and probably displacing established market leaders and alliances (Bower and Clayton 1995). The higher the degree of innovation, the larger the potential influence on the market and the more significant the challenge is likely to be for a company. As Nünlist (2015) stated when talking about competition: “We are not afraid of our competitors, rather more of a sudden game changing start-up that set new market rules.” But why are large enterprises with more resources than start-ups not disruptively innovating themselves? One reason is that such companies might not be able to adjust to fast changing market needs with a workforce of, say, 2500 employees compared to a start-up with only 8

Table 1 Object and degree of innovation with examples from Tidd et al. (2001)

Degree of innovation	Disruptive (high)	Direct democracy	Internet	E-mail	Freeware
	Radical (moderate)	Agile software development	Smartphone	Telealarm	Self-assembly of furniture
	Incremental (low)	Discard redundant forms	Thinner solar panels	Faster food delivery	Maintenance contracts for dishwasher
		Process	Product	Service	Business model
		Object of innovation			

employees—it is as comparing the manoeuvrability of oil tankers with speed boats.: Speed and flexibility is an advantage of start-ups.

2.2.2 Innovation Inhibitors

New technologies can change markets. Given that the market defines what is needed from companies, those companies that can adapt to market needs will survive and others will perish irrespective of their company size. One prominent example is Nokia that missed the changing market demand for smartphones (Lääperi and Torkkeli 2013; Lindholm and Keinonen 2003). But why did this happen? Assink (2006) examined factors that impair companies' ability innovate in a disruptive manner. Figure 2 summarises these barriers to identify disruptive innovation.

- **Path dependency (Field 1)**: Companies which focus on their successful dominant product and service designs tend to concentrate exclusively on incremental innovation (Paap and Katz 2004). With this strategy, companies fail to recognize the emergence of important enhancing technology in their field (Divernich 2007). Nokia, which was slow to react to the emergence of the smartphone concept, is one example (Lääperi and Torkkeli 2013).
- **Inability to unlearn old patterns, logic, and methods to adapt to something fundamentally new (Field 2)**: Companies are forced to change mental models and their theories-in-use to be able to adjust to market dynamics. This requires a learning organisation in which employees master their own development which includes unlearning of old patterns and learning new ones (Senge 2011). Sinkula and Baker (2002) distinguish three innovation drivers which have an influence on a learning organisation: first, management-driven which is mainly incremental; second, market-driven which is also predominantly incremental; and third, engaged generative learning driven which leads to radical or disruptive innovation.

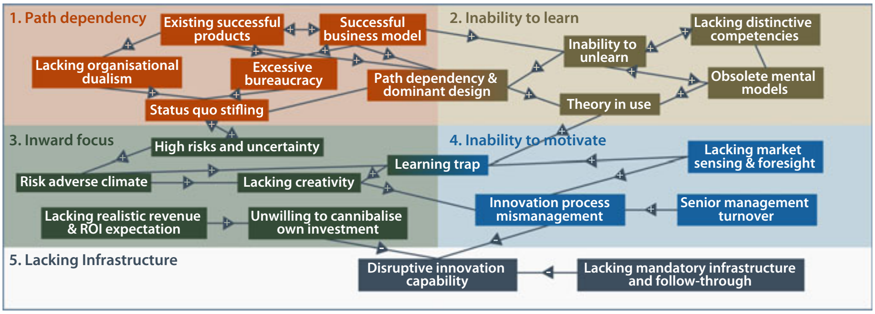

Fig. 2 Model of limiting factors for disruptive innovation (Assink 2006)

- **Inward focus (Field 3)**: Companies are occupied with internal risk optimisation and stabilisation. Required external changes do not register on the company's risk radar. The company exists in a bubble, oblivious to required changes from the outside world. New challenges are tackled by routine processes that have been successful in the past. This leads to biases and distorts realistic revenue expectations, often combined with reluctance to write-off previous unsuccessful investments. All of this severely hinders the development and exploration of disruptive ideas or proactive behaviours (Sandberg 2002).
- **Inability to motivate employees for innovation (Field 4)**: Companies lack the ability to motivate or attract creative and innovative employees with ground-breaking ideas (Stringer 2000). Often these companies observe the market with conventional methods which then result in incremental innovations (Trott 2001).
- **Lacking infrastructure (Field 5)**: Companies might lack the necessary infrastructure, for instance, the transfer of computer files changed drastically with the introduction of internet and wide-area networks (Paap and Katz 2004). It is also possible that there is an insufficient support of infrastructure (Innovatie in Nederland 2003).

Reflecting on the factors which limit disruptive innovation, Chesbrough (2006a) introduced the open innovation approach.

2.2.3 Open Innovation

Open innovation assumes that organisations can use external ideas and externally created paths to market as well as their own pre-existing internal mechanisms.

Table 2 Closed versus open innovation (Chesbrough 2006b)

Closed innovation	Open innovation
The smart people in the field work for us directly	Not all the smart people work for us directly. We need to collaborate with smart people inside and outside our company
To profit from R&D, we must discover, develop, and ship R&D ourselves	External R&D can create significant value; internal R&D is needed to claim some part of it
We will get it on the market first, if we discover it ourselves	We do not have to originate the research to profit from it
The company that first gets an innovation to market wins the race	Building a better business model is more important than being on the market first
We win if we create the most and the best ideas in the industry	We win if we make the best use of internal and external ideas
We should control our intellectual property (IP), so that our competitors do not profit from our ideas	We should profit from others using our IP and we should buy others' IP whenever it advances our business model

Research shows that companies which employ open innovation principles are more likely to create radical or disruptive innovations and tend to sell a greater number of new products (Innauen and Schenker-Wicki 2012). Table 2 compares the characteristics of open and closed innovation (Chesbrough 2006b).

The awareness of opening a company's doors to co-create with outside stakeholders is a crucial factor to the innovation process. The top-management team of a company needs to establish the required framework and space to innovate processes, products, services, and business models. This is not easy, as Google demonstrates. Larry Page and Sergey Brin admitted in Google's IPO Letter for investors 2004, "We encourage our employees, in addition to their regular projects, to spend 20% of their time working on what they think will most benefit Google. This empowers them to be more creative and innovative. Many of our significant advances have happened in this manner." This famous 20%-policy often falls victim to productivity ranking tools designed to appraise management efficacy. These tools force managers to focus on the "here and now" rather than allocating time to more "out there" ideas which do not currently contribute to the bottom line (Ross 2015). Implementing a culture of innovation can take many years. However, a beneficial starting point is moderated pilot projects in heterogeneous groups with stakeholders from the supply chain outside the company. This helps to unfreeze the mind-sets of employees (Lewin 1947).

3 Co-creation in Innovation Management

The reality of innovation management is that data gathering for new products or services in fledgling markets often focuses on internal capabilities and on quantity of data, not on data quality (Kohn 2006). Furthermore, the insight produced from market data is often limited since it can only describe patterns about how customers use already existing products; the data seldom indicate the motivation behind the actual usage of products or the deeper needs of customers. Co-creation fills this gap by involving customers or stakeholders directly in product or service design. In the last ten years, the role of knowledge about users and their respective needs has advanced from specifying functional, usability, and performance requirements alone to also capturing deeper, more affective needs (Schütte et al. 2004). For instance, Apple does not only understand the functional needs of their customers, but also knows the lifestyle, wishes, and emotional states of their clients. Unlike traditional waterfall models of software or product development, user-centred design approaches, e.g. design thinking, uncovers these affective demands. It defines phases in developing innovations by observing stakeholders and eliciting feedback about their state of mind. ISO 9241-210 is a generic example of user-centred design processes for specific technologies including collaborative work systems (Wobbrock et al. 2009). When customers not only provide feedback, but are also integrated in the development process as partners to produce a valued outcome it is called co-creation (Prahalad and Ramaswamy 2004b).

In a supply chain context, this can be seen as co-creation between customer and product or service provider. Co-creation is an approach to value creation through interactions between stakeholders across and even from outside the supply chain to shake up existing, rigid collaboration patterns. Crucially, these stakeholders include the customer who had hitherto been regarded as simply someone to be offered a value proposition (Prahalad and Ramasawamy 2004a, b). From a human factors perspective, collaboration and not only contribution within the supply chain requires skills such as communication, community, shared spaces and open thinking has to be anchored in a company's culture to create mutual benefit. It is a change management challenge to work together as partners instead of a supplier-customer relationship. Design thinking goes even further by placing one partner in the position of naïve apprentice in order to learn from other partners within and also outside the supply chain. The objective is to obtain feedback about a project from a person in the natural setting of the product or service application. Take the example of post-it of Minnesota Mining and Manufacturing (3M) Company: In 1968, Spencer Silver intended to invent the strongest glue ever—but his result was only a weak removable adhesive that failed the goal. In 1974, Art Fry, a friend of Spencer, got annoyed because his little notepapers fell out of his choir book. He asked Spencer to use the removable adhesive to fix his notepapers. The notes adhered without damaging the music sheets when they were removed and so Post-It's found their final purpose through a stakeholder who was not a part of the supply chain (3M 2005). A closed approach may well seek to limit this seemingly unauthorised use, whereas an open co-creative perspective would invite these new users to explain how they are using the product and to possibly build their requests into future iterations, provide schematics, or make the product easier to adapt. A further example of harnessing the ideas of users for product developing is the computer game industry: it actively cultivated fan forums to develop and beta-test their games. Mutual value is therefore created by the company locating interest and therefore a new market and the consumer a new requested game experience.

Design thinking is both a methodology and a mind-set for designing innovations by means of a co-creational process thus bringing a culture of innovation to companies. The change of existing mind-sets starts when participants realise the potential success of the design thinking approach and start to question habitual processes in their company (Brown and Martin 2015). Co-creation and design thinking are gaining more awareness and traction in the business world. More and more large organisations have started collaborating with external parties. Procter and Gamble, for instance, has created the position of "Director of External Innovation". Based on open innovation, new collaboration forms emerged, through which engagement and compelling experiences, new ideas and approaches from various internal and external sources are integrated in a platform to generate new value for customers (Lee et al. 2012). Brown (2008) describes first experiences with design thinking as a methodology of meeting people's needs and desires in a technologically feasible and strategically viable way. In iterative loops visualised assumptions in the form of prototypes are verified by stakeholders or customers.

Osterwalder and Pigneur (2010) created the business model canvas as a supportive tool to visualise prototypes of a business model for iterative development.

"If three people get together, you get the wisdom of not just three, but that of ten people". This Japanese saying shows the power of co-creation, where people with different knowledge and experiences come together to solve a problem (Fast Forward 2030 2014). "Co-creation is the joint, collaborative, concurrent, peer-like process of producing new value, both materially and symbolically" (Galvagno and Dalli 2014, p. 644). Their framework of co-creation (Fig. 4) provides an overview of existing literature on value co-creation. The framework originated from the fields of service science, marketing and consumer research, and innovation and technology. It is organised into two topics: first, theory of co-creation that contains four areas to outline and define co-creation approaches: Service Dominant Logic (SDL), co-creating value through customer experience and competences, online and digital customer involvement, and development of service science. And second, collaborative innovation in new product development which comprises two approaches applied in co-creation: Service innovation and individual consumers and communities, collaborating with companies (Fig. 3).

"Theory of Co-Creation" and "Collaborative Innovation in New Product Development" are described in more detail in the following:

- **Service dominant logic (SDL)**: In SDL, Vargo and Lusch (2008, p. 7) state that "service is the fundamental basis of exchange". This perspective allows a car seller to support the customer with much more than just the car. Now, security support such as driving insurance, or exercises to prevent back pain on long journeys add possible value. Over the last decade Vargo and Lusch (2016) have developed various SDL axioms and premises. Their model envisages co-creation as customers working with companies to build a shared future. Therefore methods, techniques, and tactics to engage productive dialogues need to be developed; additionally, research into motivation for co-creation is overdue and should be carried out (Lusch and Vargo 2015).

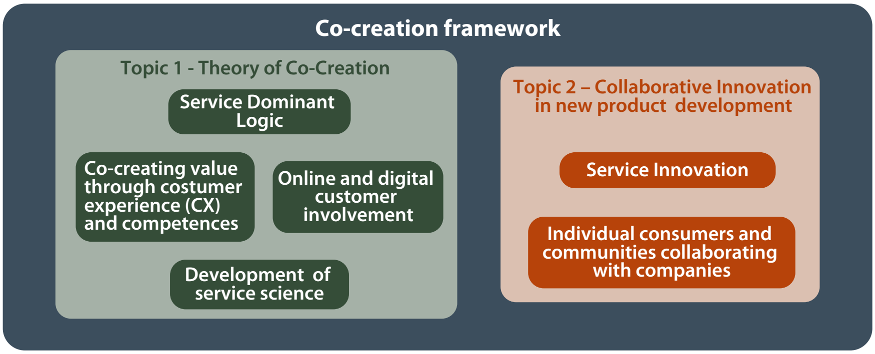

Fig. 3 Value co-creation topics and respective areas (Galvagno and Dalli 2014)

- **Co-creating value through customer experience (CX) and competences**: Customer experience is “the cognitive acknowledgment or perception that follows from stimulated motivation of a customer who observes or participates in an event. Such acknowledgment or perception consequently enhances the value of products and services” (Chen and Lin 2015, p. 41). Verhoef et al. (2009) proposed a conceptual model of the determinants which influence a customer’s experience.
- **Online and digital customer involvement**: Nambisan and Nambisan (2008) formulated five different virtual customer roles for innovation and value co-creation: product conceptualiser, product designer, product tester, product support specialist, and product marketer. Brodie et al. (2013) highlight the importance of enhancing loyalty, satisfaction, empowerment, connection, emotional bonding, trust, and commitment of virtual community members.
- **Development of service science**: Maglio and Spohrer (2008, p. 18) defined service systems as “configurations of people, technology, value propositions connecting internal and external service systems, and shared information (e.g., language, laws, measures, and methods). Service science is the study of service systems aiming to create a basis for systematic service innovation.” In an attempt to integrate service research from different disciplines to meet complex business and societal challenges, four core principles are described by Maglio and Spohrer (2013, p. 669). First, service system entities dynamically configure four types of resources: people, technologies, organisations, and information. Second, service system entities compute value given the preferences of multiple stakeholders. Third, the access rights associated with entity resources are reconfigured by mutually agreed value propositions. And finally, service system entities plan and coordinate actions with others through symbolic processes of valuing and symbolic processes of communicating.
- **Service innovation**: “Service innovation is a new service or a renewal of an existing service which is put into practice and thus providing benefit to the organization that has developed it; the benefit usually derives from the added value that the service innovation provides the customers.” (Toivonen and Tuominen 2009, p. 893). Snyder et al. (2016) propose four emerging themes out of 43 service innovation categories: degree of change, type of change, newness, and means of provision.
- **Customer involvement, individual consumers and communities collaborating with companies**: Within SDL, it is recognised that socio-technical systems are dynamic in as much as they simultaneously function and reconfigure themselves (e.g., Vargo and Lusch 2011). It is also recognised that typical product development stage-gate plans are of limited use when something such as a system adaptation has to be developed in an unknown way and involves predominantly tacit knowledge. Rather, methods that enable the creation of a

shared experience are seen as more effective. The UIW-adaptation system (Chapter "The Challenge" and "The Use-It-Wisely (UIW) Approach" of this book) involves collaboration and self-organisation in the concurrent design of goods, services, business models, and production processes based on evolving and interoperable human and machine knowledge.

In the next section we introduce the methodology of design thinking.

4 Deep Dive 1: Design Thinking

4.1 Purpose of the Methodology

The design research community has yet to clearly defined design thinking (Dorst 2011), but according to Brown (2009), "design thinking functions within a framework of three intersecting 'constraints.' They are 'feasibility', which is what can be done; 'viability', what you can do successfully within a business; and 'desirability', what people want or will come to want." The principle underlying the intersection of desirability, feasibility, and viability is an iterative process. This process includes the development of visualized prototypes, then demonstrating them to customers and observing the customers to learn what they really desire (Maurya 2012). Although this process leads to more failures than successes, it tent to reveal customers' current needs (bootcamp bootleg 2015). To navigate through this process requires a different mind-set and also a high level of empathy for people, hence a human centred approach. The objective of design thinking is to improve the rate at which successful product, service, and business model innovations are brought to the market (Harvard Business Review 2015).

4.2 The Application Process

Even though different design thinking processes are in use (SAP 2016; Tschimmel 2012), all of them apply an iterative exploration and learning process following the 'trial and error' principle. Trial and error is understood as learning by unearthing assumptions and falsifying them in the real world by means of iterations until a sufficient match between problem and solution is found. Figure 5 shows a typical design thinking process. It is the amalgamation of the processes suggested by d. school (bootcamp bootleg 2015) and the Hasso Plattner Institute (2016). The iterative process ceases when the resulting prototype fulfils both people's needs, is technical feasible, and economically viable. The process consists of the six phases: understand, empathise, define the problem, ideate, prototype, and test the solution (Fig. 4).

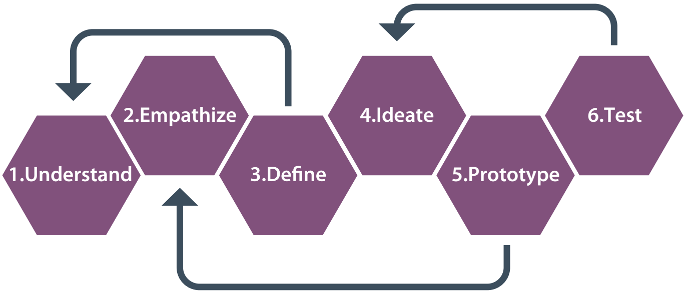

Fig. 4 Amalgamated design thinking process

In the following, we look at these phases in more detail and provide guidance for concrete applications. Here, we do not provide specific techniques for each phase. The interested reader should consider the following references for more details (Curedale 2016; Stickdorn and Schneider 2014).

Before we consider the design thinking process, a short word on the design team. In general, a heterogeneous design team produces a brother range of insights and ideas, but suffers of misunderstandings because different use of expressions. Team setup depends on the type and degree of innovation project (Table 1).

4.2.1 Phase 1: Understand

The phase 'understand' first defines the design scope within a number of actors interact with each other in certain places, and it is within this scope that the design team carries out its search for innovation. Secondly, it helps the design team to communicate their knowledge with mental pictures about actors, places, and reasons in such rather chaotic situations to build up a common understanding in the team. For instance, the design scope for the case of public transport: A design team member shares his knowledge that on average, a commuter (actor) arrives 5 min before boarding a train on the platform in the train station (place) to make sure not to miss the train (reason). The design scope is not fixed. In case new insights emerge in the following phases, the design scope can be adjusted. For example, at the beginning the design scope about public transports includes only trains and buses. Then, through insights from iterations the team includes the last mile and a bicycle sharing in the design scope. Within the design scope, a team elaborates their initial assumptions about a topic leading to a common understanding about actors, places and reasons. This is similar to the boundary of the context used in requirement engineering (Hull et al. 2011).

Hint: Team members often share they knowledge related to existing products or services that can be collected as existing solutions or hints for existing problems. In business, the customer explains his problem based on that a **design challenge**. For example: How can we make public transport for passengers smarter?

4.2.2 Phase 2: Empathise

The goal in this phase is to empathise with people especially target stakeholders to understand their physical and emotional needs and to visualise them. The guiding principle is to walk in the shoes of others. One way is to shadow target stakeholders in their everyday life. For instance, the actor Dustin Hoffmann spent time with Kim Peek, an autistic person, preparing himself for his role in the movie “Rainman”. In the example of smart mobility in public transport this could require following different stakeholders, e.g. commuters, bus drivers, bicycle parking clerks, ticket collectors, disabled passengers, but also extreme users such as fare dodgers, football hooligans, or carnival bands. These groups should be observed not only at the train station or bus stop, but also on their way from home to their destination. Besides participatory observation of their behaviour, taking pictures and videos of problematic or challenging situations is also useful. Another possibility is interviewing people about their positive and negative experiences while using a product or a service. If they feel functionality or information is missing it is known as a “pain point”. If they experience satisfaction, this is called a “gain point”. An important aspect in this phase is to approach uninvolved people and to listen to their stories naively, i.e., without using your previous knowledge. Assume a state of a neutral observer and reporter. Then, create fictive stories that summarise the gained insights during the empathising phase. This helps to convey them to the design team. For instance, Peter (WHO) commutes every day and has to look for a free seat on the train every day during rush hour gets annoyed (WHAT) because he loses ten minutes working time because of this search time (WHY). While WHO and WHAT are visible, some WHY’s are formulated by the stakeholder, but some motives are latent and have to be assumed by the design team. For instance, commuter Peter mentions he needs a seat to work in the train. But latently, he needs to go from A to B and able to work on his laptop during this time. Therefore, the seat is not necessarily a part of the solution to fulfil this needs. Latent motives partly surface in this phase or during phase 3. The team members can imagine such story-based situations and are able to add their comments. For this purpose, team members can visualise their stories on flipcharts. This phase ends, when all obtained stories are communicated and discussed.

Hint: Use story-telling. Every team member has one minute per story to communicate to the team the task in the journey as well as pain and gain points of the stakeholder. Then, the team asks questions and provides feedback to formulate insights within four minutes. An insights for the commuting case is, for example, that a seat is not necessarily needed.

4.2.3 Phase 3: Define

The ‘define’ phase develops a problem statement with a clear **point of view** (**POV**). A POV is the formulated perception of a chosen stakeholder group, about their behaviour and their needs/requirements and motives within the design scope based on the analysis of stories and insights from the previous phase. The analysis consists of discussing and clustering information of the story or insights to reveal latent motives and solution requirements. The following is a possible template: **Who** (stakeholder A) needs **what** (requirement) to do **what** (task) to fulfil **what** (motive). For instance, Peter **needs** a calm place with electricity supply and place for his laptop **to** work in the train **to** reduce his workload to gain time (motive) **to** feel that the time has used meaningfully (latent motive). This POV has once again to be validated by the chosen stakeholder group. Especially the reaction of the stakeholders by confronting them with the latent motive might lead once again to new insights. One example, what else besides work brings a feeling of use time meaningfully in train?

Hint: Technique to reveal latent motives are also called and described as "job to be done" (Silverstein et al. 2012). Another technique is "persona" that describes ab archetype of a stakeholder group.

In principle, the define phase ceases when an accurate definition of a POV exists. However, it might be that new insights emerge during the remaining three phases which require the POV to be reformulated and re-explored. Since this is possible, the speed by which the remaining three phases are executed becomes crucial. It is feasible to have a full-fledged POV within three or four days, when the team has expertise about the design scope. By formulating the POV the working mode of design team changes from formulating customer's needs to finding solution for those needs. For our example: How might we support Peter in working efficiently while he is travelling home from workplace during rush hour? The POV forces the team to focus. Without this focus the team finds itself in an ongoing search without any result, therefore moderation within the design thinking process is recommended.

4.2.4 Phase 4: Ideate

This phase generates ideas for solving the design challenge. A design team may use the technique brainstorming to post ideas on an empty pinboard. A standard brainstorming session consists of three steps under time pressure: First, the design team answers the design challenge by collecting all thoughts and ideas that come to mind without criticizing them (7 min). Second, the team sorts and clusters the ideas and provides headlines (10 min). During this process, new, complementary, or lateral ideas are welcome. And finally, the design team evaluates and rates clusters to decide which solution to prototype in the next phase (8 min). Another way to find novel ideas besides brainstorming is to image how a fictional person might face the POV needs. For instance, what spell would Harry Potter use so that Peter finds space to work while travelling home from work?

The criteria to evaluate and select which idea should be prototyped emerges from the verified requirements of phase 3, for instance, calmness to concentrate or electricity supply. If the idea does not fulfil these validated motives, it should not be prototyped. But ideas should not be rejected too fast; sometimes wild ideas open a new view on the design scope and therefore open up new opportunities. Sometimes it is true that the wilder and newer the idea, the fewer people have thought about this. In our example, if Peter is placed on the top of the train in a glass dome his needs might be fulfilled.

4.2.5 Phase 5: Prototype

In the prototype phase, ideas get visualised in a form that stakeholders can interact with. This may be, for example, a drawing, a business canvas, a storyboard, a cardboard construction combined with role-play, or a LEGO model to allow a "walk through". It is crucial in this phase that the design team focusses on functionality instead of appearance. It is not important how the prototype looks as long as it is recognized as one and the test persons recognise the functionality. However, prototypes can create barriers to progress. Often, the longer a person works on a prototype, the more the person defends it, which is likely to be counterproductive from a learning perspective. It is recommended that the team formulates what they want to explore or test with a prototype before they visualize the function in a most rapid and cost-efficient way. Uebernickel et al. (2015) list several types of prototypes according to the state of the project. In our example the team might construct a cardboard prototype of a train carriage with a plastic dome, showing how it could be accessed.

4.2.6 Phase 6: Test

In this phase, you solicit feedback from your stakeholders about the prototype to learn about the context and gain new insights. Ideally, the prototype is shown without any explanation and creates an experience for stakeholders. The experience is more intensive in an appropriate location. For example, the glass dome prototype is likely to receive more accurate feedback on a noisy train track platform than in a calm restaurant because it is an authentic environment. In the role of a naïve reporter (phase 2) using the technique "5 why's" to inquire about cause-and effect relations to reach a profound level in the test. Perceiving verbal and non-verbal feedback to gain new insights. These new insights might result in reframing the design scope (phase 1) and start a new iteration of the design process. It is important to work through all of the six phases quickly to prevent too much frustration resulting from failing prototypes. After several, sometimes hundreds of, rounds of prototyping, a fitting solution to a problem or even an innovation may be found. Moreover, the design team should have gained a lot of knowledge about the design scope.

4.3 Expected Results of Applying the Methodology and Limitations

Design thinking is a methodology which seeks to reveal unknown opportunities for innovation because neither the designer nor the test person nor the stakeholder knows the outcome of a design project. Design thinking is a human-centred approach and therefore suitable for every human interaction with products, services, processes or proof of concepts development. Design thinking is meant to be used for radical or disruptive innovations. It is less useful in contexts of incremental innovation projects, because it reveals and focuses on unknown or latent needs of stakeholders. IDEO's example of the first computer mouse for Apple is exemplary for a radical innovation. Financial resources alone are not sufficient for successful design thinking projects. What is required is a mind shift of team members, who learn to deal with failing by focusing on generating insights and learning, instead of being correct in their assumptions. Design thinking helps to transform companies into learning organisations (Senge 1996).

Pangaro (2012) describes design thinking as an improvement over analytical thinking in business. But he also states that design thinking will not solve problems, because it is neither a discipline nor a methodology and hence lacks clear process descriptions. He rather sees design thinking as a set of techniques. Meinel, Plattner and Leifer address this lack and establish a design thinking research program to improve and describe design thinking in more detail (HPI—Stanford 2016). Initial research into performance measurement of design thinking in co-located and business teams has been published (Meinel et al. 2012), and their results show that, amongst other things, the concept of mind shift or strengthening the development of epistemological viewpoints (POVs) improve in participants while performing design thinking projects. HPI provides further examples of the impact of design thinking in practical applications (HPI 2016).

5 Deep Dive 2: Business Model Canvas

Business model is one of the four types of innovation (Table 1). The following section outlines the business model canvas, which is relatively quick and simple way of capturing nine important elements of a business model. These nine elements are clustered into the revenue and expense section of the table thus reflecting more profoundly the relationship between customer profile and value proposition (Fig. 5).

5.1 Purpose of the Method

To keep up with this pace of change, tools are required to assemble and visualise the most important facets of potential business opportunities. The business model canvas (Osterwalter and Pigneur 2010) is one such tool used to analyse and develop business models. It focuses on the most important elements to obtain a quick overview of an organization's business model, thereby providing a basis for discussions. The canvas method was developed to create a common understanding and thus increases the effectiveness of teams. The business model canvas specifies nine elements and follows a clear procedure, which will be dealt with in section "Applying the method".

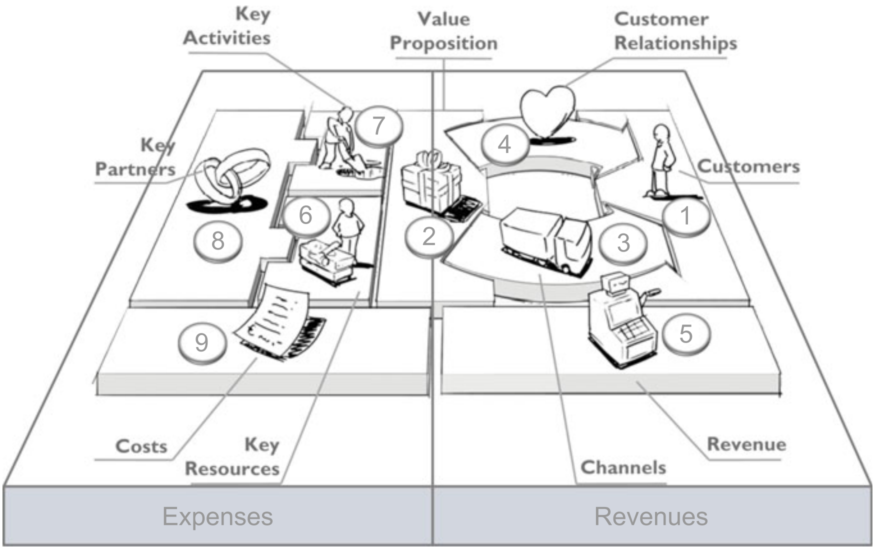

Fig. 5 Elements of business model canvas (Osterwalter and Pigneur 2010)

5.2 *Applying the Method*

When following the business canvas method, we recommend copying the template (Abb. 4.5) to a flipchart, providing the team with markers and using Post-It's to describe each element with content in the provided field. A team workshop typically requires 45 min. The process of describing the nine elements (3 min for each element, in total: 27 min) is followed by a phase for sorting and discussing the intermediate results (13 min) and ends with a wrap-up phase (5 min) to finalize the canvas. This section briefly describes the process, guiding questions, and recommendations for each element.

1. **Customers**: Customers pay for the offered value proposition and they are segmented for the purpose of the canvas. For whom are we creating value? Potential customer segments are listed. The level of detail in the segmentation depends on the type of market (e.g., niche vs. mass market). In the creation of a business model for new products and/or services, it is important that the team identifies and empathises with promising customers, as described in first deep dive about design Thinking. For instance, commuters with an ICT affinity, who work with laptops on their way home.
2. **Value Proposition**: The value proposition is not necessarily a product or a service, it can be any added value. For instance, commuting by train is not just the physical transfer but there is also the ecological life style aspect, which certain customers will value. What value do we offer to our customers? A list with monetary, emotional, environmental or sustainable values is created. To

avoid confusion, we recommend choosing only the most promising customer segments for which the value proposition is then defined. One example is the working ICT affine commuters, who are concerned about their ecological footprint. The match between customer and value proposition is essential as we explain later in more detail.

3. **Channels**: How does our value proposition reach the customer? Both current and potential information and distribution channels are listed here. It is helpful to imagine a typical customer journey and concentrate on the points of contact with the customer. It is important that the selected channel fits to the customer's expectation of the value. Hence, the channel supports or enables the value proposition. For instance, ecological ICT affine commuters might identify a glossy brochure as a waste of paper.
4. **Customer Relationship**: What is the relationship to our customer? The answer depends on how the company segments its customers. The relationship to a key customer may be different than to a sporadic customer. The needs of an infrequent holiday train traveller can be distinguished from a daily commuter. One idea is to use the customers' images and add attributes to define the relationship. For instance, the personalised customer's image of a railway company might be a conductor in uniform who emits reliability and kindness. This picture changes or solidifies through experience with the railways.
5. **Revenues**: What are the revenue streams? All revenues streams the organization can possibly generate should be listed. It is best to distinguish between unique payments, licencing royalties, rental payments or membership fees to estimate recurring revenues. For instance, Swiss National Railways offers annual cards (allowing "free" travel or half price), monthly cards or day/return/single tickets. In addition Swiss National Railways is a partner of a bicycle renting company located at train stations, where travellers can rent bicycles.
6. **Key Resources**: What is needed to create the value? Resources required to create the value proposition have to be detailed. Key resource might be infrastructure resources (trains and tracks), human resources (conductor), knowledge resources (research reports, intellectual property rights.
7. **Key Activates**: What has to be done to create the value? List all the activities that resources from the previous element have to fulfil. A mental walkthrough through the value creation process is the best way to discover these important activities. Resources without any activity in the value creation process are eliminated. Moreover, activities without any internal resources should be outsourced to partners. In our case of the commuter example this would be the train wagon interior equipment and services offered for commuters during the train ride.
8. **Key Partners**: What key partner do we need to guarantee the key activities? Reflect on the partners needed to create the value and to complete the tasks we cannot complete internally. Consider the additional transaction costs of external partners. Cooperation also results in interdependency by asymmetrical information. An advantage however is that the organization obtains expertise and external resources to actually produce the high quality value. For instance, the

core business of the Swiss National Railway is to transport people not to support them with ICT services. Therefore, the railway might cooperate with an ICT service provider.

9. **Cost**: What are the costs associated with creating the value? Activities, resources, and costs of using partners have to be summarized. Distinguishing between fix and variable costs helps to estimate the recurring costs.

The business model canvas contains the described nine elements and should be elaborated in this order. Additionally it is partitioned in two sections: A revenue section which contains the elements #1 to #5, and a cost section which contains the elements #6 to #9. Figure 5 shows both sectors. The comparison of these two sectors results in a rough estimation of the viability of the developed business model and provides a basis for discussion. The business model canvas was criticised of its rather superficial guidance for defining the value proposition. Hence, Osterwalder et al. (2015) provided a more detailed approach, which is shown in Sect. 5.3.

5.3 Customer Profile and Value Proposition

A better understanding of the customer allows us to create a more appropriate and sophisticated value proposition. The two arrows in the middle of Fig. 6 indicate the essential question: Does the product or service fulfil the jobs of the customer? What function eases the customer's pains? What function increases the customers' gains?

Osterwalder et al. suggest interviews or observations to collect information about customers' jobs and their pains and gains to create a customer profile. For instance, Peter commutes every day by train from home to work. Compared to driving with the car, he can work on his computer in the train (gain), but gets annoyed by the noise in a train wagon (pain). Peter in the example, is a fictional person and represents the customer segment "working commuters".

Then, the design of a value proposition can be used to create the answer to what product or service might ease the pains and increase the gains for this customer segment. For instance, the Swiss National Railway might offer Peter a train to commute from home to his office (service) and in the train they offer him a working space with bench and table and also an electricity socket for his laptop (gain creator). Finally, they label a train wagon with "Business Wagon" where only silent working is aloud (pain killer). The match between customer profile and value proposition has to be verified by customer tests. In iterative loops customer profile and value proposition have to be adjusted till test customers approve the match.

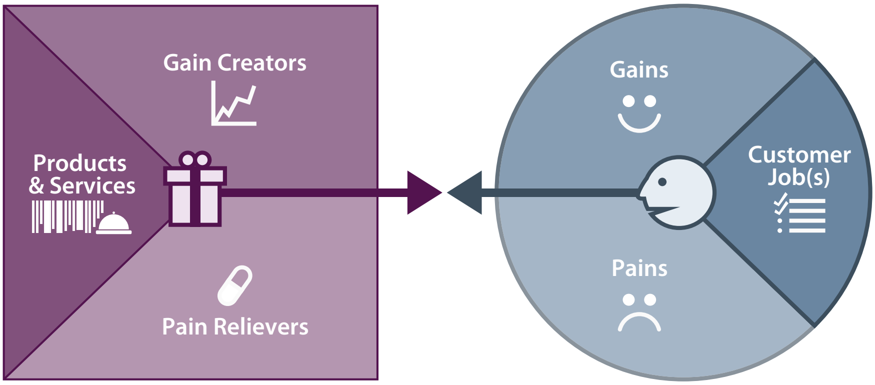

Fig. 6 Match of value proposition and customer profile (Osterwalder et al. 2015)

5.4 *Expected Results of Applying the Methods and Its Limitations*

The business model canvas forces the author to focus on the important nine elements of a business model. The business model canvas is a method that allows, within a short time, the user to gain an overview of a business model and builds a basis for discussion. The tool is also beneficial for prototyping. However, these nine elements only consider the business meso-level. To allow for a more general overview, Osterwalter and Pigneur (2010) have been working on a business macro-level model consisting of four elements: Market forces, industry forces, key trends and macro-economic forces. However, the business canvas model does allow a profound understanding of the relationship between customer and value proposition on a micro-level provided by defining the customer profile in accordance with the value proposition (Osterwalder et al. 2015).

Currently the business model canvas is predominantly used in an early phase of the business model development to develop a common understanding within the development team and to communicate ideas. It can be used as a basis for discussion to reveal misunderstanding and gaps. The business model is however less suited to analysing the internal or external dynamic consequences of a new business model. One possible way to overcome these limitations is to use system dynamics simulation to quantify the relevant elements of a business model as suggested by Groesser and Jovy (2016) and also Groesser in Chapter "Complexity Management and System Dynamics Thinking" in this book—in which the strengths of simulation methodologies when designing business models are discussed.

6 Conclusion

The maxim *survival of the fittest* seems to apply to most established companies operating in fast-changing markets prone to disruptive entry by start-ups. Companies are forced, through permanent contact and interaction with their market environment, to constantly adapt their offerings. This adaption happens not only in R&D departments but also throughout whole companies (Gassmann and Sutter 2011). To manage innovation we recommend creating an innovation portfolio which differentiates in object (process, product, service, or business model) and degree of innovation (incremental, radical, or disruptive). Interaction with, and adaption to the market environment lead to fundamentally new forms of collaboration for innovation; this is known as co-creation (Galvagno and Dalli 2014). Established enterprises fear disruptive innovations emerging from start-ups which change the whole market. Despite resources and methods like design thinking (Brown 2008) or business model canvases (Osterwalter and Pigneur 2010), companies, especially large enterprises, suffering from inhibiting factors (Assink 2006) and difficulties regulating open innovation (Chesbrough 2006b) that decelerates the speed of adjustment to the market or exploitation of new technologies. As a stop gap, while attempting to evolve into learning organisations (Senge 1996), companies are scanning the start-up market for take over opportunities or implementing separate organisational entities such as innovation centres (Lee et al. 2012).

References

3M. (2005). *Post-it Haftnotizen feiern Geburtstag*. Retrieved April 7, 2016, from http://presse.3mdeutschland.de/buero-kommunikation/Post-it_Haftnotizen__2005-02-21_14_50_20

Assink, M. (2006). Inhibitors of disruptive innovation capability: A conceptual model. *European Journal of Innovation Management, 9*(2), 215–233.

Bergmann, G., & Daub, J. (2008). *Systemisches Innovations- und Kompetenzmanagement*. Wiesbaden: Gabler.

bootcamp bootleg. (2015). *d.school*. Retrieved from https://dschool.stanford.edu/wp-content/uploads/2011/03/BootcampBootleg2010v2SLIM.pdf

Bower, J. L., & Clayton, C. M. (1995). *Disruptive technologies: Catching the wave*. Boston: Harvard Business Review.

Brodie, R. J., Illic, A., Juric, B., & Hollebeek, L. (2013). Consumer engagement in a virtual brand community: An exploratory analysis. *Journal of Business Research, 66,* 105–114.

Brown, T. (2008). Design thinking. *Harvard Business Review, 86*(6), 84–92.

Brown, T. (2009). *Change by design*. New York: HarperCollins.

Brown, T., & Martin, R. L. (2015). *Design for action*. Harvard Business Review.

Bundesministerium für Bildung und Forschung. (2015a). *Die neue Hightechstrategie*. Retrieved from https://www.bmbf.de/de/die-neue-hightech-strategie-86.html

Bundesministerium für Bildung und Forschung. (2015b). *Zukunftsprojekt Industrie 4.0*. Retrieved from https://www.bmbf.de/de/zukunftsprojekt-industrie-4-0-848.html

CHAOS Manifesto 2013. (2013). *Vision one*. Retrieved from https://www.versionone.com/assets/img/files/CHAOSManifesto2013.pdf

Chen, S. C., & Lin, C. P. (2015). The impact of customer experience and perceived value on sustainable social relationship in blogs: An empirical study. *Technological Forecasting and Social Change, 96,* 40–50.

Chesbrough, H., Vanhaverbeke, W., & West, J. (2005). *Open innovation: A new paradigm for understanding industrial*. Oxford: University Press.

Chesbrough, H. W. (2006a). *Open innovation: Researching a new paradigma*. Oxford: Oxford University Press.

Chesbrough, H. W. (2006b). *Open innovation—The new imperative for creating and profiting from technology*. Cambridge: Harvard University Press.

Crossan, M. M., & Apaydin, M. (2010). A multi-dimensional framework of oragnizational innovation: A systemic review of the literature. *Journal of Management Studies, 47*(6), 1467–6486.

Curedale, R. (2016). *Design thinking process and methods*. Topanga: Design Community College.

Damanpour, F. (1991). Organizational innovation—A meta-analysis of effects of determinants and moderators. *Academy of Management Journal, 34,* 555–590.

Divernich, F. E. P. (2007). *Pfadabhängigkeit im Management*. Stuttgart: W.Kohlhammer.

Dorst, K. (2011). The core of 'design thinking' and its application. *Design Studies, 32*(6), 521–532.

Edison, H., Bin Ali, N., & Torkar, R. (2013). Towards innovation measurement in the software industry. *The Journal of Systems and Software, 86*, 1390–1407.

Fast Forward 2030. (2014). *CBRE*. Retrieved from http://www.cbre.com/research-and-reports/future-of-work

Galvagno, M., & Dalli, D. (2014). Theory of value co-creation: A systemic literature review. *Managing Service Quality, 24*(6), 643–683.

Gassmann, O., & Sutter, P. (2011). *Praxiswissen Innovationsmanagement*. München Carl Hanser.

Groesser, S. N., & Jovy, N. (2016). Business model analysis using computational modeling: A strategy tool for exploration and decision-making. *Journal of Management Control, 21*(1), 61–88. doi:10.1007/s00187-015-0222-1

Harvard Business Review. (2015). *The evolution of design thinking*, from https://hbr.org/product/harvard-business-review-september-2015/BR1509-MAG-ENG

Hasso Plattner Institute. (2016). *School of design thinking*. Retrieved January 31, 2016, from http://hpi.de/en/school-of-design-thinking.html

Hauschildt, J., & Salomo, S. (2011). *Innovationsmanagement*. München: Vahlen.

HPI. (2016). *Design thinking research program*. Retrieved June 13, 2016, from http://hpi.de/de/dtrp/programm/uebersicht.html

HPI—Stanford. (2016). *Design thinking research program*. Retrieved June 6, 2016, from http://hpi.de/en/dtrp/program/overview.html

Hull, E., Jackson, K., & Dick, J. (2011). *Requirements engineering*. Heidelberg: Springer.

Innauen, M., & Schenker-Wicki, A. (2012). Fosterin radical innovations with open innovation. *Journal of Innovation Management, 15*(2), 212–231.

Innovatie in Nederland. (2003). Voorburg: Centraal Bureau voor de Statistiek.

Kohn, K. (2006). Managing the balance of perspectives in the early phase of NPD: A case study from the automotive industry. *European Journal of Innovation Management, 9*(1), 44–60.

Lääperi, A., & Torkkeli, M. (2013). *Case study: Challenges in innovation management through paradigm shifts in the mobile phone and smartphone markets.* Paper presented at the ISPIM—The International Society for Professional Innovation Management, Manchester.

Lee, S. M., Olson, D. L., & Trimi, S. (2012). Co-innovation: conver genomics, collaboration, and co-creation for organizational values. *Management Decision, 50*(5), 817–831.

Lewin, K. (1947). Frontiers in group dynamics: Concept, method and reality in social science; social equilibria and social change. *Human Relations, 1,* 5–41.

Lindholm, C., & Keinonen, T. (2003). *Mobile usability: How Nokia changed the face of the cellular phone*. New York: Mc Graw-Hill.

Lusch, R. F., & Vargo, S. L. (2015). *The service-dominant logic of marketing: Dialog, debate, and directions*. London: Routledge.

Maglio, P. P., & Spohrer, J. (2008). Fundamentals of service science. *Journal of Academic Marketing Science, 36,* 18–20.

Maglio, P. P., & Spohrer, J. (2013). A service science perspective on business model innovation. *Industrial Marketing Management, 42,* 665–670.

Maurya, A. (2012). *Running lean*. Sebastopol: O'Reilly.

Meinel, C., Plattner, H., & Leifer, L. (2012). *Design thinking research: Measuring performance in context*. Berlin: Springer.

Müller-Prothmann, T., & Dörr, N. (2009). *innovationsmanagement - Strategien, Methoden und Werkzeuge für systematische Innovationsprozesse.* München: Carl Hanser.

Nambisan, S., & Nambisan, P. (2008). How to profit from a better 'virtual customer enviornment'. *MIT Sloan Management Review, 49*(3), 53–61.

Nünlist, S. (Producer). (2015, April 30). Vernetzte Welten. *Swisscom User Experience Day*. Retrieved from https://www.swisscom.ch/de/about/innovation/open-innovation/cx-day-april-2015.html

Osterwalter, A., & Pigneur, Y. (2010). *Business model generation*. Hoboken: Wiley.

Osterwalder, A., Pigneur, Y., Bernarda, G., & Smith, A. (2015). *Value proposition design*. Frankfurt: Campus.

Paap, J., & Katz, R. (2004). Anticipating disruptive innovation. *Research Technology Management, 47*(3), 13–22.

Pangaro, P. (2012). *Limitations of design thinking*. Retrieved May 28, 2016 from https://vimeo.com/42136543

Prahalad, C. K., & Ramaswamy, V. (2004a). Co-Creating unique value with costumers. *Strategy & Leadership, 32*(3), 4–9.

Prahalad, C. K., & Ramaswamy, V. (2004b). Co-creation experiences: The next practice in value creation. *Journal of Interactive Marketing, 18*(3), 5–14.

Ross, A. (2015). *Innovating professional services: Transforming value and efficiency*. Farnham: Ashgate.

Sandberg, B. (2002). Creating the market für disruptive innovation: Market proactiveness at the launch stage. *Journal of Targeting, Measurement and Analysis for Marketing, 11*(2), 184–196.

SAP. (2016). *Introduction to design thinking*. Retrieved January 31, 2016, from https://experience.sap.com/skillup/introduction-to-design-thinking/

Schumpeter, J. A. (1934). *The theory of economic development*. Cambridge (MA): Harvard University Press.

Schütte, S. T. W., Eklund, J., Axelsson, J. R. C., & Nagamachi, M. (2004). Concepts, methods and tools in Kansei engineering. *Theoretical Issues in Economics Science, 5*(3), 213–214.

Senge, P. M. (1996). *The fifth discipline and the infrastructures of a learning organization [Videocassette (VHS)].* Waltham, MA: Pegasus Communications.

Senge, P. M. (2011). *Die fünfte Disziplin - Kunst und Praxis der lernenden Organisation*. Stuttgart: Klett-Cotta.

Silverstein, D., Samuel, P., & DeCarlo, N. (2012). *The innovator's toolkit*. Chichester: Wiley.

Sinkula, J. M., & Baker, W. E. (2002). Market orientation, learning orientation and product innovation: Delving into the organization's black box. *Journal of Market-focused Management, 5*(1), 5–23.

Snyder, H., Witell, L., Gustafsson, A., Fombelle, P., & Kristensson, P. (2016). Identifying categories of service innovation: A review and synthesis of the literature. *Journal of Business Research. 69,* 2401–2408.

Stickdorn, M., & Schneider, J. (2014). *This is service design thinking*. Amsterdam: BIS.

Stringer, R. (2000). How to manage radical innovation. *California Management Review, 42*(4), 70–88.

Tidd, J., Bessant, J., & Pavitt, K. (2001). *Managing innovation: Integrating technological, market and organizational change*. Chichester: Wiley.

Toivonen, M., & Tuominen, T. (2009). Emergence of innovations in services. *The Service Industries Journal, 29*(7), 887–902.

Trott, P. (2001). The role of market research in the development of discontinuous new products. *European Journal of Innovation Management, 4*(3), 117–125.

Tschimmel. (2012). *Design thinking as an effective toolkit for Innovation*. Tschimmel 2012.

Uebernickel, F., Brenner, W., Pukall, B., Naef, T., & Schindelholzer, B. (2015). *Design thinking—Das Handbuch*. Frankfurt: Frankfurter Allgemeine Buch.

Vahs, D., & Burmester, R. (2005). *Innovationsmanagment—Von der Produkt Idee zur erfolgreichen Vermarktung*. Stuttgart: Schäffer-Poeschel.

Vargo, S. L., & Lusch, R. F. (2008). Service dominant logic: Continuing the evolution. *Journal of Academic Marketing Science, 36,* 1–10.

Vargo, S. L., & Lusch, R. F. (2011). It's all B2B…and beyond: Toward a systems perspective of the market. *Industrial Marketing Management, 40*(2), 181–187.

Vargo, S. L., & Lusch, R. F. (2016). Institutions and axioms: An extension and update of service-dominant logic. *Journal of Academic Marketing Science, 44,* 5–23.

Verhoef, P. C., Lemon, K. N., Parasuraman, A., Roggeveen, A., Tsiros, M., & Schlesinger, L. A. (2009). Customer Experience creation: Determinants, dynamics and management strategies. *Journal of Retailing, 85,* 31–41.

von der Oelsnitz, D. (2009). *Die innovative organisation*. Stuttgart: Kohlhammer.

Wobbrock, J. O., Ringel Morris, M., & Wilson, A. D. (2009). *User-defined gestures for surface computing*. Paper presented at the CHI'09 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems New York.

Complexity Management and System Dynamics Thinking

Stefan N. Grösser

Abstract With the dawn of the internet, mobile technology, cloud computing etc. our socio-technical environment has become ever more intertwined and hyper-complex. The field of complexity management tries to devise methods and methodologies to cope with the challenges arising from complexity. This chapter provides a brief overview of the field of complexity management. More specifically, it defines in detail the terms complexity and dynamic complexity. Dynamic complexity is most relevant for high impact decisions and I examine two methods First, causal context modelling (CCM). This is an integrative, qualitative, transdisciplinary approach which creates a qualitative description of a system including key variable interdependencies and system boundaries. The second methodology I explore is system dynamics (SD). Here I provide examples from a project carried out within the Use-it-Wisely project which helped the companies involved understand and deal with the dynamic problems facing them.

Keywords Systems thinking · Causal context model · Context analysis · Qualitative method · Simulation method · Quantitative method · System dynamics · Mixed-methods · Integrative design · Complexity management · Dynamic complexity

1 Introduction

Leonardo Da Vinci said "simplicity is the ultimate sophistication" (Gaddis 1955; Granat 2003). Most managers would agree. Nobody would deny that the world has become more complex during the past decades due to technological change and globalization. With digitization, the interconnectivity between people and things has rapidly increased. Dense networks now define our technical, social, and

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particularly, business environments. The idea of applying complexity science to management was first discussed in the 1990s (Straub 2013). Popular literature propagated the ideas of complexity theory—in particular, the notion of the "butterfly effect" by which a small event in a remote part of the world could trigger a chain of events that would add up to a disruptive change in the whole system. Managers' eyes were opened to the reality that organizations are not just complicated but complex.

This growing complexity is why many management thinkers have been urging businesses to embrace complexity to become, in effect, system thinkers rather than reductionists. However, Straub (2013) states that complexity is not something managers need to embrace, merely something executives need to accept and manage. In fact, complex issues are often made worse by organizations themselves, especially by the approaches they adopt to deal with these issues (Isanda 2014). Managers and other business leaders seem to be vaguely aware of complexity's existence, and those that know of its existence do not know how best to deal with it—usually resorting to wishing it away or using models that give simplistic solutions that cannot be applied in turbulent and complex environments.

If you ask managers for the major business challenges within the next ten years, you will get the answer "complexity" quite frequently. It is a reoccurring theme in annual reports, analyst calls, and public speeches (Satell 2013). Failing to manage complexity causes high transition and overhead costs as well as frictional losses, inefficiencies, and difficulties in overall strategic orientation or incomprehensibility of the value chain. In particular, the challenge of managing high value assets has become ever more complex (see the challenges in chapter "The Challenge" in this book). It is therefore all the more important that decisions makers develop a deep understanding of complexity.

In this chapter, I provide a brief background on complexity and tools for its management. I define different types of complexities and then focus on dynamic complexity. Thereafter, I introduce causal context modelling (CMM) a specific method to structure messy problems. Then, I introduce the simulation methodology of system dynamics (SD). Both methods are highly useful when addressing the challenges resulting from the maintenance and upgrading of high-investment, industrial product-service systems (IPSS).

2 Background on Complexity and Tools for Its Management

Complex systems can be found anywhere multiple actors interact, are subject to feedback dynamics, and are influenced by time delays between cause and effect (Sterman 1994, 2002; Groesser 2014). Section 2 details six systems approaches that can help to understand and manage complex systems. These are soft system modelling (SSM), viable system model, mental models of dynamic systems, and group model building. Additionally in Sects. 3 and 4, I detail the methods of CMM and SD. But first, let us take a look into the underpinnings of complexity theory.

2.1 Selected Background on Complexity

The field of complexity theory or complexity science is vast and I do not intend to cover it comprehensively in this chapter. Rather, I briefly introduce complex adaptive systems (CAS) because they can be considered a theoretical background to many methods developed in the field of complexity management. More comprehensive overviews are available (Anderson 1999; Lewin 1999; Phelan 2001; Schwaninger 2009a, b).

"Adaptive social systems are composed of interacting, thoughtful (but perhaps not brilliant) agents. […] What it takes to move from an adaptive system to a complex adaptive system is an open question and one that can engender endless debate. At the most basic level, the field of complex systems challenges the notion that by perfectly understanding the behaviour of each component part of a system we will then understand the system as a whole" (Miller and Page 2007: 3). Miller and Page refer to the difficulty of including aspects of complexity in a definition such as this. Simon understands CAS as "a large number of parts that have many interactions" (Simon 1997: 230). This definition corresponds with Gell-Mann (1995) who speaks of a CAS as an information processing system that "acquires information about its environment and its own interaction with that environment, identifying regularities in that information, condensing those regularities into a kind of 'schema' or model, and acting in the real world on the basis of that schema. In each case, there are various competing schemata, and the results of the action in the real world feedback to influence competition among those schemata" (Gell-Mann 1995: 117).

As Levy (1994) states, CAS can be found in a number of fields, including ecology, medicine, international relations and economics. In each case there are nonlinear and network feedback systems that handle information in a similar way. Gell-Mann (1995), Stacey (1995), Beinhocker (1997) and Pascale (1999) assert that the behaviour of CAS is at the root of the science of complexity. An illustration is provided by Bonabeau and Meyer (2001) who cite the example of ant colonies. In these colonies, interacting ants (agents) in an open-system are guided by simple rules. On an individual level, the behaviour of the ants seems to be random and unpredictable. However, on the macro-level, the collective behaviour that emerges out of the interactions between the ants exhibits a distinct pattern, resulting in a nonlinear growth of efficiency in the system—the ants' behaviour is characterized by flexibility, robustness and self-organization (Bonabeau and Meyer 2001). A similar example is provided by Kupers (2000) who observes that a group of door-to-door sales persons use random feedback loops to exchange information with each other on how to increase sales (i.e. how to increase the efficiency of the system). These feedback loops and exchanges of information lead to nonlinear and jumpy growth in sales (i.e. nonlinear increases in the system's efficiency). Thus, small causes of change can possibly have enormous effects on the outcome (the butterfly effect), through the non-linear amplification from feedback loops. Even a simple feedback system may result in (deterministic) chaos with an unpredictable outcome (Holbrook 2003). Anderson et al. (1999) suggests four elements that characterize [CAS] models that have particularly interesting implications for organizational theorists.

- **Agents with schemata**: Anderson's first element entails the idea that an organization's higher-level outcomes are produced by a system of agents at a lower level of aggregation such as individuals, groups or coalitions of groups. The agents act according to a schema, i.e., a cognitive structure that determines what action the agent takes at time *t*, given its perception of the environment at time *t* (or at an earlier time, if theoretical considerations suggest applying a delay). The schemata are often modelled as a set of rules, but they can also be represented by a neural network that consists of a set of connected nodes where a signal from one node leads to a specific activation of the other. This understanding seems to be similar to Gell-Mann's (1995) depiction of CAS processes.
- **Self-organizing networks sustained by importing energy**: The second key element characterizing CAS is seen in the self-organization in such systems, where pattern and regularity emerge without the intervention of a central controller. There are three important notions behind the concept of self-organization: First, self-organization is the natural result of nonlinear interaction between simple agents. Nonlinear interaction in this context refers to self-reinforcing feedback cycles that can lead to self-amplifying behaviours. One condition for the existence of self-reinforcing feedback cycles is that interaction takes place between a large numbers of components. However, there is niether a lower boundary of interactions for self-organization nor also an upper one. Second, if interaction takes place between too many organizational actors, self-organization does not lead to pattern formation. In real human systems, however, agents only act on information available in their immediate environments: from those few agents connected to them in a feedback loop. And third, self-organization only occurs in open systems such as human organizations when energy is imported from the outside. The pattern, or dissipative structure, can only be sustained when the members contribute energy to make, break or maintain their ties to others.
- **Coevolution to the edge of chaos**: The third element is represented in the model of a "fitness landscape". This is a metaphorical map of a mountain region, where agents act to increase their payoff or fitness, i.e., their altitude (Epstein and Axtell 1996). The landscape continually shifts because it is affected by the agent's actions. Also, the individual fitness functions of agents affect each other as each individual trajectory is adjusted according to the successes of its neighbours (Eberhart et al. 2001). In this sense, agents usually co-evolve at a local level. The co-evolvement leads to a dynamic equilibrium in the system which might be thought of as teetering on the edge of chaos (Beinhocker 1997). Small changes in the actions or the behaviour of agents can have small, medium,

or large impacts on the system as a whole. If the system is in chaos, i.e., beyond the edge, then small changes in behaviour lead to widely different fitness levels, systems can reach extraordinary fitness peaks, but cannot remain on them. The slightest change in behaviour will send the system tumbling off its peak, perhaps plunging into a region of very low fitness. On the other hand, if small changes in behaviour lead only to small cascades of co-evolutionary change, the system's performance can never improve much.

- **Recombination and system evolution**: The fourth element is that every aspect of a complex adaptive system—agents, their schemata, the nature and strength of connections between them, and their fitness functions can change over time. That is, new agents and new schemata can be introduced to the system, and ties between agents emerge, break and are sometimes re-established. To model an organization, it is important to consider that the relationship between variables (or agents) is not fixed (as in traditional causal models).

2.2 *Definition of Complexity*

After this brief examination of the theoretical background of complexity research, let us move our attention to practical side of things and concentrate on the management of complexity and the tools used. Research on the management of complexity and complex systems is particularly considered in technological and natural sciences (Bleicher 2004; Kastl and Schmid 2008). Since the 1960s, the social sciences have repeatedly analysed the steering of complex systems within the field of management theory (Malik 2008). In both the realms of scientific research and society in general, there is still no uniform understanding and consensus on the concept of complexity. Equally, it is not possible to find a consistent and generally-accepted definition of complexity. Depending on the pursued research goal or which method is applied, definitions and interpretations differ substantially (Kirchhof 2003; Scherf 2003; Rall and Dallhöfer 2004; Kersten et al. 2012).

Ulrich and Fluri (1992) define complexity in terms of situations that contain a high diversity of influencing factors and numerous mutual interdependencies which prevent structural decision-making. However, complexity must be distinguished from complicated systems. The difference between complex and complicated issues is determined by the degree of predominant uncertainty. Results in complicated systems are predictable due to the linear behaviour of their variables (Simon 1962).

Casti (1994) determines complexity by means of specific criteria. Complex systems do not possess a central control centre but rather consist of numerous, communicating units. Furthermore, feedback relationships between variables and delayed cause-and-effect are present within the complex system. The most prominent feature, however, is the characteristic of irreducibility, i.e., the system as a whole is greater than the sum of its parts and exhibits dynamic, emergent patterns.

Klabunde (2003) describes complexity through the characteristics of variety, connectivity and dynamics. Variety concerns the number and type of elements in a system, whereas connectivity deals with the number and type of the relationships between the variables. The characteristic "dynamic" captures the uncertainty and unpredictability of complex systems (Denk and Pfneissl 2009; Schoeneberg 2010).

Groesser (2015a, b, c) and others create the distinction between simple, complicated, complex, and hyper-complex (i.e., chaotic) systems. These four types of systems can be divided into a four-field matrix representation (Fig. 1), which is spanned by the system characteristics "variety/diversity" (y-axis) and the "variability/momentum" (x-axis).

- A **simple system** is characterized by a low number of components, which are not subject to variability themselves. An example is a simple process of predetermined steps in a production chain. In a simple system it is possible to estimate the progression of effects since they are stable over time.
- A **complicated system** comprises many combinatorial possibilities that arise due to the large number of components in the system and the array of possible combination between them. This complexity is also referred to as "detail complexity" or "combinatorial complexity". Everyday decisions are complex if a large number of different elements have to be considered for decision-making. One example is an antique church bell. The mechanical system is highly complicated. However, in principle the stages of each element can be known, moreover, how they interact is definable and thus limited. Moreover, the progression of these interactions is relatively stable.
- The defining characteristics of a **complex system** are its high variation in the elements and their relationships in a system, i.e., their variability, momentum, or behaviour. This leads to the concept known as "dynamic complexity" (Richardson and Pugh 1981; Senge 1990) which is the ability of a system to be able to develop into different states over time. For a complex system, it is still possible to understand the interrelations and development ex-post. The amount

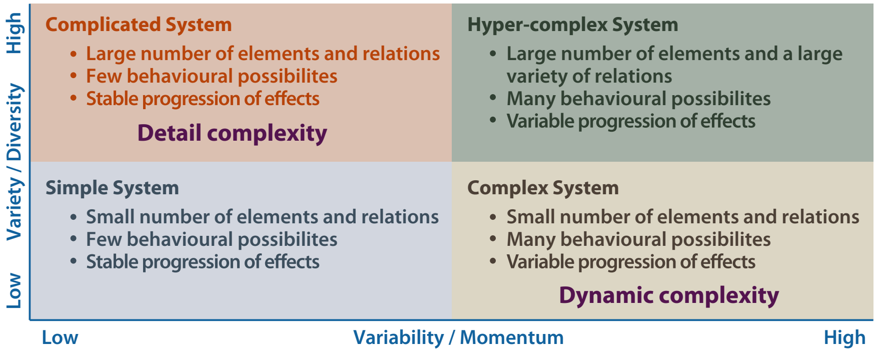

Fig. 1 System types from simple, to complicated, to complex (Ulrich and Probst 1991; Groesser 2015a, b, c)

of variables and interconnections is moderate; the amount of interconnections can be large.

- A **hyper-complex (chaotic) system** comprises of a large amount of different variables which have a large number of interconnections. Understanding the development of the system over time is not feasible due to the many interacting and changing variables. From a management science perspective, it is only of little use to try to detail the inner workings of such hyper-complex systems since they cannot be inspected and clearly analysed or only with large estimation errors.

Table 1 details the definition of simple, complicated and complex systems based on the system's characteristics: number of elements, similarity of the elements, variability of the elements over time, the number of relationships and the connectedness of the relations. The characteristics of hyper-complex systems are not detailed here. They can be derived from the characteristics of complicated and complex systems.

Complex systems, as defined in Fig. 1 and Table 1, can exhibit dynamic complexity. Dynamic complexity is the label given to a system whose characteristics do not follow direct and simple (i.e., linear) cause-effect relationships. Dynamic complexity results from temporal interactions and interrelationships of system elements. It is considered to be caused specifically by delays, feedback, accumulations and nonlinearities. Dynamically complex situations are essentially not transparent for a decision-maker. He or she has no means of intuitively detecting the connection of circular causality and way of modelling and predicting them exactly. The decision-maker must expect surprises, side effects and unintended effects of decisions in different parts of the system.

Criteria for dynamic complexity: A system is dynamically complex if the following, but not necessarily all, criteria are met:

Table 1 Comparison of simple, complicated, and complex systems

Characteristics	Simple systems	Complicated systems	Complex systems
Number of elements	Few	Large	Moderate
Similarity of the elements	Identical in all characteristics	Partly or entirely different	Partly or entirely different
Variability of elements over time	No	No	Yes
Number of relationships	Few	Moderate/large	Large
Connectedness of relations	Few	Moderate/large	Large
Example	Pendulum	Car, engine	Business ecosystem

1. **Dynamic**: The system develops or changes over time. What seems to be fixed, varies over a longer time horizon.
2. **Close connection of the system elements**: The system elements or agents in the system interact strongly with each other.
3. **Feedback**: Systems are controlled by feedback. This coupling between system elements actions and events can react upon themselves.
4. **Non-linearity**: Non-linearity exists when at least one element in the system interacts with another in a non-linear way. Non-linearity is graphically expressed as a curved, e.g., exponential or quadratic line. In particular, "non-linear" means that an effect is seldom proportional to its cause.
5. **Past dependent**: Past dependent means that the decisions, which must be made by an agent, depend on the decisions already taken in the past. Structure in any system is the product of past actions (interactions).
6. **Self-organizing**: The dynamics of the system are formed by self-organization and spontaneous consequence of its internal structure.
7. **Adaptive**: Adaptive means that a system itself changes as a result of experience. Thus, the skills and decision rules of agents change in a complex system over time.
8. **Counterintuitive**: Decision-makers cannot capture causes and their effects only relying on intuition. The behaviour of the system is often against, i.e., counter, the behaviour the decision-makers expect. This is because causal relationships are often not sufficiently understood since it is often neglected that causes may have different intended and unintended effects.
9. **Intervention resistant**: The complexity of the system, in which an agent is embedded, overwhelms his or her ability to understand the system. Consequently, implemented solutions often fail in a complex system or even aggravate the situation. Interventions do not produce obvious (expected) effects or even lead to unintended consequences.
10. **Temporal balancing decisions (trade-offs)**: time delays result in a system in which the long-term effects of an intervention are often different from the short-term effects.

2.3 Short Overview of Some Tools for Managing Complexity

After introducing the foundations of different types of complexity, I will now briefly look at several tools from the field of complexity and systems theory which have been developed to cope with the ever growing situations of complexity. We will not concern ourselves with the methods of CCM and SD in this section since they are introduced later in detail in dedicated subchapters.

2.3.1 Soft System Modelling

SSM incorporates an interpretive perspective of social settings (Lane and Oliva 1998). With a focus on action-research, SSM practitioners do not attempt to describe the real world, rather they use several models, i.e., ideal types, to explain a problem from different perspectives. The ultimate goal is to gain insights and changes by comparing ideal types with the real world problem. The models themselves are represented by a mapping technique which results in “rich pictures” of the problematic situation (Fig. 2).

2.3.2 Cybernetic Models

The cybernetic view of socio-technical systems is suitable for diagnosing and de-signing organizations. Stafford Beer’s viable system model (Beer 1979, 1981) is one of the most wide-ranging theories in this discipline (Fig. 3). Despite its applicability to any human or social system, it has primarily been used to describe the viability of organizations. An underlying proposition is that an organization is only viable if it has a set of management functions and interrelationships as specified by the theory (Schwaninger and Ríos 2008). Differences between the

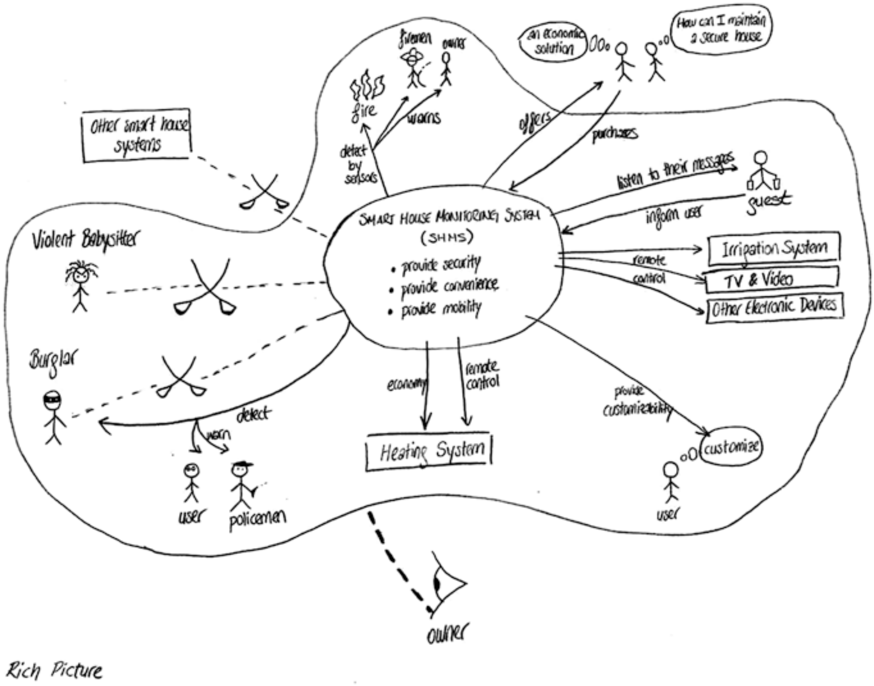

Fig. 2 Rich picture as used in the SSM (Checkland 2001)

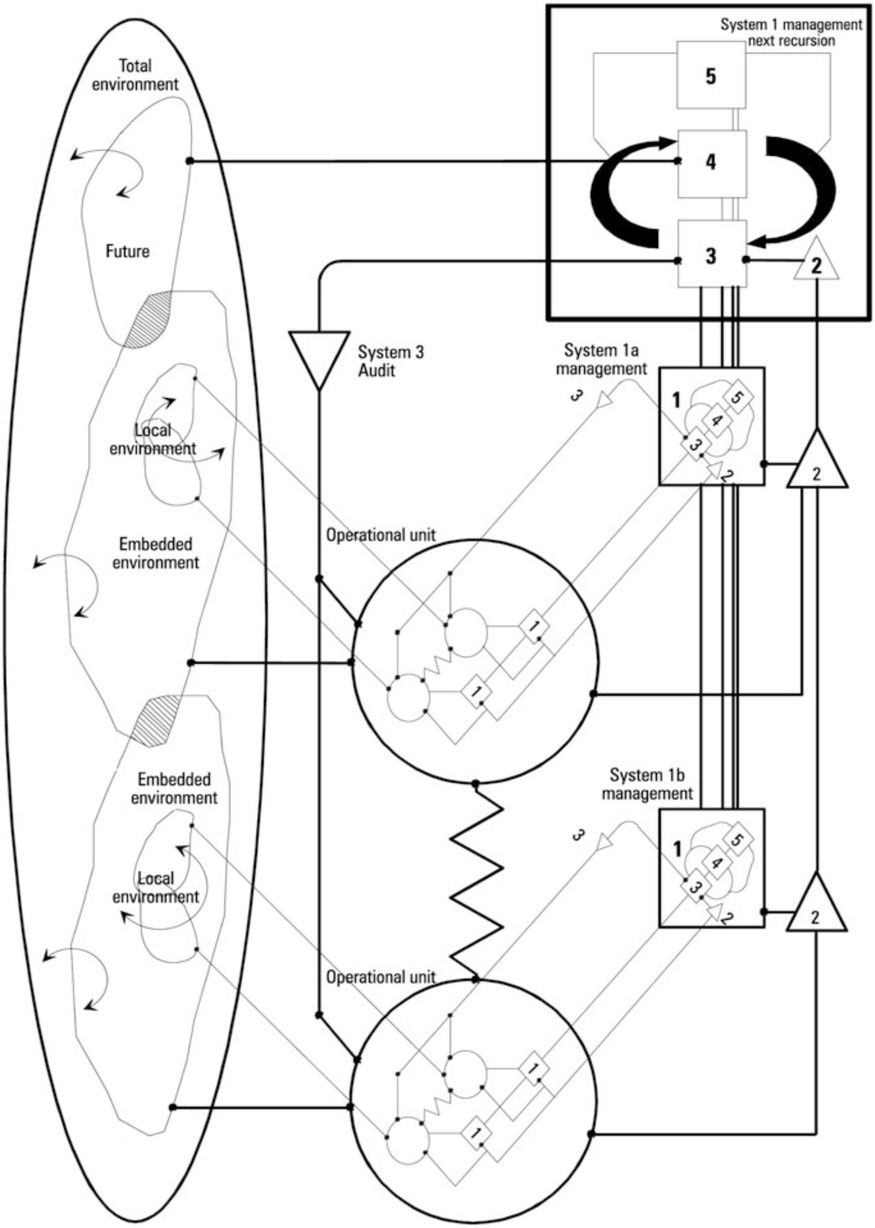

Fig. 3 Viable system model (Beer 1981)

elements and links of the real system and the elements and links as proposed by the Viable System Model result in a possible threat to the viability of the organization.

2.3.3 Mental Models of Dynamic System

An anthropocentric approach focussing on humans' ability to reason is the concept behind mental models. It has been shown that humans' ability to perform in dynamic complex settings is limited and biased. Therefore, improved mental models which account for accumulation processes, time delays, and feedback loops are required (Groesser and Schaffernicht 2012). The mental model approach to dynamic systems has been developed to elicit managerial cognitions about dynamic situations to represent these cognitions, and to analyse the mental models with the objective of improving decision-making. The most recent methods of elicitation and comparison can be found in (Schaffernicht and Groesser 2011; Groesser and Schaffernicht 2012; Schaffernicht and Groesser 2014).

2.3.4 Group Model Building

Group modelling is a process which is expected to adapt mental models and foster the implementation of decisions (Rouwette et al. 2011). This process is based on involving different actors, e.g., clients and experts, who provide particular knowledge about contents or techniques (Vennix 1996). The goals of group model building are versatile. By means of group model building, the individual and group mental models can be aligned. This improves the clarity and efficiency between different system actors.

3 Deep-Dive I: Causal Context Models

3.1 Purpose of Causal Context Models

This section provides details about CMM. A CCM is a qualitative word-and-arrow diagram, i.e., a graphical representation that details the cause-and-effect relationships between variables in a system. A CCM follows, in principle, the method of a causal (loop) diagram (Richardson and Pugh 1981; Sterman 2000; Lane 2008; Groesser 2016). It emphasizes the interdisciplinary interaction between technological, social, legal, and natural spheres when high-value IPSS, and other systems, are managed (see chapter "The Challenge" of this book for the challenges of upgrading and managing IPSS).

The objective of a CCM is to explain the behaviour of technical- and business-level variables which are key to an organization's objectives. In doing so, a good model will reveal the network of influences that impinge on those variables. Before one can start to use CCMs some prerequisites are helpful: (1) openness to a new qualitative method, (2) thinking in variables and how they are interconnected, (3) a mind-set open to crossing disciplinary boundaries to connect different fields of thought (e.g., engineering, informatics, and business). A CCM helps those involved to evaluate the impact of changes to their business-level objectives and compare various these scenarios using behaviour over time charts. To do this, the user imagines changing the value of a relevant variable in the model and then traces the consequences through the model to see if the desired and expected outcomes are achieved. This is done in a qualitative, imaginative way of reasoning.

3.2 Elements of a Causal Context Model

A CMM consists of variables and directional causal links that have one of two possible polarities. A link marked positive (+) indicates a positive causal relation and a link marked negative (–) indicates a negative causal relation.

- A **positive** causal link (+) means the two variables, which are connected by this causal link, change in the same direction. In other words, if the initial variable decreases, the other variable also decreases. Similarly, if the variable, in which the link starts, increases, the other variable increases as well.
- A **negative** causal link (–) means the two variables, which are connected by this causal link, change in opposite directions. In other words, if the initial variable increases, the other variable decreases and vice versa.

It is common for CCM to have closed chains of causal links known as feedback loops (Sterman 2000). A feedback loop can either be reinforcing or balancing.

- A reinforcing feedback loop (R) is a closed causal chain in which the effect of a variation in any variable propagates through the loop and returns to the variable thus reinforcing the initial deviation. In other words, if a variable increases in a reinforcing loop the effect through the cycle will return an increase to the same variable and vice versa. An example of a reinforcing loop is the word of mouth dynamics. In reaction to any questionable statement or activity of an organization, social media users can create huge waves of outrage within just a few hours. These so-called online firestorms pose new challenges for marketing communications—reinforcing feedback dynamics.
- A balancing feedback loop (B) is the closed causal chain in which the effect of a variation in any variable propagates through the loop and returns to the variable a deviation opposite to the initial one. In other words, if a variable increases in a balancing loop the effect through the cycle will return a decrease to the same variable and vice versa. An example of a balancing loop is the actions executed by managers to prepare and avoid online firestorms, as described above. The company's capabilities are built-up until the management is satisfied. Then, no further investments are executed. A balancing feedback loop leads to goal-seeking dynamics of the respective system.

A CCM explicates the assumptions and helps thereby to reveal how things are connected to each other within a system. The example in Fig. 4 shows an example of a CCM developed for an organization taking part in the UIW-project. The figure should provide an indication of how a CCM looks; I do not intend to detail or explain the CCM here. It shows the *technical-level* (e.g., total construction time or number of vague regulations) and **business-level objectives** (e.g., return on investment), scenario variables (e.g., number of future regulations issued or effectiveness of future regulations), and feedback loops (B1 to B4).

In addition to the causal, structural model, a CCM requires that at least one behaviour over time chart (also known as a BOT or a time chart) of an important variable is developed. The variable has to be an element of the CCM (see Fig. 5).

3.3 Causal Context Model Development

CCMs are developed to create comprehensive causal maps, i.e., models that include different perspectives on a challenge that needs to be managed. For instance, all companies that participated in the UIW-project (see Part III of this book) established CCMs that show the relationships between technical-level objectives and business-level objectives. The CCM supports the definition of the problem to be addressed as well as helping elaborate possible solutions. The generic process of CCM development follows six steps:

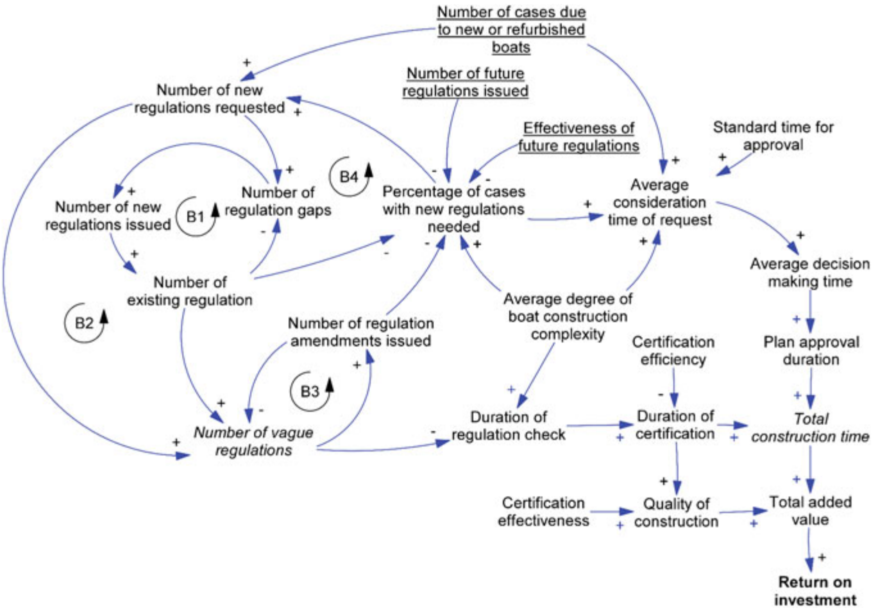

Fig. 4 Example of a causal context model

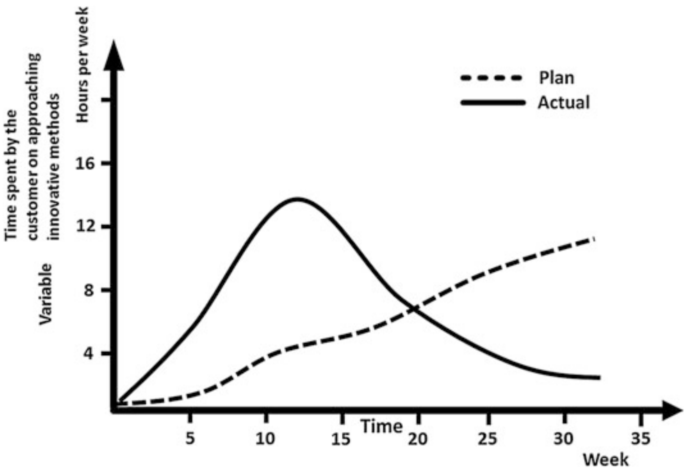

Fig. 5 Example of a behaviour over time (BOT) chart

1. **Define the reference behaviour in technical-level objectives by means of behaviour over time charts**: the reference behaviour is the over time development of an important technical variable, e.g., availability of relevant information to project team. This variable shows problematic behaviour, e.g., that the level of relevant information the team has access to does not conform to the intended level. One, or ideally, several such reference modes in technical-level variables should be defined. The tutorial https://www.youtube.com/watch?v=ktKGrDds3No provides additional information about step 1.
2. **Define the reference behaviour in business-level objectives by means of behaviour over time graphs**: Then, perform step 1 now for business-level objectives. Develop behaviour over time charts for variables that show business-level objectives. Examples of such variables are market share, revenues, customer satisfaction, or throughput time. The business-level objectives are then: to have a higher market share, increased revenues, higher customer satisfaction, or lower throughput time (see the charts in Fig. 4).
3. **Develop the causal model**: in order to develop a causal model the next step is to connect the technical-level and business-level variables by means of causal links. One will certainly have to include new variables about relevant aspects of the system being modelled to create the causal paths between the different variables. Only include variables and causal links that exist in the system. All the relevant variables have to be included in the final model so as to sufficiently explain the behaviour of the objective variables in steps 1 and 2.
4. **Define scenario variables**: After the causal model is completed, ensure that the model includes important scenario variables. A scenario is a description of possible external developments in the future. A scenario variable, e.g., requirements for energy efficiency, operationalizes these possible developments by embedding these clearly in the causal model. Scenario variables assume

different values, e.g., legal requirements for energy efficiency might be change. The CCM helps the user to think about the following developments:

   - If the scenario *variable X* increases (or decreases respectively), how will the technical-level objectives develop?
   - If the scenario *variable X* increases (or decreases respectively), how will the business-level objectives develop?

5. **Define policy variables**: A policy is a set of basic principles and associated guidelines, formulated and enforced by the governing body of an organization, e.g., a decision maker, to direct and limit his or her actions in pursuit of long-term goals. In other words, a policy is a decision rule that defines how available information is used for decision making. One example is a hiring policy: it guides the each (monthly, annual etc.) decision about how many people should be hired. Polices are operationalized by policy variables which are under the control of the decision maker. This step should ensure that the relevant polices, i.e., measures a decision maker can influence, to achieve the technical-level and business-level objectives are included in the CCM.
6. **Continuously validate the model being created**: Validation activities occurs continuously during the model creation process. For more information on this, see Groesser and Schwaninger (2012) who go through the modelling process (both qualitative and quantitative) in more detail (see also Barlas 1996; Forrester and Senge 1980; Schwaninger and Groesser 2009). The modeller has to ensure that the resulting CCM only features variables and causal links with polarities. Other concepts are not used in CCMs.

The process of developing a CCM is a learning process for the participating organization. For each iteration, the CCMs are expanded with new variables, causal relationships, scenario and policy variables. Discussions about different meanings of specific variables as well as different causal relationships foster understanding between participants and also nurture learning about the context in which the decisions on the technical and business-level are made.

CCMs offer several benefits: first, different perspectives, e.g., economic, technical, and social aspects, can be integrated into one holistic model; second, CCMs are statements about causes and consequences. Such a causal model becomes a tool with which concrete actions to overcome challenges can be found. A CCM is, however, a qualitative model. The next step of analysis would be do develop a quantitative simulation model. The advantage of such a simulation model is that the participants cannot only identify positive and negative effects, but also by how much the changes can impact their technical-level objectives and their business-level objectives. Furthermore, the rigor a simulation model requires leads to a more intense and in-depth thought process regarding the different causalities and values as well as the expansion of the model boundary. This is what I address next.

4 Deep-Dive II: System Dynamics Simulation Modelling

4.1 *Purpose of System Dynamics Modelling*

System Dynamics (SD) is one of the most popular, widespread and validated simulation (computational) methodology and cannot be overlooked when discussing decision making tools and complexity management. In this Sect. 1 will briefly address SD simulation methodology and address in more detail how it can be useful when managing real world complexity. The more curious reader will benefit greatly from the references supplied here.

The basic idea of SD is to capture the underlying characteristics of complex dynamic systems to understand them better and foster desirable developments (Schwaninger and Ríos 2008; Schwaninger and Groesser 2008). To capture all these characteristics SD-models must represent nonlinearities, long-term patterns and the internal structure of a system. This is technically achieved by mapping the system's stock- and-flow structure. Jay Forrester, the founder of SD, devised the means of modelling any dynamic situation by means of stocks and flows. The process of building an SD model is a continuous learning process consisting of formulating hypotheses, testing, and revising formal and mental models. SD captures essential characteristics of management reality, for instance, nonlinear behaviours, accumulations, delays, and information feedback, which are not systematically taken into account by existing methods (Sterman 2000; Schöneborn 2003; Morecroft 2007; Warren 2008). A computational modelling approach is most helpful in providing insights about the type and magnitude of interaction in high value asset system and allows an integrated evaluation and thereby complements the existing methods in the analysis of such systems.

4.2 *System Dynamics Modelling Process*

When creating a System Dynamics model, a six step modelling development process is used: (1) selection of the dynamic problem, (2) conceptualization, (3) formulation, (4) scenario and policy analysis, (5) selection of policies and implementation planning, and (6) implementation (Fig. 6).

4.2.1 Step 1: Selection of the Dynamic Problem

The first step of the modelling process is to identify the issue and the relevant stakeholders. This enables modellers to identify from whom to draw expertise when developing the model as well as from where to collect data in the latter stages of the process. The development of a model will require the collaboration between the

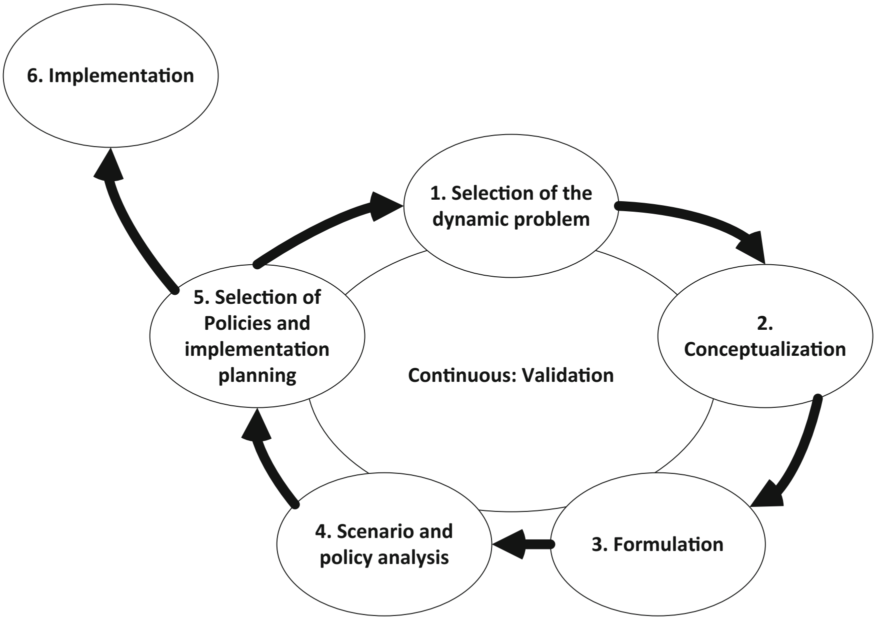

Fig. 6 Process for developing system dynamics simulation models

"problem owners" and modellers to produce a high-quality model. Initially, the problem owners provide the essential information about the issue at hand and are then involved in every iterative modelling step. It is essential that the problem owners comprehend the basic functioning of the model and continuously validate the output of the model. After getting an initial feel for the environment of the model, the modeller formulates a dynamic hypothesis of the problem. This dynamic hypothesis is founded on the information provided by the owners as well any current theories which help to explain the problem.

4.2.2 Step 2: Conceptualization

After identifying and selecting the dynamic problem, the task is to decide upon a provisional list of variables and a suitable time horizon for the model, from which the necessary behaviour over time graphs (BOTs) can be generated. All this is done based on data or the expectations of the relevant stakeholders. This stage should not be considered as final since the modelling process is iterative and the modeller, together with the stakeholders and problem owner, will revise these decisions repeatedly until the model is completed. This iteration also includes repeated feedback from the stakeholders to gain a better understanding of the model.

4.2.3 Step 3: Formulation

Based on the available data resources (e.g., a previously generated Causal Context Model (CCM)) and the identified problem, the modeller now defines what kind of model is to be created. For some dynamic problems a qualitative model might suffice, meaning the model can start out as Causal Loop Diagram (CLD). If a quantified model is the goal, then a Stock- and Flow-Diagram (SFD) should be considered more suitable. In the case of a quantified model, after translating the variable list into a SFD, the modeller populates the variables with values to create a first iteration of the simulation model. Initially the values and functions added to the model can be guesses or estimates (or even guessimates!), as the modeller will revise them for every iterative step and continuously increase their precision. Also, continuously simulating the model will provide the modeller with insights for further model development. Step 3 also enables the modeller to continuously test their model BOTs by comparing it to the initially generated BOTs, by testing the robustness of the model and/or testing sensitivity.

4.2.4 Step 4: Scenario and Policy Analysis

Finally, when the modeller is satisfied that the model is of sufficient quality he or she can start analysing and evaluating policies and scenarios. Scenarios are analysed by changing exogenous variables to simulate different developments in the environment of the system. If for example the model depends on economic growth, the modeller can evaluate the impact and the sensitivity of the system to an economic slowdown or sudden increase in economic activity. The degree to which the system changes as a result of that external change reveals the model's sensitivity to that exogenous variable. This allows the practitioner to analyse the likelihood of any given situation to materialize under a certain set of external conditions. The model also allows the efficacy of different responses to external changes in the system to be tested. This gives the modeller the opportunity to select policies and responses to optimize the resilience of the system in the face of external shocks.

4.2.5 Step 5: Selection of Policies and Planning of Implementation

After agreeing on the most important scenario settings and most effective policies, the modeller applies these conditions to the model and discusses the results with the stakeholders. The stakeholders can then evaluate and define the most effective way to apply the policies in the system in question. With the insight gained from the discussion of the model, the stakeholders can then implement actions necessary to change the system in real life while already anticipating and validating whether the measures achieve the desired effect.

4.2.6 Step 6: Implementation

Implementing the planned changes and measures is in the responsibility of the problem owner. Often it is helpful, when the simulation model and its results are demonstrated to the people who are affected by the changes and measures. It is especially productive to hold demonstration workshops during which the participants can experiment with the simulation model for themselves. These sessions will often throw new light on the problem and provide fresh impetus to make any necessary changes.

4.3 Applying System Dynamics

With regard to managing complexity, the following paragraphs describe five advantages of SD simulation methodology as well as explaining some of its disadvantages. First, any tool for decision-making has to satisfy several criteria to effectively deliver decision support. According to John D. C. Little (1970) these criteria are simplicity, robustness, ease of control, adaptiveness, completeness on important issues, and simplicity of communication. In close connection with the decision maker, a computational modelling process begins with a simple model structure and continuously improves in an evolutionary way using rapid prototyping. As a result, this process of elaboration and calibration creates a sufficient, robust and purpose-oriented model. Furthermore, the involved decision makers learn how to control the model during its execution. The unfolding model is permanently represented as a visual object to ensure transparent communication with the target audience (Black and Andersen 2012; Nistelrooij et al. 2015).

Second, the approach can improve a company's capabilities when analysing the interdependencies in their business models in the face of external changes in the environment. Since simulation approaches are capable of representing highly complex situations and handling them in a reasonably simple way, it becomes possible to address a higher degree of the dynamic complexity present in business reality (Groesser and Schwaninger 2012). As a direct consequence of structuring and linking knowledge about a business system, SD allows decision makers to take decisions which are based on integrative qualitative and quantitative analysis.

Third, risks can be identified through sensitivity analysis of the feedback dynamics in a simulation model. Risks are often identified in the following three areas: firstly, balancing feedback loops that limit a desired growth or decay; secondly, reinforcing feedback loops that lead to undesired growth or decay; and thirdly, external factors that exacerbate any of above two types of feedback loops. Analysis of feedback dynamics can make some systemic risks apparent, which otherwise might be too vague to attract notice. SD can be used to quantify risks which are attributed to be most relevant (Rodrigues and Bowers 1996).

Fourth, SD emphasizes a continuous perspective (Sterman 2000). This perspective strives to look beyond single events to see the dynamic patterns underlying them in the short-, as well as, long-term. Then, by identifying those patterns, simulations help to understand the causes of current issues and can support decision makers in tackling them. Moreover, applying computational modelling supports the validation of strategic initiatives and their effect on existing business models—just as engineers test new technologies or products extensively in a laboratory before their market launch. In particular, the ability to experiment with different scenarios and strategic initiatives in a computational environment has the potential to reduce erroneous management decisions and reveal overlooked factors and patterns that could become relevant in the future (Groesser 2015a, b, c).

And finally, by amalgamating computational methods with existing business modelling approaches SD provides an insightful, valid, relatively rapid, and inexpensive approach to business model analysis and design (Eden et al. 2000). Moreover, from a perspective of consistency, it is known that humans cannot deduce the behavioural consequences of a system with many interdependent elements (Miller 1956; Forrester 1961; Sterman et al. 2015). Computational modelling is one of the means, amongst others, of reducing the issue that qualitative models seem to be insufficient when systems are highly complex (Sterman 2000). Hence, it enables a deep and integrated understanding of a system through the quantitative exploration of systemic interdependencies.

Computational modelling of complex systems is a relatively innovative approach for top management decision makers. Some disadvantages of this method relate to the relative ease of linking variables together to quickly create large, highly complex models. Some users may, however, be overwhelmed by this complexity if they do not exercise a cautious approach to modelling (Groesser and Schwaninger 2012). The existence of user-friendly visual representations has, in some cases, been a disservice by offering the false impression that modelling is always simple and done quickly. In addition, inclusion of uncertain or only hypothesized feedback loops may create complex model behaviour that may be difficult to track, falsify, or validate. Moreover, the empirical evidence about the learning outcomes of computational modelling and its effectiveness is still inconclusive (Karakul and Qudrat-Ullah 2008; Sterman 2010; Qudrat-Ullah 2014). Consequently, it is not yet possible to state that businesses applying computational modelling systematically produce better results than those that do not use it and thus, the requirements of the strong market test are not yet met (Labro and Tuomela 2003). At the same time, this is a call for action to conduct more empirical research to prove (or disprove) the case for computational simulation methods.

5 Conclusion

This chapter introduced the reader to systemic methods which are highly beneficial in the analysis and management of complexity, especially in cases when managing high value assets. The chapter introduced two methods in more detail: the qualitative method, CCM, and the quantitative method, SD, methodology. The chapter explained both methods and provided the reasoning for their applications as well as discussing their potential benefits.

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References

Anderson, P. (1999). Complexity theory and organization science. *Organization Science, 10*(3), 216–232.

Anderson, P., & Meyer, A., et al. (1999). Introduction to the special issue: Applications of complexity theory to organization science. *Organization Science, 10*(3), 233–236.

Barlas, Y. (1996). Formal aspects of model validity and validation in system dynamics. *System Dynamics Review, 12*(3), 183–210.

Beer, S. (1979). *The heart of the enterprise*. Chichester: Wiley.

Beer, S. (1981). *Brain of the firm*. London: Penguin Press.

Beinhocker, E. D. (1997). Strategy at the edge of chaos. *McKiney Quarterly, 1*(24–39).

Black, L. J., & Andersen, D. F. (2012). Using visual representations as boundary objects to resolve conflict in collaborative model-building approaches. *Systems Research and Behavioral Science, 29*(2), 194–208.

Bleicher, K. (2004). Das Konzept Integriertes Management. Visionen - Missionen - Programme. Frankfurt, Campus.

Bonabeau, E., & Meyer, C. (2001). Swarm intelligence—A whole new way to think about business. *Harvard Business Review, 79*(5), 106–114.

Casti, J. L. (1994). *Complexification, explaining a paradoxial world through the science of surprise*. New York City: HarperCollins Publisher.

Checkland, P. (2001). Soft system methodology. In J. Rosenhead & J. Mingers (Eds.), *Rational analysis for a problematic world revisited: Problem structuring methods for complexity, uncertainty and conflict* (2nd ed.). Chichester, New York, Weinheim, Brisbane, Singapore, Toronto: Willey.

Denk, R., & Pfneissl, T. (2009). *Komplexitätsmanagement*. Wien: Linde.

Eberhart, R. C., & Shi, Y., et al. (2001). *Swarm intelligence*. Morgan Kaufmann.

Eden, C., Williams, T., et al. (2000). The role of feedback dynamics in disruption and delay on the nature of disruption and delay (D&D) in major projects. *The Journal of the Operational Research Society, 51*(3), 291–300.

Epstein, J. M., & Axtell, R. (1996). *Growing artificial societies: Social science from the bottom up*. Cambridge, Washington D.C.: Brookings Institution Press, The MIT Press.

Forrester, J. W. (1961). *Industrial dynamics*. Cambridge: Productivity Press.

Forrester, J. W., & Senge, P. M. (1980). Tests for building confidence in system dynamics models. In A. A. Legasto, J. W. Forrester, & J. M. Lyneis (Eds.), *System dynamics: TIMS studies in the management sciences* (Vol. 14). Amsterdam, North-Holland.

Gaddis, W. (1955). *The recognitions*. San Diego: Hartcourt Brace & Company.

Gell-Mann, M. (1995). *The quark and the jaguar: Adventures in the simple and the complex*. London: Abacus.

Granat, H. (2003). *Wisdom through the ages: Book two*. Bloomington: Trafford Publishing.

Groesser, S. N. (2014). Co-evolution of legal and voluntary standards: Development of energy efficiency in Swiss residential building codes. *Technological Forecasting and Social Change, 87*(1), 1–16.

Groesser, S. N. (2015). Lab or reality: Entwicklung und Anylse von Geschäftsmodellen durch das kybernetische Unternehmensmodell Blue Company. In *Exploring Cybernetics: Kybernetik im interdisziplinären Diskurs* (pp. 91–116). Berlin: Springer.

Groesser, S. N. (2015). *Stichwort: Dynamische Komplexität. Gabler Wirtschaftslexikon*. Heidelberg: Gabler.

Groesser, S. N. (2015). *Stichwort: System dynamics*. Gabler Wirtschaftslexikon.

Groesser, S. N. (2016). *Qualitative modellierung mit system dynamics*. North Charleston: CreateSpace Independent Publishing Platform.

Groesser, S. N., & Schaffernicht, M. (2012). Mental models of dynamic systems: Taking stock and looking ahead. *System Dynamics Review, 28*(1), 46–68.

Groesser, S. N., & Schwaninger, M. (2012). Contributions to model validation: Hierarchy, process, and cessation. *System Dynamics Review, 28*(2), 157–181.

Holbrook, M. B. (2003). Adventures in complexity. *Academy of Marketing Science Review, 6*(1–18).

Isanda, M. (2014). *Strategies for managing complexity*. University of Nairobi.

Karakul, M., & Qudrat-Ullah, H. (2008). *How to improve dynamic decision making? Practice and promise. Complex decision making* (pp. 3–24). Berlin: Springer.

Kastl, T., & Schmid, A. (2008). *Projektmanagement aus dem Blickwinkel von Komplexitäts- und Netzwerktheorie. Advanced Project Management. Herausforderungen - Praxiserfahrung - Perspektiven.* (pp. 213–232). Berlin: LIT.

Kersten, W., & Lammers, T., et al. (2012). *Schlussbericht zum Projekt "Komplexitätsanalyse von Distributionssystemen"*. Institut für Logistik und Unternehmensführung an der Technischen Universität Hamburg-Harburg.

Kirchhof, R. (2003). *Ganzheitliches Komplexitätsmanagement - Grundlagen und Methodik des Umgangs mit Komplexität im Unternehmen*. Wiesbaden: DUV.

Klabunde, S. (2003). *Wissensmanagement in der integrierten Produkt- und Prozessgestaltung: Best-Practice-Modelle zum Management von Meta-Wissen*. Wiesbaden: DUV.

Kupers, R. (2000). What organizational leaders should know about the new science of complexity. *Complexity, 6*(1), 14–19.

Labro, E., & Tuomela, T.-S. (2003). On bringing more action into management accounting research: Process considerations based on two constructive case studies. *European Accounting Review, 12*(3), 409–442.

Lane, D. C. (2008). The emergence and use of diagramming in system dynamics: A critical account. *Systems Research and Behavioral Science, 25*(1), 3–23.

Lane, D. C., & Oliva, R. (1998). The greater whole: Towards a synthesis of system dynamics and soft systems methodology. *European Journal of Operational Research, 107*(1), 214–235.

Levy, D. (1994). Chaos theory and strategy—Theory, application, and managerial implications. *Strategic Management Journal, 15,* 167–178.

Lewin, A. Y. (1999). Application of complexity theory to organization science. *Organization Science, 10*(3), 215.

Little, J. D. C. (1970). Models and managers: The concept of a decision calculus. *Management Science, 16*(8), 466–485.

Malik, F. (2008). *Strategie des Managements komplexer Systeme. Ein Beitrag zur Management-Kybernetik evolutionärer Systeme*. Bern: Haupt.

Miller, G. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *The Psychological Review, 63*(1), 81–97.

Miller, J. H., & Page, S. (2007). *Complex adaptive systems: An introduction to computational models of social life*. In S. A. Levin & S. H. Strogatz (Eds.). Princeton Press.

Morecroft, J. D. W. (2007). *Strategic modelling and business dynamics: A feedback systems approach*. Chichester: Wiley.

Nistelrooij, L. P. J. V., & Rouwette, E. A. J. A., et al. (2015). The eye of the beholder: A case example of changing clients' perspectives through involvement in the model validation process. *Systems Research and Behavioral Science, 32*(4), 437–449.

Pascale, R. T. (1999). Surfing the edge of chaos. *MIT Sloan Management Review, 40*(3), 83–95.

Phelan, S. E. (2001). What is complexity science really? *Emergence, 3*(1), 120–136.

Qudrat-Ullah, H. (2014). Yes we can: Improving performance in dynamic tasks. *Decision Support Systems, 61*(2014), 22–33.

Rall, K., & Dallhöfer, J. (2004). Komplexität indirekter PRozesse bei der Erstellung variantenreicher Produkte. *Zum Wirtschaftlichen Fabrikbetrieb, 11,* 623–640.

Richardson, G. P., & Pugh, A. L., III. (1981). *Introduction to system dynamics modeling with DYNAMO*. Cambridge: MA, Productivity Press.

Rodrigues, A., & Bowers, J. (1996). The role of system dynamics in project management. *International Journal of Project Management, 14*(4), 213–220.

Rouwette, E. A. J. A., Korzilius, H., et al. (2011). Modeling as persuasion: The impact of group model building on attitudes and behavior. *System Dynamics Review (Wiley), 27*(1), 1–21.

Satell, G. (2013). *Management has to change in an increasingly complex world*. Business Insider.

Schaffernicht, M., & Groesser, S. (2014). The SEXTANT software: A tool for automating the comparative analysis of mental models of dynamic systems. *European Journal of Operational Research*.

Schaffernicht, M., & Groesser, S. N. (2011). A comprehensive method for comparing mental models of dynamic systems. *European Journal of Operational Research, 210*(1), 57–67.

Scherf, O. (2003). *Komplexität aus systemischer Sicht*. München: Difo-Druck.

Schoeneberg, K.-P. (2010). *Komplexität - Eine Einführung in die Komplexitätsforschung und Auswirkungen auf das Management komplexer Projekte. Marktorientierte Problemlösungen im Innovationsmarketing*. Wiesbaden: Gabler: 482 ff.

Schöneborn, F. (2003). *Strategisches controlling mit system dynamics*. Heidelberg: Physica-Verlag.

Schwaninger, M. (2009a). *Intelligent organizations: Powerful models for systemic management*. Berlin and Heidelberg: Springer Publishing.

Schwaninger, M. (2009b). System dynamics in the evolution of the systems approach. In R. Meyers (Ed.), *Encyclopedia of complexity and system science*. Berlin, London, Paris: Springer Publishing.

Schwaninger, M., & Groesser, S. N. (2008). Model-based theory-building with system dynamics. *Systems Research and Behavioral Science, 25*(4), 447–465.

Schwaninger, M., & Groesser, S. N. (2009). System dynamics modeling: Validation for quality assurance. In *Encyclopedia of complexity and system science*. London: Springer Publishing.

Schwaninger, M., & Ríos, J. P. (2008). System dynamics and cybernetics: A synergetic pair. *System Dynamics Review, 24*(2), 145–174.

Senge, P. M. (1990). *The fifth discipline: The art and practice of the learning organization*. New York: Currency & Doubleday.

Senge, P. M. (1996). *The fifth discipline and the infrastructures of a learning organization*. Pegasus Communications: Waltham, MA.

Simon, H. (1962). The architecture of complexity. *American Philosophical Society, 106*(6), 467–482.

Simon, H. A. (1997). *Administrative behavior: A study of decision-making processes in administrative organizations*. New York, London, Toronto, Sydney, Singapore: The Free Press.

Stacey, R. D. (1995). The science of complexity—An alternative perspective for strategic change processes. *Strategic Management Journal, 16*(6), 477–495.

Sterman, J. D. (1994). Learning in and about complex-systems. *System Dynamics Review, 10*(2–3), 291–330.

Sterman, J. D. (2000). *Business dynamics: Systems thinking and modeling for a complex world*. Boston: MA, McGraw-Hill.

Sterman, J. D. (2002). All models are wrong: Reflections on becoming a systems scientist. *System Dynamics Review, 18*(4), 501–531.

Sterman, J. D. (2010). Does formal system dynamics training improve people's understanding of accumulation? *System Dynamics Review, 26*(4), 316–334.

Sterman, J. D., Oliva, R., et al. (2015). System dynamics perspectives and modeling opportunities for research in operations management. *Journal of Operations Management, 39–40* (November), 1–5.

Straub, R. (2013). Why managers haven't embraced complexity. *Harvard Business Review, 56*(5).

Ulrich, H., & Probst, G. (1991). *Anleitung zum ganzheitlichen Denken: Ein Brevier für Führungskräfte*. Bern: Paul Haupt Verlag.

Ulrich, P., & Fluri, E. (1992). *Management*. Bern: Haupt.

Vennix, J. A. M. (1996). *Group model building: Facilitating team learning using system dynamics*. Chichester: Wiley.

Warren, K. (2008). Strategic management dynamics. Chichester, West Sussex, England: Wiley.

Managing the Life Cycle to Reduce Environmental Impacts

Tiina Pajula, Katri Behm, Saija Vatanen and Elina Saarivuori

Abstract Driven by public awareness and international regulations and standards, sustainability and environmental impacts have become increasingly important distinguishing factors between competing products and services. Circular economy aims to increase economic growth by using natural resources and ecosystems in a more effective way with the aim of maintaining products, components and materials at their highest utility and value at all times. More effective use of materials enables the creation of more value both by cost savings and by developing new markets or by developing existing ones. Reduced acquisition of resources is a driver for innovation for sustainable use of materials, components and products as well as new business models. This chapter introduces methods and tools to assess and reduce environmental impacts, and improve resource efficiency and sustainability management. Life cycle thinking forms one of the basic principles of sustainable development, and Life Cycle Assessment (LCA) is the leading method for assessing the potential environmental impacts of a product, process or service throughout its life cycle (ISO 14040-44). Other methods based on life cycle thinking are also introduced. LCA focusing on the contribution of a product or service to global warming uses methods for Carbon Footprint measurement and facilitates the tracking of greenhouse gas (GHG) emissions (ISO 14067). Water footprint is a tool that assesses the magnitude of potential water-specific environmental impacts of water use associated with a product, process or organisation. It aims at describing the impact of water utilization on humans and ecosystems due to changes in water quality and quantity (ISO 14046 Environmental management—Water footprint—Principles, requirements and guidelines 2014). The concept of

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handprint has recently been introduced to measure and communicate the positive changes of actions and the beneficial impacts created within the life cycle of products, services, processes, companies, organizations or individuals. A handprint of a product can be created either by preventing or avoiding negative impacts (footprints), or by creating positive benefits. When adopting the circular economy way of thinking, companies need these tools and methods to ensure resource efficiency, cost cuts and improvements in their environmental performance which provide them with more earning opportunities. Fundamental changes throughout the value chain, from product design and production processes to new business models and consumption patterns, support this trend.

Keywords Life cycle assessment · Carbon footprint · Water footprint · Carbon handprint · Sustainability

1 Introduction

The interaction between industry and the natural environment is strong. The climate change and other environmental impacts related to industrial manufacturing have been discussed and agreed very widely during recent decades, which has increased pressure on industrial businesses (Lieder and Rashid 2016). Scientific understanding of the climate system and its sensitivity to greenhouse gas (GHG) emissions is nowadays more comprehensive than ever before. In December 2015, 195 countries and the European Union reached a global climate deal, agreeing to a long-term goal of limiting the increase in global average temperature to well below 2 °C, which means that countries need to scale up their efforts and actions to reduce emissions (European Commission 2016). This will bring great challenges for industries of different sectors, such as those considered in the Use-It-Wisely (UIW) project (turbines, machinery, space, trucks, shipping and furniture). The existence of environmental regulations has been a considerable influence on some of these companies.

In addition to the environmental considerations, the companies also face another challenge, since resources are becoming scarcer and the competition for their acquisition harder (Lieder and Rashid 2016). Earth Overshoot Day is the annual marker of when we begin living beyond our means in a given year (Global footprint network 2015, www.overshootday.org). Although only an approximate estimate of time and resource trends, Earth Overshoot Day is as close as science can get to measuring the gap between our demand for ecological resources and services, and how much the planet can provide. Our demand for renewable ecological resources and the services they provide is now equivalent to that of more than 1.5 Earths. The unsustainable use of resources brings challenges to resource supply and price, since the increasing requirements for resources cannot be met everywhere (Lieder and Rashid 2016). The changing markets require quick responses from the industry, requiring green growth and a resource-efficient economy.

Environmental topics have a direct effect on humans, but industry is also closely related to social aspects via employment and customer experiences related to the industrial products. Economic competence and growth bring new jobs to the market and thus create well-being, and satisfying customer experiences boosts the demand for products. Thus these three components—economic, environmental and social aspects of sustainability—create a positive circle supporting one another and can all be interlinked, managed and measured with a toolkit of various sustainability indicators.

The UIW-project aims to find solutions enabling rapid response to changing markets, business environments and customer needs. Sustainability methods and indicators presented in this article can help companies to achieve these goals by providing tools for managing and improving the sustainability performance of the manufacturing industry and its products. They can be used in finding new and improved business opportunities by e.g. increasing the efficiency of practices, and reducing waste streams both in the companies' own processes and elsewhere in the value chain. They can be applied in any industrial sector and for products as well as for services.

The methods presented in this chapter are based on life cycle thinking. It is a prerequisite to understand "the bigger picture", i.e. all the requirements and impacts that relate to the value chain of a product. Life cycle assessment (LCA) considers all materials and energy aspects during the entire supply chain, including raw material and fuel acquisition, different manufacturing and conversion processes, the use and consumption of the product and finally recycling or disposal. Together with life cycle thinking, circular economy emphasizes the sustainable use of resources by reducing, reusing and recycling materials and energy as much as possible (Yuan et al. 2006). Life cycle thinking and circular economy are presented in Sect. 2. These approaches ensure minimization of the overall environmental impacts and help avoid shifting the potential burden between different life cycle stages or individual production units or material and energy.

Section 3 introduces LCA, which is a method for assessing the environmental impacts created during the life cycle of a product. LCA can be used for identifying opportunities to improve the environmental performance of products; informing customers, stakeholders and other interest groups of environmental impacts from different stages of the life cycle; and marketing purposes in the forms of e.g. eco-labelling or environmental product declaration (EPD) (Tukker 2000). Section 4 describes other assessment methods that are based on life cycle thinking. The carbon footprint presented in Sect. 4.1 reflects the impact on climate change during the life cycle of a product. It typically describes the global warming potential within the next 100 years (BSI PAS2050:2011). Water footprint, presented in Sect. 4.2, is a measure of the magnitude of potential, water-specific environmental impacts of water use associated with a product, process or organisation, including both water quality and quantity aspects (ISO 14046 2014). Handprint, presented in Sect. 4.3, is a new concept that focuses on benefits rather than on negative impacts. The positive impacts can occur in the company's own actions or e.g. reduce the customer's footprint via improved product qualities (Shine 2015). Finally, the conclusions are presented in Sect. 5.

2 Life Cycle Thinking and Circular Economy

The basic understanding of life cycle methods is that all products and services have a value chain connected to them, that nothing in this world "stands alone", and that all our actions have consequences. Life cycle thinking considers all materials, fuels, energy and water consumed and the possible by-products, emissions and waste created when making, using and/or disposing a specific product. The life cycle begins from raw material extraction and conversion and continues via manufacturing and distribution to use and/or consumption. The life cycle ends with the so-called end-of life stage, including re-use, recycling of materials and energy recovery and/or disposal. In all these life cycle stages, the actions are connected to consequences, e.g. the materials used must be supplied from somewhere, with some energy demand and release of emissions. Resources are consumed and impacts to the environment are created within the life cycle of every product.

The core of life cycle thinking is to avoid shifting the environmental burden (European Commission 2010). This means that minimising impacts at one stage of the life cycle or in one environmental impact category should not cause increasing impacts elsewhere. Very often the value chains are international and the impacts e.g. on climate change have an effect on a global level. For example, saving energy during the use stage might increase the amount of material needed in manufacturing, or increase the energy needed in disposal of a product. Life cycle thinking aims to avoid these kinds of consequences.

The circular economy is based on sustainable use of resources. In a circular economy, the value of products and materials is maintained for as long as possible; waste and resource use are minimised, and resources are kept within the economy when a product has reached the end of its life, to be used again and again to create further value. The "3R" principles—reduce, reuse, and recycle materials and energy—describe different possibilities to practice circular economy (Yuan et al. 2006).

Traditional economic systems tend to be based on a linear "take-make-dispose" production model (Sitra 2015). Products and production are based only on the initial use of the product and recycling is segregated from production. For the circular economy, however, there is a difference between the consumption and use of materials. Consumed materials become waste, but the circular economy aims to reduce waste through the efficient use of materials and other resources. Waste is prevented if products and services were designed for reuse, remanufacture or recycling as secondary materials. The goal is to retain the maximum possible value, related to production and the used materials, within the circular economy (Sitra 2015).

The circulation of products and raw materials can be promoted in the following ways (Sitra 2015):

1. **Maintain**: Build products to last longer without repairs and offer maintenance services to prolong product life cycles, enabling longer use by the same owner.
2. **Reuse/redistribute**: Reuse the product for the same purpose on the resale markets.

3. **Remanufacture**: Plan the product life cycle as several life cycles and resell the product after thorough remanufacture.
4. **Recycle**: Recycle product materials for reuse and design products so that their materials are easy to sort. For biological materials, it would also be important to consider how to ensure the safe and sustainable return of nutrients to the nutrient cycle following their optimal use.
5. **Cascade**: Make use of a material or parts of it in another value chain, when it can no longer be used in the original sector.

The following conceptual diagram (Fig. 1) illustrates in a simplified way the main phases of a circular economy model. The phases are interlinked, as materials can be used in a cascading way, for example when industry exchanges by-products, products are refurbished or remanufactured, or consumers choose product-service systems. The aim is to minimise the resources escaping from the circle so that the system functions in an optimal way (European Commission 2014).

The circular economy seeks to make more efficient use of resources and materials, for the better recycling of their value and raw materials. Reuse and remanufacturing are good examples of the circular economy, since they save much of the energy used in the original production, such as in extraction of resources and further processing.

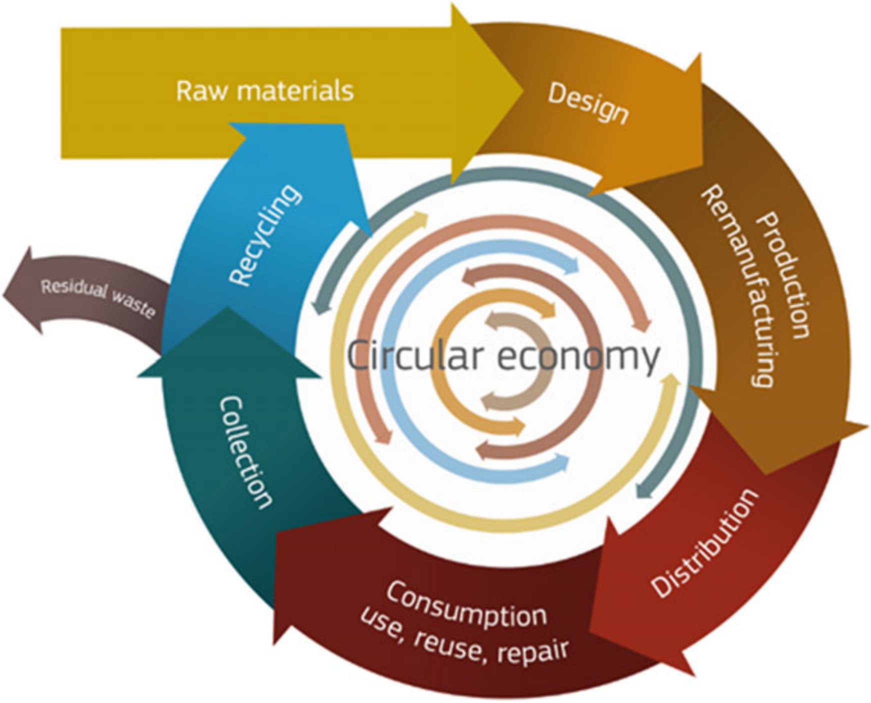

Fig. 1 Circular economy and life cycle phases (European Commission 2014)

For companies, adopting the circular economy way of thinking would create opportunities to cut costs, grow their businesses and reposition themselves strategically (Sitra 2015). Resource and energy efficiency are precisely the areas where cost savings are most often achieved. Correspondingly, the circular economy provides companies with more earning opportunities for each manufactured product. However, this requires fundamental changes throughout the value chain, from product design and production processes to new business models and consumption patterns (EEA 2/2016). Whereas the order of magnitude of expected benefits of a transition to a circular economy is reasonably well known, the exact numbers in existing studies need to be treated with some caution, owing to methodological and data limitations. Furthermore, benefits will not be evenly distributed: some industrial sectors, businesses, regions and societal groups are likely to lose, while others will benefit. Chapter Sustainable Furniture that Grows with End-Users introduces how Gispen, a major office furniture producer in the Netherlands, has embraced circular economy principles to create new business, extend product life time and improve the adaptability of their products.

3 Life Cycle Assessment

The standards of LCA are ISO 14040:2006 "Environmental management—Life cycle assessment—Principles and framework" and ISO 14044:2006 "Environmental management—Life cycle assessment—Requirements and guidelines" (ISO 14040:2006; ISO 14044:2006). LCA can be used for identifying opportunities to improve environmental performance of products; informing customers, stakeholders and other interest groups of environmental impacts from different stages of a product's life cycle; and marketing purposes in the forms of e.g. eco-labelling or environmental product declaration (EPD) (Tukker 2000). LCA makes it possible to reveal mitigation points and critical phases along the supply chain of a product, process or a service and can also assist in strategic risk management, facilitate resource efficiency and optimization of environmental management as well as be a communication tool.

LCA has four stages (ISO 14040:2006; ISO 14044:2006). The first stage is Goal and scope definition. This defines the goal of the study, sets the system boundaries and lists the assumptions needed in the calculation. The second stage, called the life cycle inventory (LCI), includes data collection of input/output data and a balance calculation to all unit processes (the smallest element considered for which input and output data are quantified) in the life cycle. The results are presented as inputs and outputs of the entire system. The results from the inventory can be converted into impacts on the environment in the third stage, the life cycle impact assessment (LCIA). One example of this is the carbon footprint calculation; the emitted GHG from the inventory calculation are converted into global warming potentials in the impact assessment stage (ISO/TS 14067:2013). There are also several other impact categories, e.g. eutrophication, acidification and photochemical ozone formation.

The final stage of LCA is interpretation of the results, which is based on all three previous stages of the assessment and summarises and discusses the conclusions and possible recommendations in accordance with the goal and scope definition. In some cases, the goal of the study can be fulfilled with just the LCI calculation and the interpretation, and the LCIA phase can be omitted. These studies should be called LCI studies and not LCA studies (ISO 14040:2006; ISO 14044:2006). The stages of the LCA are presented in Fig. 2.

When calculating LCA, the life cycle is modelled from unit processes which are connected to each other with material or energy flows (ISO 14040:2006). Each process has inputs and outputs which are connected to previous and subsequent processes from the beginning until the end of the product life cycle.

LCA results are sensitive for the chosen system boundaries and assumptions. One of the most important issues is definition of the system boundaries, i.e. the determination of stages of the product's life cycle that are included in the assessment (Pajula 2014). Full LCA is calculated from "cradle to grave" or "cradle to cradle". In addition to the linear part of the life cycle (production of raw materials and energy, manufacturing of the product, all transportations, use phase, and any disposal of the product or other end-of-life treatment) a "cradle to cradle" study includes recycling, reuse or remanufacturing. "Cradle to cradle" coverage is necessary when evaluating the concept of circular economy. "Cradle to gate" and "cradle to customer" calculations are partial LCAs considering the life cycle until the production of the product only (cradle to gate) or until the product has been transported to the customer (cradle to customer), but excluding the use phase and end-of-life steps. They are mainly used for business to business communication and as a starting point for more comprehensive LCAs.

There are two types of LCA approaches, which have different perspectives and thus can be used for different types of needs (Finnveden et al. 2009).

- Attributional LCA can be seen as a "conventional" approach that focuses on describing the environmentally relevant flows and impacts related to a product or process. It includes the full life cycle as it is, uses allocation (partitioning of the input or output flows of a process between the product system under study and one or more other product systems) and typically uses average data.

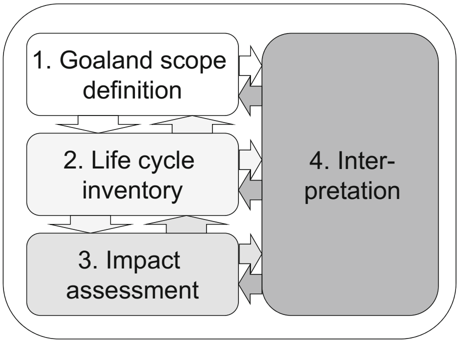

Fig. 2 The four stages of life cycle assessment

- Consequential LCA studies the change in environmental impacts related to a change in the life cycle. The result describes the consequences of actions within the life cycle, allocation is avoided through system expansion, and marginal data is used in the calculations. The selection between attributional and consequential approach should be made in the goal and scope definition phase depending on the purpose of the study.

The unit processes within the life cycle can be grouped according to the life cycle steps (e.g. energy production, transportation) or other coding (raw material supply, own processes, end-of-life), and the results can be studied transparently (ISO 14040:2006; ISO 14044:2006). Figure 3 shows an example of a life cycle, presenting the life cycle steps of a fibre product and the types of input and output flows related to each life cycle step.

Life cycle inventory (stage 2) calculations require vast amounts of highly specific data. The procedures related to LCI are shown in Fig. 4. Data can be collected from the production sites within the value chain, or it may be obtained from other sources, e.g. public databases. The LCA standards set specific requirements for e.g. time-related coverage, geographical coverage, technology coverage, precision, completeness and representativeness of the data. In addition, uncertainty and sensitivity of assumptions can be demonstrated via sensitivity analyses. The results of LCA are represented per functional unit, which describes the need that is fulfilled with the product or service. Typical functional units are numbers of product (e.g. one car or a book) or amounts of product (e.g. 1000 kg paper or 1 l of diesel).

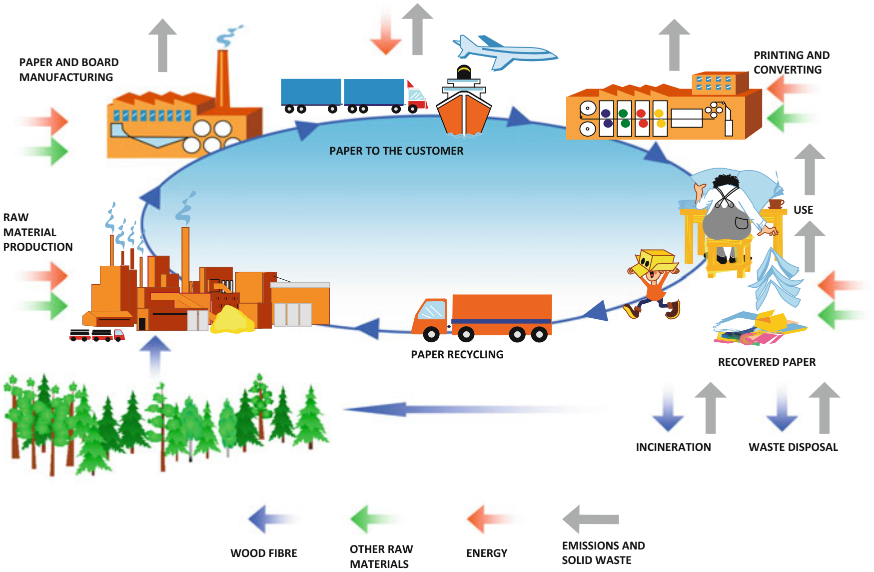

Fig. 3 Life cycle example of a fibre product

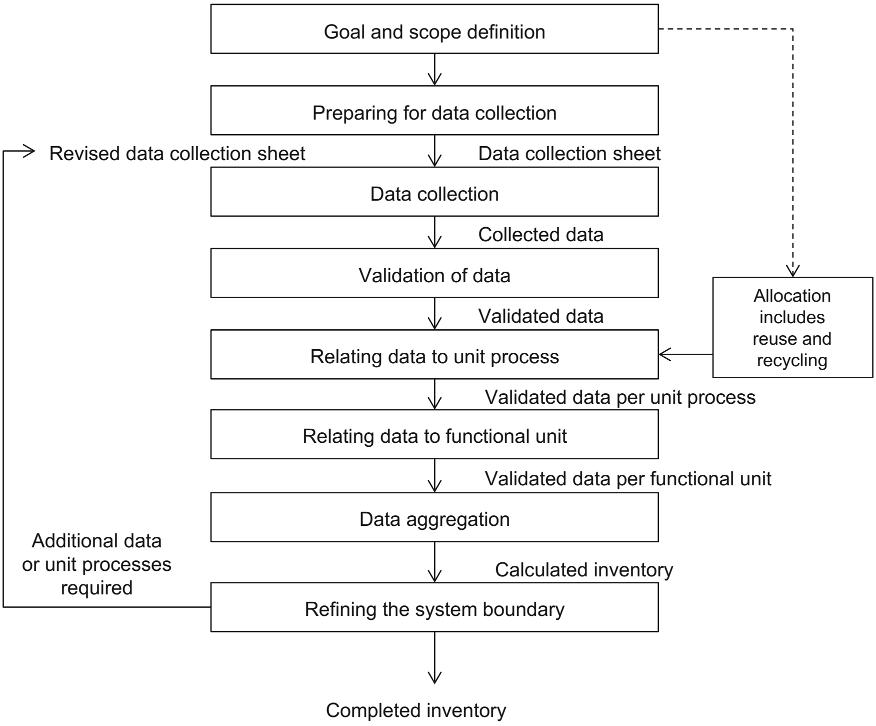

Fig. 4 The simplified procedures of life cycle inventory (ISO 14044)

Life cycle impact assessment (stage 3) consists of the following steps (ISO 14044:2006):

- **Classification** assigns the LCI results to one or more impact categories, e.g. CO_2 influences global warming and SO_2 can impact human health and acidification.
- **Characterisation** converts the LCI results into common units and aggregates the results within the same impact category. For example, CH_4 and N_2O are converted into CO_2 equivalents with emission-specific factors (a global warming potential of 1 kg CH_4 equals 25 kg CO_2 eq.) and reported as CO_2 equivalents.
- **Normalisation** calculates the magnitude of category indicator results relative to some reference information, which should be relevant considering the spatial and temporal scales of the study. The purpose is to better understand the relative magnitude for each indicator result of the product system studied. This step of impact assessment is optional, not mandatory.
- **Grouping** means that the impact categories are sorted and ranked. Grouping can be carried out either by sorting the impact categories on a nominal basis (e.g. by characteristics such as inputs and outputs) or by ranking the impact categories in

a given hierarchy (e.g. high, medium and low priority). Ranking is based on value-choices and the results may be different when calculated by different parties. This step of impact assessment is also optional, not mandatory.

- **Weighting** converts and possibly aggregates indicator results across impact categories using numerical factors based on value-choices. Sensitivity analysis can be used to assess the consequences of value-choices. This step of impact assessment is again optional, not mandatory.

The steps of impact assessment are presented in Fig. 5.

The LCA standards do not determine which impact assessment methods should be used in a study. Selection of the method should be made in the goal and scope definition phase (stage 1), considering the spatial and temporal aspects of the study. Some methods include only characterisation factors but not normalisation or weighting factors, and these methods are called "the midpoint methods". For example, the CML 2001 impact assessment method can be mentioned as a midpoint method (CML 2001), and the ReCiPe method includes both midpoint and endpoint-indicators (ReCiPe 2013). According to Goedkoop et al. (2008), the midpoint indicators without weighting can be seen as more robust and less subjective than the endpoint indicators, but they might be difficult to compare or interpret due to their abstract meaning.

Environmental Product Declaration (EPD) is an LCA-based tool to communicate the environmental performance of a product. It is a document that communicates information about the life cycle environmental impact of products in a transparent and comparable way (ISO 14025 2006). To control the calculations and data collection, detailed requirements for some product group are developed; these are called Product Category Rules (PCR). For example there is a PCR for the assessment of the environmental performance of office furniture (EPD 2012).

"Critical review" is a specifically determined process for LCA that aims to ensure consistency between a LCA study and the guidelines of the ISO standard. This has to be used if the results of the study are to be published and used for a comparative assertion. Critical review can be carried out by an internal or external

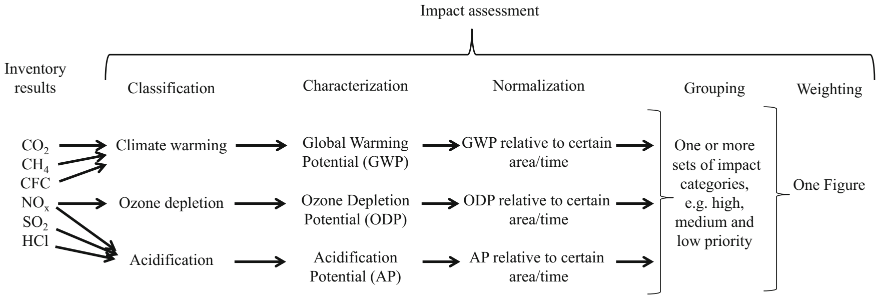

Fig. 5 Steps of impact assessment

expert, who is independent of the LCA, or by a panel of interested parties. The review statement, comments of the expert and any responses to recommendations by the reviewer(s) must be included in the LCA report (ISO 14040:2006).

Since life cycle assessments are often rather extensive and the amounts of input/output data, flows and factors are very large, several calculation softwares have been developed to help the calculations. They often include generic databases and some impact assessment methodologies which are helpful in calculations. SimaPro, GaBi and SULCA can be mentioned as examples of LCA calculation tools (Loijos 2012; VTT 2014). Naturally, like every method, LCA has its limitations, for example, inclusion of biodiversity, littering, or animal well-being may be difficult in the calculations, due to lacking data and limitations in impact categories (Finkbeiner et al. 2014). Such challenges and limitations must be considered and recognized in the goal and scope definition phase when using the method.

4 Other Methods Based on Life Cycle Thinking

In addition to LCA, carbon and water footprint are currently the most commonly applied environmental assessment methods used by companies (Saurat et al. 2014). All three are based on life cycle thinking, but whereas LCA includes all environmental aspects, the others address specific environmental impacts such as climate change (carbon footprint) or water-specific environmental impacts (water footprint). As they were developed to study questions related to a certain specific environmental topic, it is important to be aware that carbon and water footprints cannot be used for an evaluation or communication of overall environmental superiority (ISO/TS 14067:2013; ISO 14046 2014). Extensive LCAs should be conducted first to identify the hotspots related to the production and value chains and to reveal the most critical environmental impacts. This then allows companies to focus later on the most important indicators, such as for example carbon footprint. This is possible especially for companies or sectors working with basically the same raw material, or mix of raw materials, from year to year, such as the aluminium or the forest industry (Saurat et al. 2014).

4.1 Carbon Footprint

Climate change caused by human actions has created a need to measure and mitigate GHG emissions. Carbon footprint is a concept that describes the GHG emissions and removals over the life cycle of a product expressed as CO_2 equivalents (BSI PAS2050:2011). The quantification of a carbon footprint is based on the principles of LCA, focusing on the single impact category of climate change

(ISO/TS 14067:2013). Benefits of carbon footprint as an indicator are that it is easily understandable, globally interesting, broadly applicable and easy to implement for different strategies (Alvarez et al. 2016).

The carbon footprint of products standard (ISO/TS 14067:2013) provides principles, requirements and guidelines for the quantification and communication of the carbon footprint of products, including both goods and services. Calculations can also be made at an organisational level (ISO/TR 14069).

The CO_2 equivalent of a specific amount of a GHG is calculated as the mass of a given GHG multiplied by its global warming potential factor given by the Intergovernmental Panel on Climate Change (IPCC). The factors describe the global warming potential of emissions over the next 100 years. The CO_2 equivalents are then summed up and reported as carbon footprint. The factors for the most important GHG are reported in Table 1. The figures show that the impacts of different GHG on climate change vary so notably per physical unit that they cannot be directly compared and summed together at the inventory result level, but need to be converted into the impact assessment level instead (Fang and Heijungs 2015).

The typical sources of GHG emissions in carbon footprint calculations are energy production and consumption in the forms of electricity, heat or fuels, transportation and selection of raw materials. As in the LCA calculations, the results of footprint calculations can be divided into life cycle steps, and thus the most important emission sources are shown.

Carbon neutrality is a term that has been widely used in public discussion, although its meaning varies rather widely. It can be understood as zero fossil GHG emissions to the atmosphere, or as a situation in which the amount of released emissions is compensated by investing in projects that are mitigating GHG emissions elsewhere. Both perspectives have deficiencies, since the dynamics of biogenic carbon and land use change are very complex in the first approach, and the compensation does not remove the released emissions and their impacts from the atmosphere in the second approach. Thus the background and assumptions of carbon neutrality should always be reported in a high level of detail. The term “Offsetting” refers to compensating for all or for a part of the Carbon Footprint in a process outside the boundary of the product system through prevention, reduction or removal of GHG emissions, but it is not permitted in carbon footprint calculations (ISO/TS 14067 2013).

Table 1 Conversion factors of the most important greenhouse gases to carbon dioxide equivalents by IPCC (2007)

	Conversion factor by IPCC
Carbon dioxide, CO_2	1
Methane, CH_4	25
Dinitrogenmonoxide, N_2O	298

Scientific communities and international guidance agree that all GHG emissions arising from fossil sources shall be included in Carbon Footprint calculations, whereas the inclusion of biogenic carbon involves more complexity and there are different views on its inclusion (Pajula 2014). Carbon sequestration in forests and storage in end products create carbon stocks for years, decades or even centuries and make biogenic carbon time-dependent, whereas fossil emissions can be considered to be released "today" (ISO/TS 14067 2013). On the other hand, although a sustainably managed biomass system is usually carbon neutral or even accumulates carbon over time, the timing difference between the release and sequestration of forest biomass carbon leads to a situation in which part of the carbon remains in the atmosphere until it is fully sequestered back into the growing forest. This leads to the fact that carbon neutral does not equal to climate neutral. The timing difference between emission and sequestration results first in a warming effect, whereas over a long period the accumulation of carbon results in a stock (Pajula 2014). Therefore, the conclusions of a study strongly depend on the forest management system in use and the timeframe chosen for the assessment (see Fig. 6, cf. Helin et al. 2012). The suitability of the different approaches presented in the literature for biomass carbon accounting within LCA was discussed by Helin et al. (2012). As there is no scientifically correct timeframe, it is recommended that different timeframes should be considered. Moreover, the technical specification requires reporting of biogenic emissions separately from fossil-based emissions (ISO/TS 14067 2013).

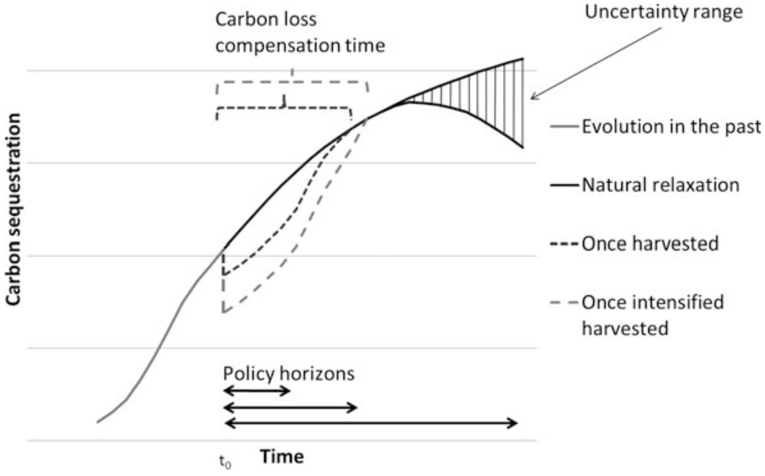

Fig. 6 A policy horizon considering climate impacts (Helin et al. 2012)

4.2 Water Footprint

Water scarcity and the availability of fresh water is a global concern. Numerous industries have become vulnerable to water disruption. In recent years, there has been an increased interest to assess water-related impacts as a basis for improved water management at local, regional, national and global levels. At the company level, it is not only important to ensure a supply of water, control the emissions to water and maintain the local environment, but also to understand the indirect water and the risk factors that occur when operating in different regions. One of the methods developed for this purpose is water footprint.

Water footprint is a tool that assesses the magnitude of potential, water-specific environmental impacts of water use associated with a product, process or organisation. It aims at describing the impact of water use on humans and ecosystems due to changes in water quality and quantity, making it possible to reveal mitigation points along the supply chain. Compared to the product carbon footprint, which describes the global warming potential of a product with a global impact, the water footprint is a local indicator.

Various initiatives by different institutions and organisations have been launched in order to develop analytical tools to measure and assess freshwater use and water footprint (Hoekstra et al. 2011; Ridoutt and Pfister 2010). Due to a great variety of different methods, comparison of the results has been difficult. In order to harmonise the methodology and approach, the ISO Standard 14046 was launched in 2014. The standard provides principles, requirements and guidelines for water footprinting. A water footprint assessment conducted according to this standard is based on a LCA (ISO 14044 2006). An LCA-based water footprint is the fraction of impact assessment results which are related to water resources. Water footprint is a sum of the water footprint of different life cycle stages, identifies potential environmental impacts related to water, includes geographic and temporal dimensions, identifies quantity of water use and changes in water quality, and utilises hydrological knowledge. Because any change in water quality and in water quantity may have an impact on the availability or possible uses of water, it is important to consider both aspects in the impact assessment.

Although the standard sets principles for the water footprint assessment, specific methods or characterization factors that should be used for the assessment are not defined in the standard. Several methods have been developed proposing different inventory schemes and impact assessment models to account for the impacts associated with water consumption or water quality degradation. Different methods use different underlying assumptions, modelling choices, and conceptualisation of what actually constitutes an impact of water use (Boulay et al. 2015; Kounina et al. 2013). Impacts may include contributions to regional water scarcity, depriving other users of access to water, reducing the water flows required to maintain ecosystem functions, or degradation of water quality. No single method is available which comprehensively describes all potential impacts derived from fresh water use

(Kounina et al. 2013). Currently, the WULCA group (Water Use in LCA, UNEP-SETAC Life Cycle Initiative) is coordinating a consensus-building process and leading the scientific work towards achieving a harmonised method to assess water use in LCA (WULCA 2015).

Water footprint can be presented as the result of a stand-alone assessment (in which only potential environmental impacts related to water are assessed) or is a sub-set of results of a larger environmental assessment (e.g. LCA, in which consideration is given to all relevant potential environmental impacts). According to the ISO standard, a qualifier is used if a water footprint study is limited to only certain aspects. A "water scarcity footprint" or "water availability footprint" assesses impacts associated with water use only, and "water eutrophication footprint" assesses the impact related to eutrophication only. If all relevant water use impacts are included (e.g. water use, eutrophication, acidification, freshwater toxicity), the study can be called water footprint (with no qualifier).

Water footprint and environmental risk assessment can be connected to derive complementary data on product water sustainability (Saarivuori et al. 2015). This provides companies with a way to manage and foresee water use related impacts and risks and can be used as a basis for a broader water disclosure, providing a deeper understanding of water risks for the companies themselves, the investors and other stakeholders. In addition, water footprint provides a scientific basis and a framework to assess water efficiency.

4.3 Handprints

The concept of handprint has been introduced rather recently (CEE 2007) to measure and communicate the positive changes of actions and the beneficial impacts, whereas the footprint measures the negative impacts in terms of emissions and resource consumption. Operating an organization always creates some kind of footprint, but it can also bring positive changes and benefits to the surrounding world. The estimate of those impacts of positive change is called a handprint (Norris 2015b).

The handprint concept can be applied to products, processes, companies, organizations or individuals, and it can consider the impacts on environment or society. Handprint evaluates the environmental impact of the object of study in two categories: the delivered benefit and the good the object of study does. Handprint builds on the concept of environmental footprint and the concept is characterized by unlimited potential and a self-reinforcing positive feedback loop (Biemer et al. 2013a, b). This means the handprint can sustain itself once it is established as companies tell others what they learned, and they in turn will tell others. The handprint and the footprint are not exclusive, but rather complementary ways of thinking.

According to Norris (2015a), a handprint of a product can be created either by preventing or avoiding negative impacts (footprints) that would otherwise have occurred, or by creating positive benefits that would not have occurred. The handprint of a company considers the footprint of the company itself, but also the positive changes the company may have on individuals or other companies. This includes changes in the supply chain and also takes into account the changes which are indirectly associated with the goods and services the company produces. Handprints can take place anywhere in the world and they can be composed of multiple small impact reductions.

Handprinting includes three steps (SHINE 2015):

1. Measure and reduce company footprint (e.g. reduce emissions, promote eco-efficiency in supply chains and dematerialize goods and services).
2. Support others to reduce their footprints (e.g. promote innovations in the supply chain which reduce the footprints of goods and services sold to other companies, improve use phase efficiency, educate downstream customers to use products more effectively or efficiently, share innovations with other businesses and increase demand for own products with better performance (smaller footprint) than that of displaced products).
3. Take actions which address the same kind of impact categories on which footprints are causing negative impacts.

Both consequential (change-oriented and focused on the consequences of possible future changes between alternative product systems) and attributional (impacts of a specific product system based on an account of the history of the product) LCA can be applied in these assessments (Norris 2013).

Generating handprints is about actions that increase sustainability and well-being and reduce harmful activities and impacts in terms of both humans and the planet (SHINE 2015). The idea is to create and communicate positive changes in the whole supply chain from factories to customers. Handprints complement the footprint and bring similar quantitative and life cycle based assessment methods to address a much wider scope of action (global focus and multiple impact categories for companies to strive towards being net positive). Handprinting also highlights the positive approach to impact assessment that can motivate and inspire company staffs and promote creativity and new ideas on how to create more positive company impacts. Handprint covers a growing set of sustainability dimensions such as climate change, human health, biodiversity and water consumption. There is also a growing set of social performance indicators. However, better assessment tools and further definition of the handprint calculation method are needed if companies want to communicate the benefits achieved and their high level of clean-tech knowhow.

5 Conclusion

The benefits of a transition towards a circular economy in Europe could be considerable, reducing environmental pressures in Europe and beyond and decreasing the continent's high and increasing dependence on imports (EEA 2/2016). Increasingly, this dependence could be a source of vulnerability. Growing global competition for natural resources has contributed to marked increases in price levels and volatility. Circular economy strategies could also result in considerable cost savings, increasing the competitiveness of Europe's industry while delivering net benefits in terms of job opportunities (EEA 2/2016).

Reduction of environmental impacts from industry can be obtained with effective life cycle management. Consideration of the full life cycle of products, i.e. life cycle thinking, is a prerequisite for full understanding of actions and their consequences, both in the industrial manufacturing phase and elsewhere in the life cycle. Sustainability indicators and tools can provide beneficial information for creating new business opportunities and innovation processes. They provide transparent information of resource and energy consumptions in different parts of the life cycle and also reveal the most important sources of emission and waste. Thus they can be of help in finding the most environmentally burdening processes and phases in the life cycle so that the correcting actions can be directed efficiently to those areas with the best improvement potentials. The life cycle management can also reduce the resource requirements and create more economic value by reducing, reusing and recycling of materials and energy while minimising the costs and the amount of waste created.

The methods listed in this article are focused on environmental impacts from the life cycles of products and services. Life cycle thinking, circular economy and LCA provide a starting point for companies to think, act and manage their production sustainably. Although still having some methodological challenges, such as the allocation of burden between products in recycling systems or inclusion of biogenic carbon, they are widely known and accepted approaches that have gained a permanent status as sustainability tools. They can be applied in all sectors, all products and all services in the world, globally and locally, and they can be used for existing processes or in the design and development phases of new products and processes. They provide information for internal use but also for communication and marketing purposes. The tools can bring benefits to the companies and industry sectors and increase the know-how of sustainability both at the producer and consumer level.

The carbon footprint and water footprint are nowadays standardized and accepted methods that are based on LCA. They focus on specific topics of climate change and water quality and scarcity, respectively. They can be useful when studying a specific product, industrial location or company, and they are rather easy to communicate and interpret. However, it is essential to keep in mind that environmental challenges are not limited to carbon or water, and optimizing a single indicator may cause trade-offs with other impacts.

The concept of handprints on the other hand is still being developed. Handprints aim at communicating the benefits of actions, the positive impacts rather than the negative impacts measured by the footprints. Companies should follow the development process of handprints and provide feedback to the concept developers in order to reach the full benefits that can be created. The positive impacts and their communication as handprints can generate competitive advantage for companies, improve the brand and reputation and increase demand for the company's products.

As new circular approaches emerge, frictions between the existing linear system and the new approaches are bound to arise. These may be perceived as threats by some stakeholders, but as opportunities by others. The UIW-project considers six clusters, namely turbines, machinery, space, trucks, shipping and office furniture. They can all apply the life cycle management options reported in this article to support sustainable design of product services and production processes. Life cycle thinking, efficient use and recycling of materials, environmental impact assessment and consideration of positive actions can enhance new business opportunities, improve competitiveness and extend the life cycles of industrial products/services. Good practical examples exist. For example, businesses are already employing or experimenting with new business models such as service- and function-based business models and collaborative consumption. Governments increasingly foster waste prevention, reuse and repair (EEA 2/2016). At the same time more information is needed to inform decision making and combine thinking about environmental, social and economic impacts. Better insight is needed into production structures and functions, consumption dynamics, finance and fiscal mechanisms, as well as triggers and pathways for technological and social innovations.

References

Alvarez, S., Carballo-Penela, A., Mateo-Mantecón, I., & Rubio, A. (2016). Strengths-weaknesses-opportunities-threats analysis of carbon footprint indicator and derived recommendations. *Journal of Cleaner Production, 121*(2016), 238–247. http://www.sciencedirect.com/science/article/pii/S0959652616001736. Accessed May 09, 2016.

Biemer, J., Dixon, W., & Blackburn, N. (2013a). Our environmental handprint. The good we do. Institute of electrical and electronic engineers. Presented at the 2013 IEEE Conference on Technologies for Sustainability. http://handprint.in/Our_Envir_Handprint_IEEE_Paper_6-14-13wc.pdf. Accessed December 10, 2015.

Biemer, J., Dixon, W., & Blackburn, N. (2013b). Our environmental handprint. The good we do. In *SusTech 2013, Portland Oregon*. *Conference presentation*. http://sites.ieee.org/sustech/files/2013/12/QL1_BIEMER-Env_Handprint.pdf. Accessed December 10, 2015.

Boulay, A.-M., Motoshita, M., Pfister, S., Bulle, C., Muñoz, I., Franceschini, H., et al. (2015). Analysis of water use impact assessment methods (part A): Evaluation of modelling choices based on a quantitative comparison of scarcity and human health indicators. *International Journal of Life Cycle Assessment, 20,* 139–160. doi:10.1007/s11367-014-0814-2.

BSI PAS 2050:2011. (2011). *Specification for the assessment of the life cycle greenhouse gas emissions of goods and services* (Vol. 38). London, UK: British Standards Institution (BSI). ISBN 978 0 580 71382 8 http://shop.bsigroup.com/upload/shop/download/pas/pas2050.pdf. Accessed March 15, 2016.

CEE. (2007). *The 4th International Conference on Environment Education*. Ahmedabad, India: Centre for Environment Education (CEE). 24–28 November, 2007. http://www.ceeindia.org/tbilisiplus30/. Accessed March 02, 2016.

CML. (2001). *Impact assessment method*.

EEA Report No 2/2016. *Circular economy in Europe, developing the knowledge base*.

EPD. (2012). PCR 2012:19. In *Other furniture, of a kind used in offices and other furniture n.e.c. (Version 1.1)*. http://www.environdec.com/en/PCR/Detail/?Pcr=8458&show_login=true&new_user=true. Accessed May 30, 2016.

European Commission. (2010). *Making sustainable consumption and production a reality. A guide for business and policy makers to life cycle thinking and assessment* (Vol. 32). Luxembourg: Publications Office of the European Union. http://ec.europa.eu/environment/pubs/pdf/sustainable.pdf. Accessed May 30, 2016.

European Commission. (2014). Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions. Towards a circular economy: A zero waste programme for Europe. In *COM (2014)* 398 final. 14.

European Commission. (2016). *Climate action. Paris agreement*. http://ec.europa.eu/clima/policies/international/negotiations/paris/index_en.htm. Accessed May 30, 2016.

Fang, K., & Heijungs, R. (2015). Investigating the inventory and characterization aspects of footprinting methods: Lessons for the classification and integration of footprints. *Journal of Cleaner Production, 108*(2015) part A, 1028–1036.

Finkbeiner, M., Ackermann, R., Bach, V., Berger, M., Brankatschk, G., Chang, Y.-J., et al. (2014). Challenges in life cycle assessment: An overview of current gaps and research needs. *Background and future prospects in life cycle assessment* (pp. 207–258). Berlin (DE): Springer.

Finnveden, G., Hauschild, M. Z., Ekvall, T., Guinée, J., Heijungs, R., Hellweg, S., et al. (2009). Recent developments in life cycle assessment. *Journal of Environmental Management, 91*(1), 1–21.

GeSI. (2012). GeSI SMARTer 2020: The role of ICT in driving a sustainable future. In *The Global e-Sustainability Initiative (GeSI)*. http://gesi.org/assets/js/lib/tinymce/jscripts/tiny_mce/plugins/ajaxfilemanager/uploaded/SMARTer%202020%20-%20The%20Role%20of%20ICT%20in%20Driving%20a%20Sustainable%20Future%20-%20December%202012.pdf. Accessed March 6, 2016.

Goedkoop, M. J., Heijungs, R., Huijbregts, M., De Schryver. A., Struijs, J., & Van Zelm, R., ReCiPe. (2008). A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level (1st ed.). In *Report I: Characterisation*. January 6, 2009. http://www.lcia-recipe.net. Accessed May 10, 2016.

Helin, T., Sokka, L., Soimakallio, S., Pingoud, K., & Pajula, T. (2012). Approaches for inclusion of forest carbon cycle in life cycle assessment—A review. *GCB Bioenergy, 5,* 475–486. doi:10.1111/gcbb.12016.

Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M., & Mekonnen, M. M. (2011). *The water footprint assessment manual: Setting the global standard*. London, UK: Earthscan.

ISO 14025. (2006). *Environmental labels and declarations—Type III environmental declarations—Principles and procedures*.

ISO 14040. (2006). *Environmental management, life cycle assessment, principles and framework*.

ISO 14044. (2006). *Environmental management, life cycle assessment, requirements and guidelines*.

ISO 14046. (2014). *Environmental management—Water footprint—Principles, requirements and guidelines*.

ISO/TS 14067. (2013). *Greenhouse gases. Carbon footprint of products. Requirements and guidelines for quantification and communication*.

IPCC. 2007: Climate Change (2007). *The Physical Science Basis*. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (Eds.), Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (996 pp)Cambridge, United Kingdom, New York, USA: Cambridge University Presshttp://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4_wg1_full_report.pdf Accessed April 25, 2016.

Kounina, A., Margni, M., Bayart, J.-B., Boulay, A.-M., Berger, M., Bulle, C., et al. (2013). Review of methods addressing freshwater use in life cycle inventory and impact assessment. *International Journal of Life Cycle Assessment, 18*(3), 707–721.

Lieder, M., & Rashid, A. (2016). Towards circular economy implementation: A comprehensive review in context of manufacturing industry. *Journal of Cleaner Production, 115*(2016), 36–51.

Loijos, A. (2012). *Comparison of best life cycle assessment software*. http://www.linkcycle.com/comparison-of-best-life-cycle-assessment-software/ (online document). Accessed April 27, 2016.

Norris, G. (2013). The new requirement for social leadership: Healing. In S. Groschl (Ed.), *Uncertainty, diversity and the common good: Changing norms and new leadership paradigms*. London: Gower Publishing. http://www.chgeharvard.org/sites/default/files/resources/Introduction%20to%20Handprinting.pdf. Accessed November 24, 2015.

Norris, G. (2015a). *Handprint-based netpositive assessment*. Sustainability and Health Initiative for NetPositive Enterprise (SHINE), Center for Health and the Global Environment, Harvard T. H. Chan School of Public Health. http://www.chgeharvard.org/sites/default/files/resources/Handprint-Based%20NetPositive%20Assessment.pdf. Accessed January 4, 2016.

Norris, G. (2015b). *A one-page introduction to handprints*. Sustainability and Health Initiative for NetPositive Enterprise (SHINE), Center for Health and the Global Environment, Harvard T.H. Chan School of Public Health. Accessed December 2, 2015.

Outotec. (2015). *Maximizing our handprint—Outotec's sustainability report 2014*. http://www.outotec.com/ImageVaultFiles/id_1598/cf_2/27729-Outotec_Sustainability_aukeemittain.PDF. Accessed December 21, 2015.

Pajula, T. (2014). Life cycle assessment of biobased materials. In *Handbook of green materials* (Vol. 5, Chapter 17). World Scientific.

ReCiPe. (2013). *Methodology for life cycle impact assessment (LCIA)*.

Ridoutt, B. G., & Pfister, S. (2010). A revised approach to water footprinting to make transparent the impacts of consumption and production on global freshwater scarcity. *Global Environmental Change, 20,* 113–120.

Saarivuori, E., Molarius, R., Wessman-Jääskeläinen, H., & Poussa, L. (2015). Connecting water footprint and water risk assessment: Case packaging board. *Water Practice & Technology, 10* (1), 229–241.

Saurat, M., Ritthoff, M., Pihkola, H., Alonso, A., & Lopez, A. (2015). Description of current industry practice and definition of the evaluation criteria. In *EU SAMT, D2.1*.

Shine. (2015). *Shine summit 2015. Innovating for netpositive impact. Summary Report*. Sustainability and Health Initiative for NetPositive Enterprise (SHINE), Center for Health and the Global Environment, Harvard T.H. Chan School of Public Health. http://chgeharvard.org/sites/default/files/resources/Shine%20Paper%202015%20for%20web-update.pdf. Accessed December 2, 2015.

Sitra. (2015). The opportunities of a circular economy for Finland. In *Sitra studies 100* (72 pp). ISBN 978-951-563-938-7.

Tukker, A. (2000). Life cycle assessment as a tool in environmental impact assessment. *Environmental Impact Assessment Review, 20*(4), 435–456.

VTT. (2014). *SULCA—Sustainability tool for ecodesign, footprints & LCA*. SimulationStore, VTT Technical Research Centre of Finland LTD. https://www.simulationstore.com/sulca (online document). Accessed April 27, 2016.

WULCA. (2015). Consensual method development: Preliminary recommendation—AWaRe v1.1. In *Water use in LCA (WULCA) working group*. Accessible from: http://www.wulca-waterlca.org/. Accessed November 10, 2015.

Yuan, Z., Bi, J., & Moriguichi, Y. (2006). The circular economy: A new development strategy in China. *Journal of Industrial Ecology, 10*(1–2), 4–8.

Virtual Reality and 3D Imaging to Support Collaborative Decision Making for Adaptation of Long-Life Assets

Jonatan Berglund, Liang Gong, Hanna Sundström and Björn Johansson

Abstract European companies of today are involved in many stages of the product life cycle. There is a trend towards the view of their business as a complex industrial product-service system (IPSS). This trend shifts the business focus from a traditional product oriented one to a function oriented one. With the function in focus, the seller shares the responsibility of for example maintenance of the product with the buyer. As such IPSS has been praised for supporting sustainable practices. This shift in focus also promotes longevity of products and promotes life extending work on the products such as adaptation and upgrades. Staying competitive requires continuous improvement of manufacturing and services to make them more flexible and adaptive to external changes. The adaptation itself needs to be performed efficiently without disrupting ongoing operations and needs to result in an acceptable after state. Virtual planning models are a key technology to enable planning and design of the future operations in parallel with ongoing operations. This chapter presents an approach to combine digitalization and virtual reality (VR) technologies to create the next generation of virtual planning environments. Through incorporating digitalization techniques such as 3D imaging, the models will reach a new level of fidelity and realism which in turn makes them accessible to a broader group of users and stakeholders. Increased accessibility facilitates a collaborative decision making process that invites and includes cross functional teams. Through such involvement, a broader range of experts, their skills, operational and tacit knowledge can be leveraged towards better planning of the upgrade process. This promises to shorten

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lead times and reduce risk in upgrade projects through better expert involvements and shorter iterations in the upgrade planning cycle.

Keywords 3D-imaging · Collaboration · Cross-functional teams · Manufacturing · Virtual reality · Simulation and modelling · Layout planning

1 Introduction

As stated by Reyes in Chapter "The Use-It-Wisely (UIW) Approach", European industries face significant challenges due to global off-shoring, rapid business environment change, shrinking investment budgets, and environmental pressures (Schuh et al. 2011). Companies that work with high investment assets need strategies and tools to enable prolonged service life and even upgrades of functionality and capability over time. A high investment asset is typically something that has an expected return on investment of several years or even decades. Their operation typically includes providing some sort of service to internal or external customers. There are plenty of examples, of which most can be modelled as product-service system (IPSS). These systems consist of Products, the physical objects that are being offered, and Services, the additional business proposals that are offered alongside the physical products (Mont 2002). Also included in this system view, and generally thought to add to the complexity are the different actors whom interact directly and indirectly with the system. A common denominator for the IPSS system discussed in this project are that their physical objects or entities exists to provide some service or function over a reasonably long time span. These systems tend to be complex in nature and are often operated on and interacted with by a large number of actors. The involved actors tend to each have their own individual needs and requirements to fulfil their tasks and purposes, making the alignment towards a common, holistically optimal, goal complex. There are many examples of the type of system mentioned here and the clusters in the Use-it-Wisely project represents a subset of them, for example a communications satellite put into orbit, a passenger vessel for shipping industry, or an automotive production facility.

This chapter explores the use of VR and 3D-imaging technologies to support such upgrades to extend the operational phase of the IPSS system's life cycle. Specific emphasis is put on how they can support maintenance, upgrade design, and implementation processes. VR technology provides immersive access to life sized models so that they can be experienced by end users in the design and upgrade stage. These users can be domain experts within the use-phase of the system that traditionally are not deeply involved in the development phase. When it comes to upgrades of existing systems, 3D-imaging provides generation of realistic, accurate, and up-to-date data which can be used as visualization models of the current system configuration. By merging these models with the upgrade design suggestions, realistic scenarios for the future system state can be created. Finally, by using VR technologies these future state models, can be reviewed by domain-experts early on in the design phase, giving them a tool to voice their needs and requirements in a concrete way. The involvement of cross functional actor teams is key in achieving a holistic approach to problem solving and ideation (Ahn et al. 2005; Song et al. 1998).

Section 2 gives an overview of the state of the art in the involved technologies. Section 3 presents the combined 3D-imaging and VR tool that was developed during the Use-it-Wisely project. Finally, Sect. 4 concludes the findings and lessons learned from this endeavour.

2 Generic Overview of Manufacturing Adaptation Processes and Related Technologies

The entry of computers to utilize digital tools and technologies in the design process has enabled an ever faster rate for developing products and services. It gives the ability for many engineers and other actors to work in parallel and share/replicate/combine their results across an infinite number of recipients with little added effort. Additions and changes to the design can be added without the need for any physical remake or rebuild of the objects. Thus, a development process can easily be shared between many actors and engineers in order to gain feedback and improvement suggestions. As the technology has been refined, more and more of the development and planning work can be conducted without the existence of any physical prototype. This reduces the need for multiple time consuming iterations of prototype building for verification and validation. This section serves as an introduction to VR, digital models, and 3D imaging in the upgrade design process.

2.1 Virtual Reality

Most commonly known as virtual reality (VR), the technology is sometimes also referred to as telepresence (Steuer 1992). The use of *presence* in the wording alludes to the experience of being present in a virtual environment. In other words, the mind is perceiving another surrounding and setting than the actual physical environment that surrounds the body. Steuer phrases the following definition:

> A “virtual reality” is defined as a real or simulated environment in which a perceiver experiences telepresence
>
> VR Definition, Steuer (1992)

Steuer presents a framework of dimensions to appraise the quality of a given VR technology. These dimensions are Vividness and Interactivity. Vividness signifies the breadth of the VR medium, e.g. how many senses that are exposed to stimuli, it also encompasses the depth of the stimuli, meaning the level of detail. Interactivity denotes the user’s possibility to navigate or affect the VR environment as well as how realistic that interaction is in terms of responsiveness and accuracy of movements (Steuer 1992).

> In general, the term virtual reality refers to an immersive, interactive experience generated by a computer.
>
> VR Definition, Pimentel and Texeira (1993)

Many authors have tried to characterize and measure VR-technologies in terms of quality of the experience. It is however an evasive quality and hard to measure in a quantifiable way. Gibson for example, who predates Steuer (1992) also talks of presence as the measure (Gibson 1979). In present terminology the word immersion is often used to describe the quality of the VR system. Immersion denotes the quality of the sensory stimuli that the system can produce. It is related, although not directly, to the subjective feeling of “presence” of the user. And logically the greater the quality of the stimuli the higher the probability of achieving a high level of presences. Though as many researchers in the field note, presence is highly dependent on the individual and some individuals have a greater capacity to experience presence. Presence can be interpreted as a measure of the extent the user forgets the medium to the benefit of the experience of “being” in the virtual environment (Loomis 1992).

Other examples are Loeffler and Anderson (1994) who defines VR as “a 3D virtual environment that is rendered in real time and controlled by the users”. Similarly to Steuer (1992) framework, they include the concepts of vividness (rendering) and interactivity (control). Although it seems to be narrower in the sense that is only alludes to visual stimuli, rendering.

There have been attempts at quantifying both immersion and presence. Pausch attempted to quantify the level of immersion in VR (Pausch et al. 1997). Meehan et al. (2002) wrote about physiological measurements of the VR experience by invoking stress on the subjects to grasp the fleeing aspect of presence. The measurements extended to heart rate, skin conductance, and skin temperature to determine the reaction of the test subject and compare to the change in the same measures given a real situation. The logic being that if our reactions to a situation in the virtual environment mimics our reaction to the same situation in the real world, our mind and bodies are likely believing the experience. The topic is debated from a different standpoint by Bowman, who poses the question of how much immersion

Table 1 Strengths and weaknesses of 3D visualisation (Teyseyre and Campo 2009)

Strengths	Weaknesses
Greater information density	Intensive computation
Integration of local and global view	More complex implementation
Composition of multiples 2D views in a single 3D view	User adaptation of 3D metaphors and special devices
Facilitates perception of the human visual system	More difficult for users to understand 3D space and perform actions in it
Familiarity, realism and real world representations	Occlusion

is enough (Bowman and McMahan 2007)? This is indeed an interesting aspect when the purpose is to facilitate work tasks in industry. Then the immersion lacks value in and off itself, as opposed to VR for entertainment purposes where elevated immersion is sought fiercely. Teyseyre and Campo (2009) represent one attempt at identifying the strengths and weaknesses of 3D visualisation in general. Their findings are shown in Table 1.

A general motivation to start using VR is the limitation of what information that can be presented by traditional 2D models (Smith and Heim 1999). The same authors argue that VR makes it possible to make accurate and rapid decisions through the added understanding an immersive virtual environment gives (Smith and Heim 1999). Another strong driver for using VR technology compared to traditional visualization of 3D models is the increased spatial understanding that is achieved in a VR environment. This helps experts in domains outside of 3D modelling and CAD to reach the same, or close to the same, understanding of the models as the model developer.

2.2 Virtual Reality in the Adaptation Process

Systems are designed to fulfil some function or need for its users. Inevitably, the needs or functions will be altered over time and to keep fulfilling these the system has to adapt accordingly. This adaptation can be achieved either by improving the system's current functions or by adding new functionality to the system. When designing and implementing adaptions to existing systems it is desirable to plan and foresee any problems that might arise. This is performed to ensure good quality and reduce the implementation time to minimize the downtime of the system during the adaptation process (Groover 2007).

Being able to access models through VR access to models through VR for better understanding. Access to models from various places. Many companies are operating on a global scale and need to be able to align and synchronize their efforts in a good and efficient way. This paper is concerned with upgrades and changes to long life assets. And specifically how to plan and optimize these upgrades in a collaborative way. Making use of the many various skills and expertise that exists in a company. In a sense, all the perceivable actors that interact with the IPSS should contribute their aspects and needs. This will support a holistic approach to the upgrade and reduces the risk of costly oversights of some critical functions and or aspects.

The idea of utilizing VR to support engineering work in general has been around for a long time. Deitz wrote in 1995 about the state of VR as a mechanical engineering tool. Concluding that it has the potential to "reduce the number of prototypes and engineering change orders", "simplify design reviews", and "make it easier for non-engineers to contribute to the design process" (Deitz 1995). High investment assets in nature tend to have many users and actors, many of them non-engineers, which interact with it over time. Often there are non-engineers that hold valuable tacit knowledge about the operational phase and maintenance of the asset. Enabling these individuals to be a part of the upgrade process can potentially bring about a more optimal end result that considers more aspects than a pure engineering solution would have.

This section goes into detail about VR, how it can be indexed and described and also gives an example of the various technological solutions that exist today. Further it introduces the field of 3D imaging as a technology to provide accurate digital 3D surface representations of the already existing assets. Discussing how these can be used in the ideation and design phase for an upgrade.

2.3 VR Technologies Related to Adaptation of Manufacturing Processes

For the purpose of the research presented in this project the focus has been on 3D environments for planning and evaluation of upcoming changes and updates of high investment assets. For this purpose, only a limited range of the field of VR have been considered and investigated. The aspects which have been included are visual stimuli, movements/locomotion in the environment and to some extent the ability to interact with modelled objects inside the virtual environment. For the extent of the implementation VR is defined as a 3D environment, rendered in real time over which the user has some ability to navigate around in *and interact with*. Apart from the addition in italics, this is much like the VR definition given by Loeffler and Anderson in 1994 (Loeffler and Anderson 1994).

When applying this scope to the field of VR there are a number of technologies to choose from. A number of them will be presented here. The selection is based on the purpose of using VR which is to give users a feeling of being inside the virtual environment, using some sort of display to visualise the 3D virtual environment (Korves and Loftus 1999).

Menck et al. lists general technologies used to create VR interfaces (Menck et al. 2012): computer display, head-mounted display (HMD), power wall, and cave automatic virtual environment (CAVE).

The above technologies are different on a number of factors, they present different inherent capabilities and their cost is also varying significantly, which can steer or limit the choice depending on application. From a capability perspective many aspects can be identified. For example; multi-user functionality, stereoscopic, real world blending or strictly virtual, passive or (inter-)active, and representing the user’s (or users’) body to name a few. These capabilities will have an effect on the level of immersion, or presence, that the users experience, as well as on their ability to conduct meaningful tasks in the virtual environment.

Computer displays are the most basic and least costly technology to interface the VE, movement is controlled using i.e. a 3D manipulator or even a regular computer mouse (Menck et al. 2012). Many users can be present at the same screen but all of them will share the same viewpoint and in that sense be passengers to the main user, who controls the navigation.

Head Mounted Displays (HMDs) have been available for a long time, but only recently have they developed to a level that can be said to trick the human sense well enough for an immersive experience. The HMD is worn over the head of the user and shuts out any external visual stimuli (Duarte Filho et al. 2010). Therefore the users is not inherently able to experience his or her body. There are ways of recording and rendering the users body and posture back into the virtual environment in real time, examples of this is using VR-gloves or 3D imaging sensors to map the user's movements (Korves and Loftus 2000; Mohler et al. 2010). If such a mapping is performed, this solution can support multi-user environments through rendering the mapped body and postures or an avatar representation of them back into the virtual environment (Beck et al. 2013; Mohler et al. 2010). Recent technological development has significantly decreased the cost of HMDs, compared to when the cited work was written. In Chapter "Sustainable Furniture That Grows with End-Users" of this publication, Berglund et al. state that the industrial partner views HMDs as a scalable solution based on the price point.

Power walls is an umbrella term for large scale back projected displays. Traditionally they are limited to one point of view in the same ways as a computer screen, although there are recent examples where this limitation is overcome through a combination of DLP projectors and shutter glasses (Kulik et al. 2011). The size of the power walls make them suitable for team collaboration, and allow for both active participants and passive spectators in a larger forum (Waurzyniak 2002).

CAVEs are room environments, encapsulated by screens on all (or at least three) sides. The user stands in-between the walls and the virtual environment is projected around him or her. Tracking equipment is used to manipulate the environment to constantly match the user's viewpoint (Duarte Filho et al. 2010).

With the many available solutions, choosing the appropriate one can be a challenging task. Mohler et al. (2010) stresses the importance of body representation in VR environments and shows that it significantly improves the users' ability to accurately judge scale and distance. Kulik et al. (2011) focus on the importance of multi-user support in VR, and even state that it isn't VR if it isn't multi-user. Figure 1 depicts an abstraction of the main components of a VR system, incorporating 3D imaging data.

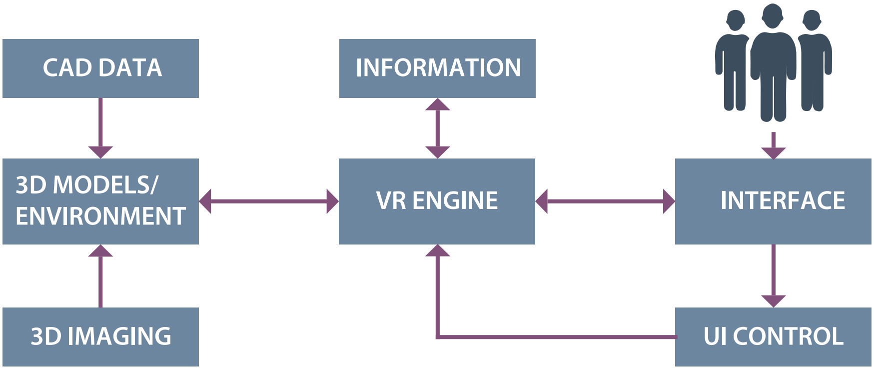

Fig. 1 Schematic view of VR decision support tool

2.4 3D Imaging Introduction

Capturing spatial data can be done in a number of ways, utilizing a wide variety of technologies. These technologies are often categorised into tactile and non-tactile (Varady et al. 1997). The tactile technologies require physical contact with the measurand, while the non-tactile rely on some non-matter media for its interaction with the measurand. While tactile technologies are often characterized by high precision they also risk influencing the measured object during the measurement process. The inherent requirement of movement tends to result in comparably low data capture speeds and a limitation on the maximum measurement area. These drawbacks can create difficulties if the measurand has a soft or yielding surface, or is above a certain size (Varady et al. 1997). An industrially proven and frequently used type of tactile sensor is the Coordinate Measurement Machine, CMM. CMM machines rely on linear movement axes which provide three degrees of freedom coupled with a three degrees of freedom probe unit. The CMM machines are programmable and can be used as an integrated resource in a production facilities to conduct in-line automated measurement of products.

Non-tactile technologies exist in a number of forms, a common classification is active and passive non-contact sensors. Passive sensors make use of the existing background signals of the environment, such as light or noise. Active sensors emit some signal into the environment as uses the returned light to map the surroundings. 3D imaging describes the field of capturing spatial data from the real world and making it available in a digital form. It exists on a wide range of scales and for different purposes. The digital spatial data can be stored for future reference, or be processed in order to perform analysis for some specific purpose. The ASTM Subcommittee E57.01 on Terminology for 3D Imaging Systems defines 3D imaging systems as (ASTM 2011):

> A non-contact measurement instrument used to produce a 3D representation (e.g., point cloud) of an object or a site.

The term point cloud in the definition deserves a closer explanation. It comes from the descriptive of the contents of the data set which results from a 3D imaging procedure. The data is recorded as coordinates in space, points. The cloud word can be traced to the fact that these coordinate points are unstructured (however, it can be argued that their sampling pattern is directly a function of the operational parameters of the 3D imaging technology). The cloud can also be said to relate to the lack of any semantic information. The point cloud generated from a measurement holds no explicit concept of objects or relationships between points. These may of course be generated or extracted using various techniques in a post processing or analysis operation.

There exists a multitude of measurement instruments for 3D imaging. Several surveys of the field exists to classify and describe available technologies for 3D imaging (Besl 1988; Beraldin et al. 2007). Figure 2 presents one such classification.

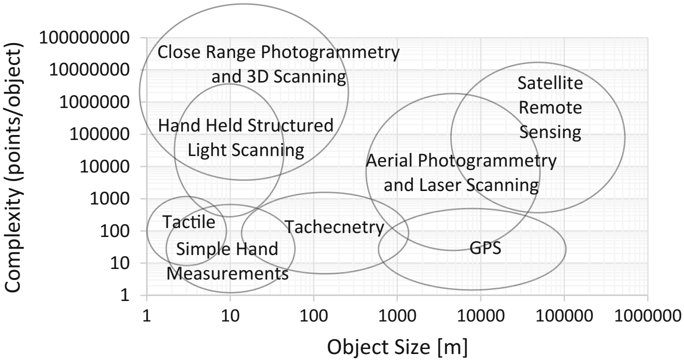

Fig. 2 Spatial measurements and their suitability/application on scales of size and complexity (adopted from Boeheler 2005)

Since the publication of the work which Fig. 2 is based on the circles have widened considerably. An example is photogrammetry which now is capable of capturing the surface geometry of very complex and feature rich objects.

3D imaging is a technology used in many different fields. Some examples are given in Fig. 3a–d. The chosen technology is relate to both scale of the objects and data requirements connected to the intended use of the data.

- Figure 3a. Product scan: 3D imaging is used in product development to digitalize for example clay models of product designs. It is also used in production to validate process output, e.g. shape conformance of the physical product to the designed tolerances (Yao 2005; Druve 2016)
- Figure 3b. 3D Scanning of a building: Building Information Model (BIM) is an Area within facilities management that has adopted 3D imaging. For one, to map the existing facility more accurately, and for the other to improve visualization quality and real world likeness.
- Figure 3c. 3D imaging of Cultural heritage: For cultural heritage preservation and archaeology 3D imaging has made a significant impact in the last decade, by digitalizing artefacts in a museum or entire structures or archaeologic dig out sites they can be share among researchers or the public at a global scale. Archaeology students from anywhere in the world can access a digital version of the Cheops pyramid or the Incan temples of Machu Pichu (Pieraccini et al. 2001; Sansoni et al. 2009).
- Figure 3d. Pipe fitting to 3D imaging data: The use of reverse engineering of for example pipes is used frequently in process industry. Typically it provides current state in-data for installing new pipes and retrofitting old pipes (Olofsson et al. 2013).

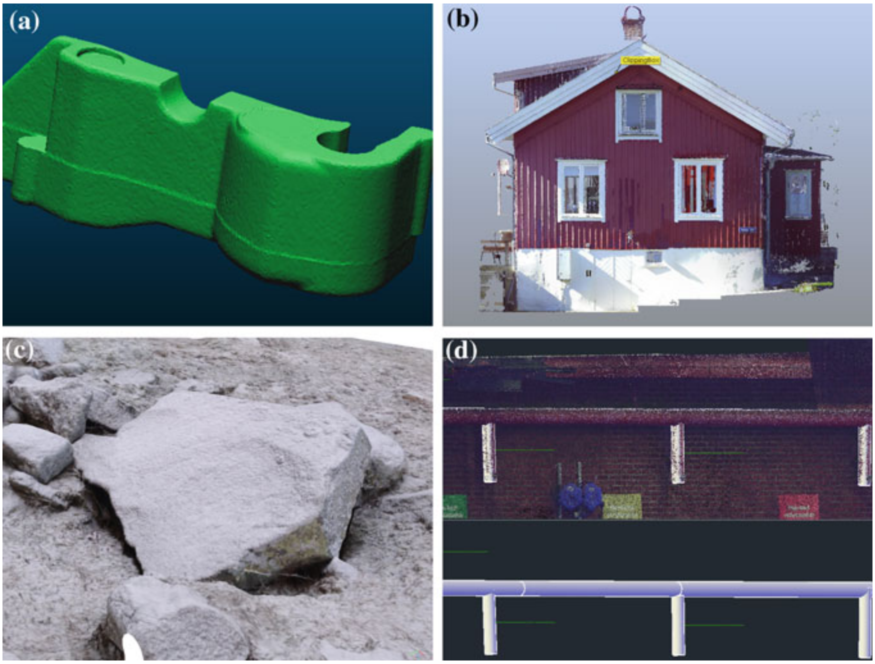

Fig. 3 3D Imaging

2.4.1 3D Laser Scanning the Adaptation Process

3D Laser Scanning or Laser Detection and Ranging (LADAR) is a non-contact measurement technology for the capture of spatial data. The technology was developed within the field of surveying as a tool to map terrain as well as to control and monitor the status of construction jobs. Today it is used in a variety of fields, such as building and construction, tunnel and road surveying, robot cell verification, layout planning and Forensics (Slob and Hack 2004; Sansoni et al. 2009).

When capturing spatial data with a 3D scanner it is placed within the environment of interest; this could be an existing production system or a brown field factory floor. A laser pulse or beam is emitted around the environment and its reflection is logged as time of flight or phase shift. Today's scanners are able to map their entire field of view up to eighty meters away in a matter of minutes with a positional accuracy of a few millimetres (FARO 2012). The resulting data is often referred to as a point cloud, a set of coordinates in 3D space, typically numbering in the tens of millions. The latest 3D scanners are equipped with RGB sensors to add colour information to the coordinates to further improve visualization.

As this technology matures and the tools and methods to capture data become more readily available there is also a steadily growing range of software tools to support its usage (Bi and Wang 2010). These tools are either specialized to visualize and edit point cloud data sets or they are extensions of traditional CAD and simulation tools able to integrate point cloud data. The integration into existing tools enables hybrid modelling environments where CAD and point cloud data are used in parallel. Using hybrid models, CAD models of new machine equipment or products in design stage are put into existing scanned production facilities for planning verification.

Some challenges with this new technology are the size of the data and issues with interoperability between vendor-specific data formats. However, several research efforts strive to automate translation of point cloud data into CAD surfaces to reduce data size (Bosche and Haas 2008; Huang et al. 2009). And new optimized software for visualization of this data format is being developed (Rusu and Cousins 2011). Ongoing standards activities are developing neutral processing algorithms and data formats to ensure repeatability, traceability and interoperability when working with point cloud data (ASTM 2011).

Figure 4 gives an insight to the nature of 3D laser-scanning data by zooming further in on the model until the individual measurement points are distinguishable. The measurement points are singular positions plotted in a 3D space, thus the software visualising them gives them an arbitrary pixel size.

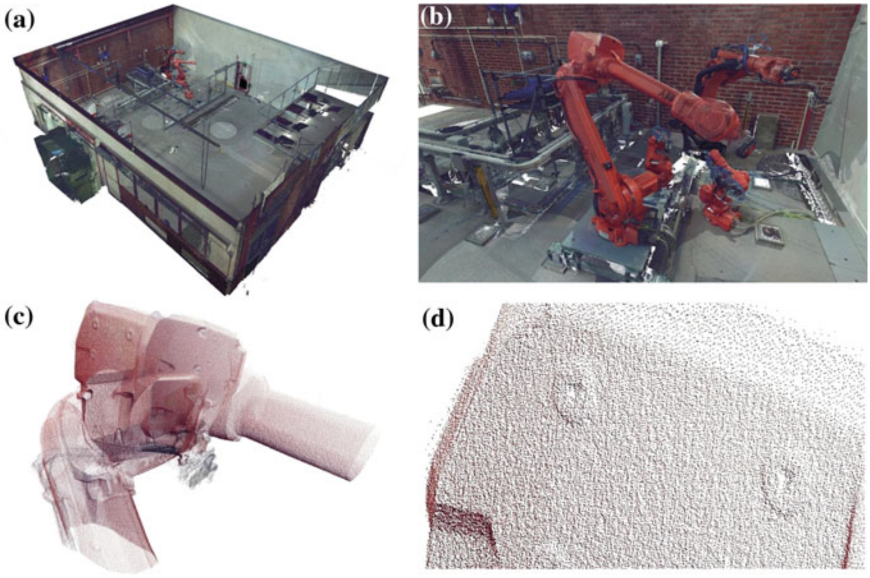

Fig. 4 3D laser-scanning

3 3D-Imaging and Virtual Reality Integration Tool

This section describes the tool for integration of 3D imaging and virtual reality which was developed during the UIW-project. The description includes how the tool should be applied, the expected result of such an application, along with the detected limitations.

3.1 Introduction

The purpose of the tool is to understand reality through improved models and model exploration/visualization. 3D imaging provides a realistic and accurate model of current conditions. Virtual models can be accessed and viewed simultaneously by several actors regardless of physical location. The model also acts as a basis for modelling and designing additions and upgrades. Both for visualizing them and designing the physical properties of interfaces and connections to the existing system. Give users an experience that closely imitates physical presence and the possibilities associated with that. Shareable over time and space. Support collaborative work in cross functional, de-centralised project teams. Current status of the development can be found in Chapter "Sustainable Furniture That Grows with End-Users" *Adaptation of high variant automotive production system: A collaborative approach supported by 3D-imaging*.

3.2 The Application Process

Following Fig. 5 from left to right including the feedback loop from the stakeholders/actors, the following steps can be identified:

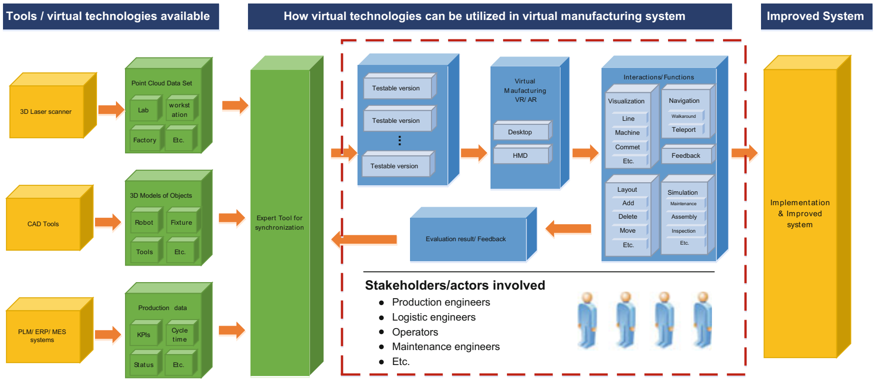

Fig. 5 Planning process using virtual technologies for manufacturing process change

3.2.1 Tools/Virtual Technologies Available as Input Data for Expert Tool

Mapping the current state of the system with PLM/MRP/MES system as well as using existing 3D imaging technologies in combination with CAD. Choice of technologies and approach is determined by the objectives as well as the size and complexity of the related objects in the system.

3.2.2 Expert Tool

The currently available input data are then reengineered by bringing in design documents and files for solutions into the environment and combined to reach an upgraded system with new functionalities using the expert development tool/programming solutions. It usually involves process like post-processing of scanned data and make it compatible for the expert tool, preparation of CAD data that are needed and integration with PLM/MES system if necessary.

3.2.3 Preparation of Testable Solutions

Based on the requirements of proposed upgrade, testable solutions can be developed using the current state data that has been collected. Thus the potential solutions can be prepared by topic expert using the expert tool and ready for evaluation by all the actors that involved in the upgraded process.

3.2.4 Accessing Solutions via Different Interfaces

The prepared testable solutions can be accessed in different platforms such as desktop web browser, desktop projector as well as virtual reality HMD. Dependent on the purpose and context of the to-be-evaluated solutions, one can choose either platform or any combination of the available platforms to facilitate better understanding of the proposed solutions.

3.2.5 Interactions/Functionalities

Various interactions are available to support the evaluation of the proposed solutions, from the basic functions like visualization and navigation through walking around and teleporting, to the more advanced functions such as new layout planning and feedback.

3.2.6 Evaluation Result/Feedback

All the involved actors give feedback based on their knowledge and experiences. The feedback is then gathered and reviewed to decide whether approve or disapprove proposed solutions. The synchronized feedback and improvements suggestions are sent upstream in the process to the designer who consolidates the information and if needed creates a new and improved set of solutions.

3.2.7 Concept Refinement

Based on the feedback, an iteration could be appropriate where the expert tool synchronisation needs to have another round of improvements of functionality/visual aids/interfacing or similar. The improved design is then prepared for a new iteration with the involved actors to re-evaluate.

3.2.8 Implementation

Once the concept and solution gives substantial benefits for the actors/stakeholders and they are satisfied with the tool, the next step will be to move towards implementation for structured use in real world cases incorporated in everyday work for the actors and stakeholders who has the most beneficial use out of the developed tool.

3.3 Expected Results from Application of the Tool

The results expected from the application of this tool are many. In response to the challenge faced by modern day industries, this tool is expected to reduce the lead times for design iterations of projects. These iterations can otherwise be costly, but with the use of VR technology early on in the process it is also expected that problems with designs can be found earlier, thereby costing less. Being able to update designs quickly is also believed to reduce the risk of faulty input data into other processes, as there will be a lower occurrence of outdated models. As VR immerses people in an alternate reality (Ref) it is further expected that project members will be able to gain an improved understanding of the project and the design, thus to improve the overall quality of the system and products. Further, this could be used as a marketing tool, where designs can be communicated in an un-ambiguous manner. Last but not least, with the realistic virtual environment available, it not only widen the accessibility of the data to all the involved actors, but can also reduce the travel substantially, which used to be needed. Therefore, further reduction in cost and improvement in sustainability are expected.

3.4 Limitations of the Tool

The technologies involved are currently available as off the shelf products and can be purchased or rented as needed with little foreseeable issues. However, the usage and operation of these tools are not yet commonplace. There is a need for expert users both for collecting 3D imaging data and for processing and preparing the data into a testable model that can be evaluated by topic experts. The navigation and usage of VR tools is also requiring a fairly experienced user to reach its full efficiency potential. The medium should not take over and be the central part of the experience when viewing a model, or else the results from the actual study will be muddled and potentially biased.

3.4.1 3D Imaging Related Limitations

Furthermore, a 3D imaging data set is not the same as having a full-fledged CAD representation. The 3D imaging data, given present day conditions, does not include any semantic information and has to be interpreted by a human to make sense. This reduces the amount of automated analysis and optimisation that is possible. This extends into the scope of the data in the case of 3D imaging, there is often not any data captured from the internal structure of the objects. Unless two technologies are combined together the user will have to choose to capture either surface geometries or internal geometries thorough, e.g. X-ray or CT scanning.

It is also clear that despite the added realism that comes from integrating 3D imaging and VR, it is not equivalent of a physical model. The strength of 3D imaging comes from the possibility of capturing reality, what is actually there, rather than what was meant to be there, i.e. a design model. However, this does not eliminate the risk of having bad data, or outdated data. Perhaps it can even strengthen the risk in some cases through its high fidelity and accuracy. It is necessary to put processes in place that verify the relevance of the datasets. This could be related to i.e. date of capture, scope of capture etc.

While there is a lot of ongoing research into the reverse engineering process and its automation, there is currently no complete way of creating CAD data from the 3D imaging data sets. This means that the process of converting data into use in conventional design software could be costly. So perhaps organizations have to take a step and broaden their design software to incorporate 3D imaging data capabilities also. This is a business decision to take in concur-rent times, but might soon be unnecessary as more and more software developers are integrating 3D imaging data support into their existing software.

Another issue that might occur is the fact that some 3D imaging technologies require the object of capture to be completely at rest during the data capture procedure. In some cases, this is either infeasible, or associated with a large cost.

3.4.2 VR Related Limitations

The current technology for viewing and interacting with VR environments is perhaps not sufficiently powerful to smoothly handle large scale 3D imaging models. If the users experience lag tendencies or other graphical glitches it might take away from the immersion and involvement during design review sessions. For instance, some observers may experience motion sickness as a result of these limitations (Kennedy et al. 1993). Ergonomic related issues is another obstacle that needs more studies and improvements as current VR solutions are not suitable for prolong usage (Cobb et al. 1999). There is also currently a limitation on physical interaction between persons, while immersed in VR. At the moment, it is not possible for multi-user interaction, something that may prove crucial when evaluating models for feasibility or suitability.

4 Conclusion

Promising technological developments have recently been made in the field of 3D imaging and VR technologies. These developments facilitate both wide spread (all employees through web interfaces) as well as detailed modelling and analysis for interesting questions and decisions for several actors (maintenance, designers, operators etc.). UIW is one of the first applied science projects in direct collaboration with industry to actually make use of these new opportunities. Acceptance/diffusion if innovation in this field is not a fast process since the actual beneficiary initially does not even know that the technology exists, and yet is the methodologies and work tasks to be performed to be tailor-made and then standardised, which is some the work UIW provides to European industry. This project provides an insight into the use of these technologies in a wide range of industries and services.

References

Ahn, H. J., Lee, H. J., Cho, K., & Park, S. J. (2005). Utilizing knowledge context in virtual collaborative work. *Decision Support Systems, 39*(4), 563–582.

ASTM E2544-11a. (2011). *Standard terminology for three-dimensional (3D) imaging systems*. West Conshohocken, PA: ASTM International. www.astm.org

ASTM Standard E2807. (2011). *Standard specification for 3D imaging data exchange, Version 1.0*. West Conshohocken, PA: ASTM International. www.astm.org

Beck, S., Kunert, A., Kulik, A., & Froehlich, B. (2013). Immersive group-to-group telepresence. *IEEE Transactions on Visualization and Computer Graphics, 19*(4), 616–625.

Beraldin, J. A., Blais, F., El-Hakim, S., Cournoyer, L., & Picard, M. (2007). Traceable 3D imaging metrology: Evaluation of 3D digitizing techniques in a dedicated metrology laboratory. In *Proceedings of the 8th Conference on Optical 3-D Measurement Techniques*.

Besl, P. J. (1988). Active, optical range imaging sensors. *Machine Vision and Applications, 1*(2), 127–152.

Bi, Z. M., & Wang, L. (2010). Advances in 3D data acquisition and processing for industrial applications. *Robotics and Computer-Integrated Manufacturing, 26*(5), 403–413.

Boeheler, W. (2005). Comparison of 3D laser scanning and other 3D measurement techniques. In *Recording, modeling and visualization of cultural heritage* (pp. 89–100). London: Taylor and Francis.

Bosche, F., & Haas, C. T. (2008). Automated retrieval of 3D CAD model objects in construction range images. *Automation in Construction, 17*(4), 499–512.

Bowman, Doug A., & McMahan, Ryan P. (2007). Virtual reality: how much immersion is enough? *Computer, 40*(7), 36–43.

Cobb, S. V., Nichols, S., Ramsey, A., & Wilson, J. R. (1999). Virtual reality-induced symptoms and effects (VRISE). *Presence, 8*(2), 169–186.

Deitz, D. (1995). Real engineering in a virtual world. *Mechanical Engineering, 117*(7), 78.

Druve, J. (2016). *Reverse engineering av 3D-skannad data*. Göteborg: Chalmers University of Technology.

Duarte Filho, N., Costa Botelho, S., Tyska Carvalho, J., Botelho Marcos, P., Queiroz Maffei, R., Remor Oliveira, R., et al. (2010). An immersive and collaborative visualization system for digital manufacturing. *The International Journal of Advanced Manufacturing Technology, 50*(9–12), 1253–1261.

FARO Technologies. (2012). FARO Technologies Inc.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston: Houghton Mifflin.

Groover, M. P. (2007). *Automation, production systems, and computer-integrated manufacturing*. Prentice Hall Press.

Huang, H., Li, D., Zhang, H., Ascher, U., & Cohen-Or, D. (2009). Consolidation of unorganized point clouds for surface reconstruction. In *ACM Transactions on Graphics (TOG)* (Vol. 28, No. 5, p. 176). ACM.

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The International Journal of Aviation Psychology, 3*(3), 203–220.

Korves, B., & Loftus, M. (1999). The application of immersive virtual reality for layout planning of manufacturing cells. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 213*(1), 87–91.

Korves, B., & Loftus, M. (2000). Designing an immersive virtual reality interface for layout planning. *Journal of Materials Processing Technology, 107*(1), 425–430.

Kulik, A., Kunert, A., Beck, S., Reichel, R., Blach, R., Zink, A., et al. (2011). C1x6: A stereoscopic six-user display for co-located collaboration in shared virtual environments. *ACM Transactions on Graphics (TOG), 30*(6), 188.

Loeffler, C., & Anderson, T. (1994). *The virtual reality casebook*. Wiley.

Loomis, J. M. (1992). Distal attribution and presence. *Presence: Teleoperators and Virtual Environments, 1*, 113–119.

Meehan, M., Insko, B., Whitton, M., & Brooks Jr, F. P. (2002). Physiological measures of presence in stressful virtual environments. *ACM Transactions on Graphics (TOG), 21*(3), 645–652.

Menck, N., Yang, X., Weidig, C., Winkes, P., Lauer, C., Hagen, H., et al. (2012). Collaborative factory planning in virtual reality. In *45th CIRP Conference on Manufacturing Systems* (pp. 317–322).

Mohler, B. J., Creem-Regehr, S. H., Thompson, W. B., & Bülthoff, H. H. (2010). The effect of viewing a self-avatar on distance judgments in an HMD-based virtual environment. *Presence: Teleoperators and Virtual Environments, 19*(3), 230–242.

Mont, O. (2002). Clarifying the concept of product–service system. *Journal of Cleaner Production, 10,* 237–245. doi:10.1016/S0959-6526(01)00039-7

Neugebauer, R., Purzel, F., Schreiber, A., & Riedel, T. (2011). Virtual reality-aided planning for energy-autonomous factories. In *Proceedings of the 9th IEEE International Conference on Industrial Informatics (INDIN)* (pp. 250–254).

Olofsson, A., Sandgren, M., Stridsberg, L., & Westberg, R. (2013). *Användning av punktmolnsdata från laserskanning vid redigering, simulering och reverse engineering i en digital produktionsmiljö*. Göteborg: Chalmers University of Technology.

Pausch, R., Dennis, P., & Williams, G. (1997). Quantifying immersion in virtual reality. In *Proceedings of the 24th Annual Conference on Computer Graphics and Interactive Techniques* (pp. 13–18). ACM Press/Addison-Wesley Publishing Co.

Pieraccini, M., Guidi, G., & Atzeni, C. (2001). 3D digitizing of cultural heritage. *Journal of Cultural Heritage, 2*(1), 63–70.

Pimentel, K., & Texeira, K. (1993). *Virtual reality: Through the new looking-glass*. Intel/Windcrest McGraw Hill.

Rusu, R. B., & Cousins, S. (2011). 3d is here: Point cloud library (pcl). In *Proceedings of the IEEE International Conference on Robotics and Automation (ICRA)* (pp. 1–4). IEEE.

Sansoni, G., Trebeschi, M., & Docchio, F. (2009). State-of-the-art and applications of 3D imaging sensors in industry, cultural heritage, medicine, and criminal investigation. *Sensors, 9*(1), 568–601.

Schuh, G., Aghassi, S., Orilski, S., Schubert, J., Bambach, M., Freudenberg, R., et al. (2011). Technology roadmapping for the production in high-wage countries. *Production Engineering, 5*(4), 463–473.

Slob, S., & Hack, R. (2004). 3D terrestrial laser scanning as a new field measurement and monitoring technique. In *Engineering geology for infrastructure planning in Europe* (pp. 179–189). Berlin, Heidelberg: Springer.

Smith, R. P., & Heim, J. A. (1999). Virtual facility layout design: The value of an interactive three-dimensional representation. *International Journal of Production Research, 37*(17), 3941–3957.

Song, X. M., Thieme, R. J., & Xie, J. (1998). The impact of cross-functional joint involvement across product development stages: An exploratory study. *Journal of Product Innovation Management, 15*(4), 289–303.

Steuer, J. (1992). Defining virtual reality: Dimensions determining telepresence. *Journal of Communication, 42*(4), 73–93.

Teyseyre, A., & Campo, R. M. (2009). An overview of 3D software visualization. *IEEE TVCG, 15*(1), 87–105.

Varady, T., Martin, R. R., & Cox, J. (1997). Reverse engineering of geometric models—An introduction. *Computer Aided Design, 29*(4), 255–268.

Waurzyniak, P. (2002). Going virtual. *Manufacturing Engineering, 128*(5), 77–88.

Yao, A. W. L. (2005). Applications of 3D scanning and reverse engineering techniques for quality control of quick response products. *The International Journal of Advanced Manufacturing Technology, 26*(11–12), 1284–1288.

Operator-Oriented Product and Production Process Design for Manufacturing, Maintenance and Upgrading

Gu van Rhijn and Tim Bosch

Abstract The nature of production in the manufacturing industry is changing, and companies face large challenges. Customers expect fast delivery times, proven sustainability, flexibility, and frequent product upgrades. To stay competitive and manage rapid technological demands, a parallel, iterative and interactive development approach for product and process design is required. Closed-loop systems will increase future customer demand for easy upgrading. This requires highly modular and operator-friendly product designs. Because the complexity, variety and unpredictability of products and production tasks will increase, information and support systems for operators are crucial elements. Human factor engineering methodologies are essential to take full advantage of new technologies that support operators in all stages of the product life cycle. Methods and tools that could support companies in improving product, process, and workstation design are presented, and directions for future research and tool development are discussed.

Keywords Production process design · Modular product design · Task allocation · Human factors · Operator support

1 Introduction

1.1 Industrial Challenges: Changing Market Demands

The nature of production in the manufacturing industry is changing, and companies face large challenges (Fig. 1). Market demands are less predictable, and the time-to-market is shorter. Manufacturers of components, modules and products need to have flexible and efficient production processes to achieve fast delivery of

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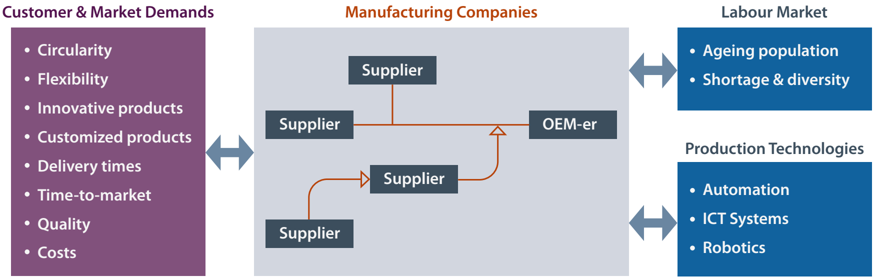

Fig. 1 The nature of production in the manufacturing industry is changing

high quality products within the context of variation in volume demands, a large mix of customer-specific product types, and short product life cycles (Van Rhijn et al. 2005; Aberdeen Group 2014). Costs, efficiency, quality, and innovative designs are still important drivers of manufacturing companies. However, driven by market demands, short product development lead times, proven sustainability, flexibility, and frequent product upgrades will become crucial elements to guarantee competitiveness, especially for manufacturers of high-investment products.

Customers have become more environmentally conscious. The global market for environmentally friendly goods and services was estimated at €4.2 trillion in 2011 (Department for Business, Innovations and Skills 2012). Manufacturers of capital-intensive products must prove the circularity of product designs and manufacturing processes (e.g., end-of-life options, sources of materials, sustainability of suppliers). Currently, most products are designed, produced, and sold to the end-user. In case of malfunction, outdatedness, or the changing requirements of the end-user, a new product is designed, produced, and sold. The circular economy concept aims to keep products, components, and materials at their highest utility and value at all times (e.g., Ellen MacArthur Foundation 2013; McKinsey 2011). In contrast to a traditional linear economy, i.e., 'take-make-dispose', the circular economy emphasizes the reusability of products and raw materials as a starting point and minimizes waste in the entire industrial and ecological system. To take full advantage, it is important for manufacturers to consider that products and components can be given a second or longer life during the design process (e.g., by 'design for disassembly, for maintenance, for reuse or remanufacturing') (Bastein et al. 2013). These challenges are topics in the Use-it-Wisely (UIW) project and objectives: Design of adaptable and upgradable products and flexible (re)manufacturing processes are crucial aspects for realizing a circular economy-based business. Remanufacturing is commonly defined as "a series of manufacturing steps acting on an end-of-life part or product to return it to like-new or better performance, with warranty to match" (APPSRG 2014).

1.2 Industrial Challenges: Changing Production Technologies

Simultaneously, production technology is developing quickly (Fig. 1). The trend of automation, including the use of robots and process control systems, has a large impact on manufacturing. Manufacturing companies (OEM = Original Equipment Manufacturers and their suppliers) face large challenges from the market, from a technology perspective and from the labour market. ‘Full automation’ however, is often not feasible in assembly work, specifically in the combination of low volumes, high product mix, and high product complexity. Therefore, hybrid production systems in which humans and robots or robot systems are intuitively collaborating are needed. A recent report on the current state of the Dutch manufacturing industry stated (Smart Industry, Dutch Industry fit for the future 2014): *“Humans are still the most flexible production factor. As smaller batches require higher investments and specialised production systems, especially in assembly, robots and robot systems will often mainly assist production personnel and remove some routine work”*. Finally, the labour market in itself is facing challenges; the proportion of older employees is rising due to the ageing population (Bloom et al. 2015). Skilled, flexible and motivated employees have become crucial ‘assets’ for companies to handle all those challenges.

The challenges and developments from the market (customers), technology breakthroughs and the labour market are summarized in Fig. 1. How can the manufacturing industry respond to the challenges of changing customer demands and technological developments?

In the UIW-project, tools and methods are developed and demonstrated to support companies in designing both adaptable and upgradable products and flexible (re)manufacturing processes. Closed-loop systems will necessitate the allowance of easy upgrading for future customer demands. This requires highly modular and operator-friendly product designs. To take full advantage of new technologies that support operators in all stages of the product life cycle, human factor engineering methodologies are essential. The starting point is a parallel, iterative and shared development approach for products and flexible (i.e., agile) production processes (Fig. 2). Part of this approach is two essential elements or ‘building blocks’:

1. **A highly modular and operator-friendly product design** that allows easy upgrading, remanufacturing and maintenance of new, refurbished and remanufactured products;
2. **Flexible, human-centred production processes** using new technologies, including workstations with correct levels of automation and assistive technology that support operators.

During the product and process development stage, manufacturing companies must pay attention to these two elements in an interconnected way because they are closely linked and thereby affect each other. Figure 2 shows an overview of the

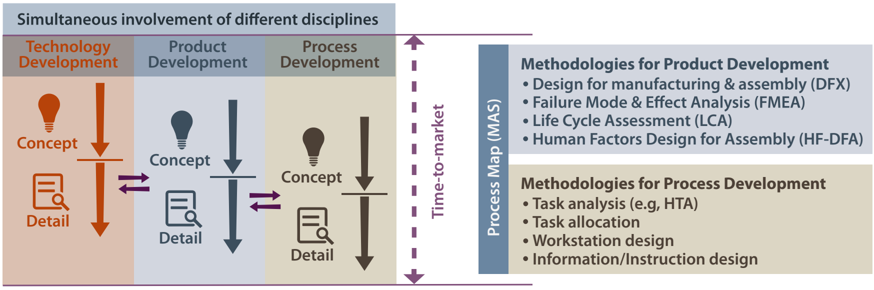

Fig. 2 A parallel, iterative and interactive development approach for modular product and flexible human-centred production processes supported by different methodologies

methodologies available to support parallel and early-stage development of modular products and flexible, human-centred production processes within the scope of high-investment products in the manufacturing industry. In this chapter, we will describe solutions to manage the above-mentioned company challenges and provide more detail about specific methodologies. More specifically, Sect. 2 describes methodologies for parallel and early stage development of products and production processes. Section 3 describes methodologies for (dis)assembly, maintainability, upgrading and modular product design. Sect. 4 presents the application of assistive technologies to support operators in a proper manner.

2 Methodologies to Support Parallel Product and Process Design

To support companies in developing new products, (re)manufacturing and upgrading processes, which are sustainable throughout the complete life cycle, several engineering and human factor methodologies are described in the literature. These methodologies may be used during the development of new technologies, products and production processes (see Fig. 2).

Examples of methodologies used during the *product design phase* are:

- Design for manufacturing and assembly guidelines (DFA or HF-DFA) to create cost-effective and operator assembly-friendly products (e.g., Boothroyd et al. 2001; Village et al. 2014). These methods and guidelines are used in the application developed in “UIW: the Circular Economy Design Framework” (see Bosch, Chapter “Sustainable Furniture That Grows With End-Users” this book).
- Failure Mode and Effect Analysis (FMEA) to detect problems that might arise from malfunctions in a product (Ginn et al. 1998; Stamatis 2003).
- Sustainable design methodologies such as Life Cycle Assessment (LCA, Pajula, Chapter “Managing The Life Cycle to Reduce Environmental Impacts” this book).

Process development tools and upgrading methodologies include:

- The lean manufacturing philosophy in the pursuit of reducing wasteful activities and improving productivity and profits (Genaidy and Karwowski 2007).
- Lead time reduction by minimization of Manufacturing Critical-path Time in Quick Response Manufacturing (QRM, Suri 1998) and Demand Flow Factory (Pot and Van Rhijn 2012).
- Value Stream Mapping (VSM) or Business Process Modelling (BPM) tools to build a common perspective of a process workflow (e.g., Rother and Shook 2003).
- To allocate tasks at a process or workstation level, task or function allocation methodologies (e.g., Fasth and Stahre 2010; Challenger et al. 2013) are commonly used.

In practice, these methods are mostly used independently by different company disciplines (i.e., departments) for improving product or process design. Development of products and processes in parallel and with strong interaction between different disciplines: sales, product design, process engineering, and operations (operators from manufacturing, assembly, maintenance) is essential for manufacturing but even more for maintenance, upgrading, and remanufacturing processes. Furthermore, parallelizing technology, product and development (as shown in Fig. 2), shortens time-to-market (first time right) and can save a significant amount of money (Quan and Jianmin 2006). To involve different disciplines in the product and process design phase, a participatory approach can be used.

This participatory approach (e.g., Vink et al. 2008; Hirschheim 1989; Muller and Kuhn 1993) is a well-known and successful approach that could lead to quality improvements and a reduction in costs (European Foundation for the Improvement of Living and Working Conditions 1999). It is a design procedure in which the relevant company stakeholders (e.g., management) and the end-users, i.e., the operators in a production process, engineers developing new products or maintenance personnel out in the field, have the opportunity to influence the content of the design target (Bouckenooghe and Devos 2007; Lines 2004). If situations are complex, a stepwise and iterative approach could be adopted so that the anticipated effort and success could be reviewed. This interactive process, which is essential for gaining support and momentum to push innovation forward, improves communication, manages expectations and uses different perspectives and skills in the design process. The involvement of different disciplines and employees enables a potential resource for creativity and innovation (e.g., Shalley et al. 2004). Moreover, the involvement of employees from different disciplines is also essential because of the great deal of knowledge and experience they have about the products, production processes and problems that occur on a day-to-day basis. For instance, some or all of the workers who will work at a forthcoming plant could take part in a number of design sessions during different design stages (van Rhijn et al. 2014).

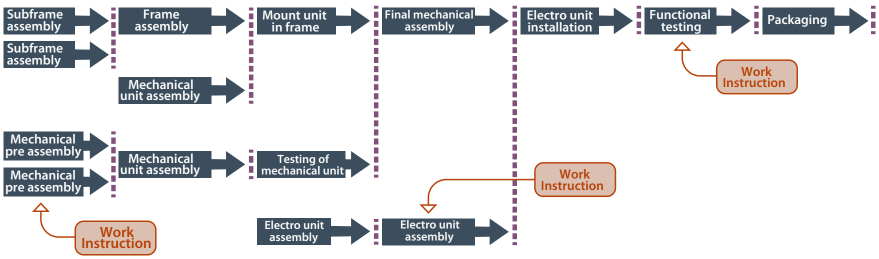

Fig. 3 Schematic representation of the process steps of the (sub) assembly and testing stages with the MAS

A starting point in this (participatory and parallel product and process development) approach is creating a commonly shared process map using the 'MAS' methodology. MAS stands for '*Montage Afloop Schema'* (assembly process flow, Van Rhijn et al. 2014). MAS is a graphical representation of successive and parallel process stages, including timing estimates (Fig. 3). This assembly process map can be used to streamline product and process design. It can also be used to compare alternatives to the product structure and the structure of the assembly process in terms of their effects on lead times and productivity both at the concept level and during the detailed development stage.

This focus on process structuring during product design is crucial for delivering components and final products in small series in a short time, as well as for getting it right the first time.

In the product design phase, the MAS instrument is used in the following steps:

- Creating a working group of different disciplines: product designers, engineers, process engineers, and operators from assembly and service/installation. The concept or detailed product design is demonstrated to the working group using drawings, sketches or 3D models. The product structure will be clarified, and a distinction will be made between product modules and individual components.
- The successive and parallel assembly process steps that are needed to assemble the total product from beginning to end are drawn on paper. The starting point is the main process. Every arrow represents a process step, consisting of several (manual) actions/tasks. Just above the arrow, the main process step and the respective part/module is described. Next, to assembly of mounting steps, other essential steps such as handling, turning, rotating or testing the component or modules are described.
- After that, parallel processes in the workflow are listed, which can be assembly or test processes of subassemblies of product modules. These parallel processes are connected to the main process at the stages in which these subassemblies are needed.
- The graphical representation of assembly, testing, packaging activities is then be discussed and adapted by the working group. For instance, the sequence of process steps may be shifted.

- The time needed for every process step is estimated and added to the process scheme. Based on this, lead times and productivity can be evaluated. Other elements, if relevant, may be added as well. For instance, specific equipment and tools needed or special conditions (cleanroom levels).
- The next step is a review of the product design for modularity and operator-centred design (see Sect. 3), including modular product structure, exchangeability of modules and parts, reducing the number and variety of parts, simplicity of handling and positioning, and physical load during handling and mounting. Based on this analysis, both the product design and the assembly process scheme may be adapted and improved.

This process work flow method can be used to analyse assembly processes and other primary processes such as maintenance, service, and installation. The advantage of the MAS method is that product and process engineers are forced to think about possible scenarios for the assembly process. Which steps are needed to assemble the product and in which order? Moreover, the modular product structure becomes clear; which units or modules can be distinguished? Modularity results in opportunities for parallel structures that provide a means for shortening the lead time of the total process considerably. Modularity can also contribute to a higher level of service and upgrading, as service-sensitive parts can be exchanged quickly. Another advantage is the involvement of different disciplines in creating the assembly process scheme within the working group. Every company discipline and its specific knowledge is involved and used to improve the process and product design. At an early stage of design, everybody agrees on design decisions, which helps prevent costly modifications later. However, using MAS during the design phase requires the discipline and openness of product engineers. Furthermore, time is needed for all participants of the working group.

MAS can also be used as a starting point to develop a new production or assembly flow for a mix of products: the number of (sub)assembly workstations can be assessed. A clearer distinction between the flow and processing of standard and special orders can be made during the design phase. Closed-loop business processes lead to extra demands on the flexibility in and organization of (re)manufacturing processes. There can be very diverse flows of products and components using different routings on a shop floor. For instance, there could be single-piece products or small batches of products coming from customers that need to be disassembled on a disassembly line, components that need to be (re)manufactured, and (new) products that need to be assembled from new and used components and modules.

Finally, as MAS is a process scheme of all the assembly steps to be performed, it is frequently used as a starting point for development of work and test instructions for the operator at every workstation (see Sect. 4 and Fig. 3).

3 Product Development: Modular Product Architecture & Operator-Centred Product Design

Product design is crucial for the entire product life cycle, such as the production, assembly, use, upgrading and remanufacturing stages. Although the exact numbers are debatable (Ulrich and Pearson 1993), the design literature suggests that, in the average product design stage, 70–80% of the costs are already defined (e.g., Sheldon et al. 1990). Traditionally, durable goods manufacturing companies focused on designing and producing physical products for their customers and end-users. Today, many of these companies are shifting their focus towards producing value-adding services for their customers. To some extent, these services are independent of the physical products, but in most cases, these products are still at the core of the services as the companies extend their services from traditional spare part delivery and maintenance towards life-cycle services and extended products. The service activities typically focus on maintaining the performance of the physical product (spare parts, repair, preventive maintenance, online monitoring of equipment, IT-support diagnosis, remote support for maintenance) or on informing the user of how to use it (training, consultation, simulation, data services).

In UIW, there has been a focus on the changing role of the product development function in manufacturing companies. The main role of this function in a manufacturing company was to produce a design to fulfil the functional requirements of the products but, since the middle of the 20th century, the focus has moved towards the development of designs suitable for production. In the 1980s, there was a growing demand for easily assembled and manufactured designs. This changed the role of the product development function, which was required to review the designs from a growing number of viewpoints. This development has been called Design for X (Kuo al. 2001). After Design for Assembly and Design for Manufacturing there were, among others, Design for Maintenance, Design for Recycling (Gaustad et al. 2010), Design for Environment (Leonard 1991) and Design for Life-cycle (DFLC) (Ishii et al. 1994).

In the near future, designing products for the circular economy will once again set new requirements for the product development function. Products must be designed in a manner that easily allows upgrades (i.e., adapt to future use, reuse, or remanufacturing) in several closed loops between the customer and manufacturing companies. This requires new methods for identifying (future) user needs and values, module-based development teams instead of department-specific teams, early-stage testing and implementation of upgrades while the product is in use anywhere in the world. An essential part of circular economy-based design is the adaptability of products by introducing product modularity (Krikke et al. 2004) and operator-centred design. Product modularity, an approach based on the decomposition of the product into independent subassemblies (product modules, Ulrich 1995), has proven to have positive effects on multiple dimensions of competitive performance such as product quality, flexibility and lead times (e.g., Jacobs et al. 2007). Using product modularity in a traditional sense, a wide range of final products can be configured using flexible methods through intelligent configuration of the product range. Product modularity results in opportunities for parallelizing production processes and thereby considerable lead time reductions for the total manufacturing process can be achieved as long as there is sufficient manpower and space. Modularity also makes it possible to outsource entire sub-modules, such as sheet metal frames, power units, and control cabinets, to specialized suppliers. For circular economy-based design, modularity contributes to a higher level of service and installation, as service-sensitive parts can be exchanged quickly. Furthermore, product modularity supports upgrading the product at the customer site by exchanging modules or reusing used modules in other products within the same product family and thereby adheres to the main principles of the circular economy (i.e., maintain products at their highest utility and value at all times and avoid waste).

In addition to modularity, operator-centred design supports ease of (dis)assembly, maintenance and upgrading and thereby improves operational performance. The Human Factor Design for Assembly (HF-DFA) tool, based on the DFA methodology described by Boothroyd et al. (2001), can be used to evaluate the ease of assembly tasks from an operator perspective (Village et al. 2014) and improve product design. The face validity and simple scoring of the tool facilitates integration into the design process. To support operator-friendly fixture design, the Human Factors Design for Fixture (HF-DFF) guidelines can be applied in the design process (Village et al. 2012). Careful fixture design ensures both product quality and improved human factors. Another methodology that can be used to ensure human-centred product design is Design for Manufacturability (DfM) (Helander and Nagamachi 1992).

4 New Technologies in Flexible Production Processes: Levels of Automation and Assistive Operator Support

Once the production process is transparently and flexibly organized, a next step in further improving efficiency can be (partial) automation. Production technology is developing rapidly, and the trend of automation, including the use of robots, collaborative robots and process control systems, has a large impact on manufacturing and on its operators in particular. ‘Full automation’ however, is often not feasible in production work, specifically in the combination of low volumes, high product mix, and high product complexity. For years, product disassembly has been performed as a primarily manual activity. However, the high demand for manual work together with the labour cost generally make disassembly economically infeasible. To overcome this economic issue, replacing the human labour with full automation has been raised as a potential solution (Vongbunyong and Chen 2015). However, task automation requires a very advanced set of robotic technology and its practical implementation still represents a challenge in terms of robustness, accuracy and execution time. Humans are still the most flexible production factor. As smaller batches require higher investments and specialized production systems, especially in assembly, robots and robotic systems will often mainly assist production personnel and remove some routine work. In a semi-structured environment with hybrid production systems, intuitive user interfaces are needed, which could be programmed by operators themselves, to ensure that humans and robot systems are safely collaborating (Robotics 2020: Multi-Annual Roadmap for Robotics in Europe 2015).

In hybrid production systems, human failure is a source of potential error. This requires effective strategies to guarantee human reliability. A strategy to minimize human error is the implementation of automated systems that control the process to a large extent. These may reduce human errors but may also have a large impact on the operator and his or her task. While skilled workers may still be needed, the majority of tasks will become simple and less challenging. Decreased motivation and alertness, potentially jeopardizing human reliability and thereby counteracting potential error-reducing technological measures, are a serious concern. Companies experience these crucial labour issues in production-automation projects, but at the same time, they are ‘hard to tackle’. The challenge is finding a good balance between the level of process control and the attractiveness of the work for the operator. Two steps in production automation projects are proven to be crucial (Fasth and Stahre 2010), which are presented in Fig. 4.

- Design of tasks: **Task Analysis** and **Allocation of Task** to humans and machines.
- **Design of operator support systems** in the case of manual activities.

A process map (e.g., MAS) can be used to create an overview of manufacturing process steps followed by a task analysis (e.g., HTA) to define the order of concrete tasks performed by operators and machines. Task allocation is used to allocate tasks to operators or machines. Finally, in the case of manual activities, the need for physical or cognitive support systems is determined.

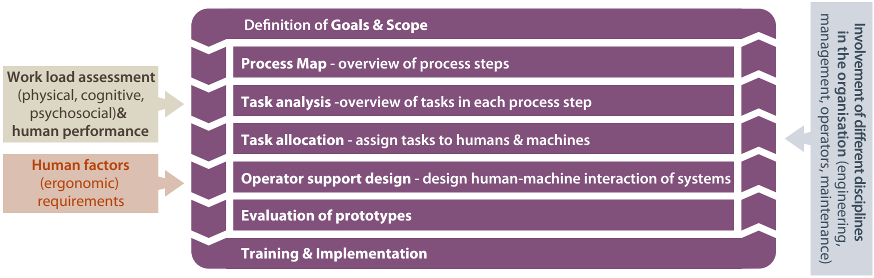

Fig. 4 Schematic overview of the iterative participatory process design approach

4.1 Level of Automation

A first step is to create a well-balanced allocation of activities between humans and robots/machines based on a task analysis. The starting point for this task analysis is the production process analysis, which provides an overview of the process steps to complete an order from beginning to end. Each process step consists of one or more tasks performed by operators and machines. Task analyses can be action oriented approaches (e.g., handling, transportation, picking and placing, replacing tools) or focus on the mental processes as cognitive approaches (e.g., decision making, perception). A common methodology for task analysis is Hierarchical Task Analysis (HTA) described by Stanton (2006). It demonstrates the requirements that tasks necessitate from workers and machines and describes the order of tasks. Task analysis can be used for both current (existing) production processes and new (to be designed) processes.

The result of the task analysis is a starting point for the next step, task allocation between humans and machine. Since Fitts published a set of heuristics on the relative strengths and limitations of humans and machines in 1951 (MABA-MABA, ‘men are better at’ and ‘machines are better at’; Fitts 1951), numerous methodologies have been developed to support task or function allocation between machines/robots and humans. An extensive body of literature describes task allocation models and approaches (e.g., Frohm et al. 2006; Fasth and Stahre 2010; Cummings 2014). In this context, the term Level of Automation (LoA) has been used to describe the relation between humans and technology in terms of task and/or function allocation (Frohm et al. 2006). LoA has been described as an indicator of the allocation of tasks in a manufacturing system and is expressed as an index of physical as well as cognitive tasks. These methodologies focus on balancing performance requirements (zero defects, productivity, costs) and human factors (physical, cognitive load, job satisfaction, motivation, alertness). All of these task allocation models should support the (optimal) division of tasks between robots and operators. The remaining human tasks should not exceed norms, recommendations and guidelines for physical, cognitive, psychosocial load and safety (e.g., ISO 11228-3 2007; ISO 9241 1997; Directive 2002/44/EC). Task allocation is often done once during the (re)design of a manufacturing process. In manufacturing and remanufacturing processes, products and its manufacturing tasks change during the day. There is a need for a more flexible/dynamic task allocation model in which the division between robots and humans can be considered continuously (on the fly), based on human-oriented parameters of workload (physical, cognitive, psychosocial load), safety, flexibility and performance criteria (quality, costs, productivity).

4.2 Operator Support Systems

Workmanship (i.e., craftsmanship) of the workforce, support from tools, support systems and work instructions are crucial ingredients for securing the quality of the manufacturing and assembly process. Especially in low-volume, high-variety and complex tasks, product-specific information and support for operators are required. If there is a (flexible or adaptive) level of automation, the remaining (inspection or manual) tasks of the operator require up to date information for the operator to perform his/her tasks properly. Here, quality refers to minimum failure costs, short lead times, ease of learning, and a high level of reproducibility of the process. In practice, work instructions are often too brief, bear too little relation to the operator's task at hand and are insufficiently systematically updated (Van Rhijn et al. 2014; Aehnelt and Bader 2015). These factors, as well as the unpredictable market, wide variety of products, flexible deployment of employees and diversity in operator characteristics (e.g., experience, backgrounds and languages), emphasize the importance of clear and updated operator assistance. For example, updated work instructions that fulfil the operator needs and feedback systems that provide a clear indication to the operator what went wrong. Especially in closed-loop systems and mixed-model assembly systems (e.g., Zeltzer et al. 2012), operator support and instructions are crucial for effective and efficient processes as the diversity of products coming back from customers is extreme. Aehnelt and Bader (2015) identify five aims of information assistance:

- *raising awareness*: increase operator awareness of relevant events within the work environment;
- *guiding*: feedforward and provide instructions;
- *monitoring*: collect relevant (sensor) data from the actual production setting;
- *documenting:* document quality issues directly in the system;
- *guarding*: monitor the actual operator status and prevent overloading.

In addition to these aims, Claeys et al. (2015) recently described a framework to support the development of industrial cognitive support systems. The authors differentiate:

- the information content: what to present. Operators need to have correct information on how to disassemble a product and how to diagnose the level of re-usability.
- the information carrier: how to present information (e.g., Google Glass, computer screens, projection, etc.). Recently, technologies such as Google Glass (Rauh et al. 2015) or gestural recognition software (Niedersteiner et al. 2015), have been used to support operators in assembly work. Augmented Reality technology has been used to assist assembly workers in the aerospace industry (e.g., Servan et al. 2012) and personnel in the field, supporting maintenance and facilitating the upgrade process (Re and Bordegoni 2014).
- in what kind of situation information should be presented: presenting information automatically or upon request depends on the operator needs and task demands.

Claeys et al. (2015) emphasize the importance of a personalized configuration, i.e., modifying instructions and feedback depending on the current state of the operator and the task at hand. Work instructions should be set out in a modular manner and applied in accordance with the degree of experience of the employees. In both manual and semi-automated or hybrid processes, operator guidance should be experienced as added value and should therefore not dictate either posture or work pace to avoid operator annoyance. The interaction should be natural and effortless. High system reliability is needed to avoid operator annoyance and mistakes (e.g., error messages should not occur if a correct action has been performed by the operator). Operator support guidelines for transferring information using text, images or signals must be used so that the information is more appropriately tailored to the operator and task at hand.

5 Conclusions

In the near future, short product development lead times, proven sustainability, flexibility, and upgrades will become crucial elements to guarantee competitive business in the manufacturing industry. Upgrading high-investment products driven by rapidly changing customer demands requires highly modular product design, flexible production processes (for new, refurbished and remanufactured products) including (semi) automated and manual workstations and a flexible, motivated and skilled workforce. To face these challenges, several methods and tools for both product, process and task design are described in scientific and grey literature. Several of these methods are described in this chapter. However, many manufacturing companies, especially small- and medium-sized enterprises, do not use these tools and methods. Possible reasons for this are that the methods are not well known or that there is a lack of experience using the tools in a correct manner. Furthermore, the practical application of scientific methodologies is difficult for engineers, as the methodologies do not use the language of their users (e.g., engineers) or are not part of their standardized working procedures, for instance, see Village et al. (2012) regarding ergonomics.

In addition to barriers for efficient tool use in companies, further development of methodologies should be closely connected to future company needs. For instance, most of the current methods are suitable and developed for designing products and processes based on the more traditional linear economy. The circular economy emphasizes the reusability of products and raw materials as a starting point and minimizing waste in the entire industrial and ecological system. Designing adaptable and upgradable products and flexible (re)manufacturing processes are crucial aspects in realizing a circular economy-based business. These aspects should be considered and integrated in the next generation of methods for product and process design.

Finally, communities of practice (see Houghton, Chapter "Fostering a Community of Practice for Industrial Processes" this book) could serve as a dedicated platform to share state-of-the-art methodologies, tools and checklists and documentation of company best practices so that practical cases and tools could be made available to SME companies.

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References

Aberdeen Group (2014). Bridging the gap between product development and operations. http://www.aberdeen.com/research/9340/rr-manufacturing-product-development/content.aspx#sthash.K8rq0kXI.dpf

Aehnelt, M., & Bader, S. (2015). Information assistance for smart assembly stations. In Proceedings of the 7th International Conference on Agents and Artificial Intelligence (pp. 143–150).

APPSRG (2014). Remanufacturing: Towards a resource efficient economy. All Party Parliamentary Sustainable Resource Group.

Bastein, T., Roelofs, E., Rietveld, E., & Hoogendoorn, A. (2013). *Kansen voor de circulaire economie in Nederland*. Delft, The Netherlands: TNO.

Bloom, D. E., Canning, D., & Lubet, A. (2015). Global population aging: Facts, challenges, solutions & perspectives. *Daedalus, 144*(2), 80–92.

Boothroyd, G., Dewhurst, P., & Knight, W. A. (2001). What is design for manufacture and assembly? *Product design for manufacture and assembly* (pp. 1–44). Boca Raton, FL: CRC Press, Taylor and Francis.

Bouckenooghe, D., & Devos, G. (2007). The role of process, context and individual characteristics in explaining readiness to change: A multilevel analyses. Vlerick Leuven Gent Working Paper Series 2007/12.

Challenger, R., Clegg, C. W., & Shepherd, C. (2013). Function allocation in complex systems: Reframing an old problem. *Ergonomics, 56*(7), 1051–1069.

Claeys, A., Hoedt, S., Soete, N., Van Landeghem, H., & Cottyn, J. (2015). Framework for evaluating cognitive support in mixed model assembly systems. *IFAC-PapersOnLine, 48*(3), 924–929.

Cummings, M. M. (2014). Man versus machine or man + machine? *IEEE Intelligent Systems, 29* (5), 62–69.

DIRECTIVE 2002/44/EC of 25 June 2002 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration) (sixteenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC).

Department for Business, Innovations and Skills (2012). Low carbon environmental goods and services.

Ellen MacArthur Foundation (2013). Towards the circular economy. In: Economic and Business Rationale for an Accelerated Transition, Vol. 1. Ellen MacArthur Foundation available from: www.ellenmacarthurfoundation.org

European Foundation for the Improvement of Living and Working Conditions (1999). Communique, July/August, Vol. 2. EFILWC, Dublin.

Fasth, A., & Stahre, J. (2010). Concept model towards optimising Levels of Automation (LoA) in assembly systems. In Proceedings of the 3rd CIRP Conference on Assembly Technologies and Systems, Trondheim, Norway.

Fitts, P. M. (1951). Human engineering for an effective air navigation and traffic control system. Tech. Report, Nat'l Research Council.

Frohm, J., Granell, V., Winroth, M., & Stahre, J. (2006). The industry's view on automation in manufacturing. In F. Mayer, & J. Stahre (Eds.), Proceedings of the 9th Symposium IFAC on Automated Systems Based on Human Skills and Knowledge.

Gaustad, G., Olivetti, E., & Kirchain, R. (2010). Design for recycling. *Journal of Industrial Ecology, 14*(2), 286–308.

Genaidy, A., & Karwowski, W. (2007). A roadmap for a methodology to assess, improve and sustain intra- and inter-enterprise system performance with respect to technology-product life cycle in small and medium manufacturers. *Human Factors and Ergonomics in Manufacturing*, *18*(1), 70–84.

Ginn, D. M., Jones, D. V., Rahnejat, H., & Zairi, M. (1998). The "qfd/fmea interface". *European Journal of Innovation Management, 1*(1), 7–20.

Helander, M., & Nagamachi, M. (1992). Design for manufacturability: A systems approach to concurrent engineering and ergonomics Taylor & Francis.

Hirschheim, R. (1989). User participation in practice: Experiences with participative system design. In K. Knight (Ed.), *Participation in Systems Development* (pp. 194–204). Columbia GP Publishing.

Ishii, K., Eubanks, C. F., & Di Marco, P. (1994). Design for product retirement and material life-cycle. *Materials and Design, 15*(4), 225–233.

International Standard Organisation ISO 11228-3. Ergonomics—manual handling: Part 3: Handling of low loads at high frequency, 2007.

EN ISO 9241-1:1997 "Ergonomic requirements for office work with visual display terminals (VDTs)—Part 1: General introduction (ISO 9241-1:1997/Amd. 1:2001)" and its amendment A1:2001.

Jacobs, M., Vickery, S. K., & Droge, C. (2007). The effects of product modularity on competitive performance: Do integration strategies mediate the relationship? *International Journal of Operations & Production Management, 27*(10), 1046–1068.

Krikke, H., le Blanc, I., & van de Velde, S. (2004). Product modularity and the design of closed-loop supply chains. *California Management Review, 46*(2), 23–39.

Kuo, T. C., Huang, S. H., & Zhang, H. C. (2001). Design for manufacture and design for 'X': Concepts, applications, and perspectives. *Computers & Industrial Engineering, 41*(3), 241–260.

Leonard, L. (1991). Design for environment. In Plastics Design Forum: 25–32.

Lines, R. (2004). Influence of participation in strategic change: Resistance, organizational commitment and change goal achievement. *Journal of Change Management, 4*(3), 193–215.

McKinsey (2011). Resource revolution: Meeting the world's energy, materials, food, and water needs. McKinsey Global Institute; McKinsey and Company Sustainability, Resource Productivity Practice. Available from: http://www.mckinsey.com/mgi

Muller, M. J., & Kuhn, S. (1993). Participatory design. *Communications of the ACM, 36,* 24–28.

Niedersteiner, S., Pohlt, C., & Schlegl, T. (2015). Smart workbench: A multimodal and bidirectional assistance system for industrial application. In Industrial Electronics Society (pp. 2938–2943).

Quan, W., & Jianmin, H. (2006). A study on collaborative mechanism for product design in distributed concurrent engineering. IEEE 7th International Conference on Digital Object Identifier (pp. 1–5).

Rauh, S., Zsebedits, D., Tamplon, E., Bolch, S., & Meixner, G. (2015). Using Google Glass for mobile maintenance and calibration tasks in the AUDI A8 production line. In Emerging Technologies & Factory Automation (pp. 1–4).

Re, G. M., & Bordegoni, M. (2014). An augmented reality framework for supporting and monitoring operators during maintenance tasks. In R. Shumaker & S. Lackey (Eds.), *Virtual, augmented and mixed reality applications of virtual and augmented reality* (pp. 443–454). Berlin: Springer.

van Rhijn, J. W., de Looze, M. P., Tuinzaad, G. H., Groenesteijn, L., de Groot, M. P., & Vink, P. (2005). Changing from batch to flow assembly in the production of emergency lighting devices. *International Journal of Production Research, 43,* 3687–3701.

Rhijn van, J.W., Tuinzaad, B., Bosch, T., & Vos, F. (2014). Increasing productivity and flexibility in manufacturing. TNO Hoofddorp.

Robotics 2020: Multi-annual roadmap for Robotics in Europe (2015). http://sparc-robotics.eu/wp-content/uploads/2014/05/H2020-Robotics-Multi-Annual-Roadmap-ICT-2016.pdf

Rother, M., & Shook, J. (2003). Learning to see: Value stream mapping to add value and eliminate muda. Lean Enterprise Institute.

Pot, F., & Rhijn van, J.W. (2012). Slimmer Werken in het MKB van de maakindustrie. http://www.industriebeleid.nl/documenten/Slimmer%20werken%20in%20het%20MKB%20van%20de%20maakindustrie.pdf

Servan, J., Mas, F., & Menendez, J.L. et al (2012). Using augmented reality in AIRBUS A400M shop floor assembly work instructions. In The 4th Manufacturing Engineering Society International Conference, Cadiz (pp. 633–640).

Shalley, C. E., Zhou, J., & Oldham, G. R. (2004). The effects of personal and contextual characteristics on creativity. *Journal of Management, 30,* 933–958.

Sheldon, D. F., Perks, R., Jackson, M., Miles, B. L., & Holland, J. (1990). Designing for whole life costs at the concept stage. *Journal of Engineering Design, 1,* 131–145.

Smart industry, Dutch industry fit for the future (2014). http://www.smartindustry.nl/wp-content/uploads/2014/07/Opmaak-Smart-Industry.pdf

Stamatis, D.H. (2003). Failure mode and effect analysis: FMEA from theory to execution. ASQ Quality Press.

Stanton, N. A. (2006). Hierarchical task analysis: Developments, applications, and extensions. *Applied Ergonomics, 37*(1), 55–79.

Suri, R. (1998). Quick response manufacturing: A companywide approach to reducing lead times. Productivity Press.

Ulrich, K. T. (1995). The role of product architecture in the manufacturing firm. *Research Policy, 24*(3), 419–440.

Ulrich, K.T., & Pearson, S.A. (1993). Does product design really determine 80% of manufacturing cost? Working paper. Massachusetts: Sloan School of Management Cambridge.

Village, J., Greig, M., Zolfaghari, S., Salustri, F., & Neumann, W. P. (2014). Adapting engineering design tools to include human factors. *IIE Transactions on Occupational Ergonomics and Human Factors, 2*(1), 1–14.

Village, J., Annett, T., Greig, M., & Neumann, W.P. (2012). Ergonomic design-for-fixture guidelines and process of implementation. A case study. In Association of Canadian Ergonomists Annual Conference, Halifax, Nova Scotia. http://digitalcommons.ryerson.ca/ie/27/

Vink, P., Imada, A. S., & Zink, K. J. (2008). Defining stakeholder involvement in participatory design processes. *Applied Ergonomics, 39*(4), 519–526.

Vongbunyong, S., & Chen, W.H. (2015). Disassembly automation: Automated systems with cognitive abilities. Springer.

Zeltzer, L., Limere, V., Aghezzaf, E.H., & Van Landeghem, H. (2012). Measuring the objective complexity of assembly workstations. In ICCGI 2012, The Seventh International Multi-Conference on Computing in the Global Information Technology (pp. 341–346).

Fostering a Community of Practice for Industrial Processes

Alyson Langley, Harshada Patel and Robert J. Houghton

Abstract A Community of Practice (CoP) is a framework for the facilitation of knowledge management and involves groups of individuals who engage in the process of collective learning around a specific topic. Recent advances in computer technology and Web 2.0 applications now allow for virtual communities to be established which permit interaction and collaboration between individuals across organisational boundaries and geographical locations. The Use-it-Wisely (UIW) project aims to design and develop a cross-industrial virtual community to support the operating environment of manufacturing organisations. Successful implementation of a virtual community has the potential to strengthen the competitive advantage of the industries involved, securing domestic employment and providing products and services that are capable of adapting to the organisational goals. This chapter provides a general overview of the literature on CoPs and virtual communities. It discusses the development of the concept of CoPs, and considers how this relates to knowledge management lifecycle and learning theories. This is followed by a discussion on the use of CoPs and virtual communities as a knowledge management strategy for the manufacturing industry, including multinational companies and Small and Medium-sized Enterprises (SMEs). The chapter finishes by discussing the essential elements for creating and maintaining a self-sustainable virtual community to enable information sharing and decision support across and between the organisations. This includes the factors required to foster a successful virtual community concerning the purpose, content, context, conversations, connections and technology, and the risks and challenges that could lead to the failure of a CoP to be sustained.

Keywords Knowledge management · Community of practice · Virtual community · Industrial manufacturing

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1 Introduction

Knowledge management has emerged as a major factor for sustainability in the increasingly evolving and competitive marketplace of today's modern manufacturing industry (Pan and Leidner 2003; Patel et al. 2012). Numerous knowledge management principles have been proposed over the years (Davenport 1996; Allee 1997; Studer et al. 1998; Luen and Al-Hawamdeh 2001), including research that has linked the concept of communities of practice (CoP) with organisational knowledge management (Lave and Wenger 1991; Brown and Duguid 1991; Wenger 1998; Wenger and Snyder 2000; Storck and Hill 2000; Wenger et al. 2002; Ardichvili et al. 2003; Dubé et al. 2006; Eckert 2006; Du Plessis 2008; Scarso and Bolisani 2008).

Wenger et al. (2002) defined CoPs as, "*a group of people who share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis*". It is through the process of regular interaction that members gain knowledge (Du Plessis 2007), for example, engineers working on a problem, university students studying together or managers sharing organisational information (Wenger 2009). This shared involvement over time, allows members of the community to develop opinions, ideas and ways of performing that deepens their knowledge and expertise on a particular subject or process, as they participate in practices and develop a common history (Gunawardena et al. 2009).

In the past, the size and scope of a CoP has been determined by geographical boundaries. However, recent advances in computer technology and Web 2.0 applications now allow for virtual communities to be established. Virtual communities are a specific type of CoP that uses a web-based platform to provide an environment where geographically distributed members can interact, and share information, knowledge and expertise (Rothaermel and Sugiyama 2001). This allows them to overcome the geographical limitations of traditional CoPs and although, members of a virtual community may participate in telephone conferences and face-to-face meetings, most interaction will involve the posting or viewing of information through web-based technology (Andrews 2002).

The ability of virtual communities to enable collaborations over time and across organisational boundaries provides the flexibility required for the strategic management of knowledge within industrial manufacturing. Interaction between the members includes distribution of news through events, announcements, and publications; problem solving opportunities from question and answer postings and best practice forums; and communication mediums such as discussion groups (Koh et al. 2007). Virtual communities have the potential to access information from different devices, and through interaction with other members, data or virtual objects (Hibbert and Rich 2006). The management of knowledge using the concept of virtual communities has the potential to increase the overall productivity and innovation of the organisation (Chiu et al. 2006).

One of the objectives of the UIW-project is to design and develop a knowledge management strategy to support the operating environment across industrial manufacturing organisations. The development of a cross-industrial virtual community, to support complex industrial activities in response to new products or the upgrading of existing products, has the potential to strengthen the industrial position of the organisations involved, securing domestic employment and providing products and services that are capable of adapting to the organisational strategy.

2 General Overview of Communities of Practice

This section aims to provide a general overview of CoPs and virtual communities by examining the literature relating to learning theories, knowledge management and its relevance to manufacturing industries. The section starts with a summary of the development of the concept of CoPs and how this supports the management of knowledge. This is followed by a discussion of the relevance of virtual communities for the manufacturing industry, including multinational companies and Small and Medium-sized Enterprises (SMEs).

2.1 *The Development of the Concept of Communities of Practice*

Individuals have engaged in the process of collective learning through sharing of experiences and knowledge for many years (Hoadley 2012). However, it was Jean Lave and Etienne Wenger who first used the phrase "*community of practice*" (Cox 2005) and introduced CoPs as a new approach to workplace learning for novice apprentices (Lave and Wenger 1991). Their studies focused on informal interaction and investigated how new workers are socialised into working practices and learn their job through legitimate peripheral participation. Legitimate peripheral participation is explained by Lave and Wenger as *legitimate* because all individuals accept the position of the novice apprentice as a potential community member, *peripheral* because the novices are initially on the edge of the community until trust is established and *participation* because it is through participating in the practice that they acquire knowledge (Cox 2005).

Lave and Wenger‘s findings showed that novice apprentices learnt the required knowledge mainly from informal social interaction, practice and participation. The authors concluded that learning was a continuous and active engagement, situated in context and social interaction (Lave and Wenger 1991). This was in contrast to the cognitive learning theory, which involved knowledge being conveyed by experts to learners through formally planned methods and was the dominant theory of that time (Cox 2005). This new approach suggested that learning is more than the acquisition of knowledge, and includes peripheral participation and active involvement in the practice (Lave and Wenger 1991). However, this approach only considered the transfer of existing knowledge and did not consider CoPs as a platform for innovation, problem solving or as a potential driver of change (Østerlund and Carlile 2003).

In the same year as Lave and Wenger proposed their new approach, Brown and Duguid (1991) also used the phrase "*community of practice*". This work was based on data from Julian Orr's earlier studies of Xerox photocopier repairmen and aimed to show how informal groups generate solutions to work-related problems (Brown and Duguid 1991) although, Orr did not use the phrase "*community of practice*", preferring to use the term "*occupational community*" (Cox 2007). The study observed how knowledge was better created and transferred through the sharing of experiences and collective problem solving activities, compared to the more traditional learning processes of expert instruction and manuals. Brown and Duguid suggested that knowledge and learning, were embedded in social practices and extended the concept of CoPs to include them as a tool for resolving work-based problems (Brown and Duguid 1991), as opposed to Lave and Wenger's concept that focused only on the reproduction of existing knowledge (Cox 2004).

Although the term "*community of practice*" was used by both Lave and Wenger (1991) and Brown and Duguid (1991), a rigorous formal definition was not offered. This was mainly due to the different interests and viewpoints of the studies and those involved (Cox 2005). However, Wenger (1998) finally defines CoPs as, "*a group that coheres through sustained mutual engagement' on an 'indigenous' (or appropriated) enterprise, and creating a common repertoire*". Wenger expanded on the initial concept of CoPs (Lave and Wenger 1991), from a theory of learning to a knowledge management strategy and discards the concept of legitimate peripheral participation in favour of social identity and trajectories of participation (Wenger 1998). The study focused on the formation and management of CoPs across organisational boundaries to enhance performance, and states that it is through the common understandings of an activity involving large amounts of interaction and problem solving, that relationships are built and CoPs are established (Wenger 1998).

Over time, the interpretation of a CoP moved from a descriptive concept (Lave and Wenger 1991) to a more prescriptive application provided by Wenger et al. (2002), who redefined CoPs as, "*groups of people who share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis*". Wenger provided a guide for the formation and management of CoPs to enhance performance and drew together ideas put forward in previous works while focussing on the value of the CoP as a knowledge management tool for innovation and problem solving, where the purpose is to learn and share knowledge and not specifically with accomplishing a common task (Cox 2005).

2.2 Communities of Practice and the Management of Knowledge

Complex knowledge, that is critical to the ability of an organisation to adapt in a fast-paced globalised marketplace, is becoming increasingly specialised and tacit in nature (Hinton 2003). Tacit knowledge is considered to be a valuable source of context-based information, but is stored and composed in the minds of individuals, so is difficult to obtain and develop (Hildreth and Kimble 2002). Duguid (2005) explains the difference between explicit knowledge and tacit knowledge, as *knowing what* and *knowing how*, respectively. Optimal performance within an organisation requires the transfer of knowledge between tacit and explicit knowledge. Novice workers need to be able to convert explicit knowledge (theory) into tacit knowledge (practice) and experienced workers need to convert their tacit knowledge (information within their head) into explicit knowledge for training and learning purposes (Duguid 2005). The process for the successful transfer between tacit knowledge and explicit knowledge is not fully understood, but is a critical resource for organisational innovation (Stephenson 1998).

CoPs have the potential to support the knowledge management process by creating a link between learning and performance (Wenger et al. 2002). This can make a significant organisational impact, by allowing managers to connect tacit knowledge to organisational processes and strategically steer innovation towards industrial growth (Du Plessis 2008). Studies have shown that workers are five times more likely to turn to a co-worker and obtain tacit knowledge about an activity, compared to obtaining knowledge from an explicit source such as a manual (Davenport and Prusak 2000). In addition, members of a CoP have reported an increase in communication, less dependence on physical proximity, and accessibility to new knowledge, which can result in open discussions and brainstorming activities, leading to new capabilities (Ardichvili et al. 2003). This sharing of tacit knowledge for manufacturing processes has the potential to increase learning trajectories and reduce workplace errors, resulting in overall organisational benefits.

A central theory for the ability of CoPs to exploit tacit knowledge is the theory of situated learning (Hoadley 2012). Situated learning describes a method of knowledge acquisition that is '*situated*' in context and interactions between individuals, professions, or pursuits (Lave and Wenger 1991). Brown and Duguid (1991) provided an example of learning by photocopy repairmen, which was situated in the context of problem solving and showed knowledge as being co-constructed, through the sharing of experiences, allowing individuals to better understand their job (Cox 2005). A number of studies have suggested that tacit knowledge, can best be transferred in the context of situated learning processes and social practices (Brown and Duguid 1991; Lave and Wenger 1991; Cox 2005; Hoadley 2012), with a number of theories suggesting that knowledge can only exist in social context and interactions, and is not in the possession of a single individual (Hoadley 2012). This implies that CoPs provide a natural environment for the existence of knowledge.

2.3 Communities of Practice and Industry

Knowledge lifecycle refers to the creation, distribution and collection of knowledge and the influence that it has on the working environment (Du Plessis 2008). Effective and efficient industrial knowledge management throughout this lifecycle facilitates collaborative work and innovation for large multinational companies and SMEs either locally or across organisational boundaries (Patel et al. 2012). However, the structure of modern multinational organisations, which can consist of many dispersed teams that span across organisational boundaries, can often impede the effective recovery, transfer and reuse of knowledge, especially when the company operates at a global level, across geographical distances and with distinct cultural and language differences (Scarso and Bolisani 2008).

The recognition that knowledge is a critical element that needs to be managed strategically, has led to the intentional formation of virtual communities to manage knowledge between different teams, departments and locations and involve groups of co-workers that exchange information to overcome complex work-related challenges (Ardichvili et al. 2003; Dubé et al. 2006; Du Plessis 2008; Scarso and Bolisani 2008; Wenger 2009). Each member of the CoP has the potential to bring a unique skill set and contribute to a greater body of knowledge that is available indefinitely and can be called upon even when they leave the community (Wenger et al. 2002). This provides the organisation with significant knowledge input for creative innovation and development of strategic capabilities, while keeping up with current progress in such areas as state-of-the-art technology, customer demands and market changes (Du Plessis 2008). In addition, knowledge transfer and learning activities associated with CoPs offer these organisations a complementary alternative to more traditional training methods (Wenger 2009).

One of the first industrial CoPs to be developed was applied to Xerox photocopy repairmen when the organisation saw the value of the informal exchange of information concerning working activities (Brown and Duguid 2001). In response to their observations, the company created a virtual community that allowed these interactions to be shared across their global network, saving the organisation time and money (Cox 2005). Following this, Shell Oil Company formed a virtual community to facilitate knowledge sharing among different teams, while Daimler-Chrysler Automobile Company designed a virtual community for problem sharing activities (Cox 2005). Since then, the concept of virtual communities have been employed by a number of multinational organizations (Eckert 2006) such as Hewlett Packard, British Petroleum, Chevron, Ford, Boeing and IBM to support workflow processes and the dissemination of case-histories through the use of meetings, forums, document repositories and libraries (Scarso and Bolisani 2008). This results in an environment where knowledge that is created, shared and collected, can influence the development of innovations, increase market responsiveness, improve performance and provide a flow of information linked to the organisational strategy (Du Plessis 2008).

Adapting to the rapid change in processes, systems and economies is also essential for SMEs within the manufacturing industry, as their product will often be more specialised and their profit margins smaller, compared to multinational organisations (Desouza and Awazu 2006). Virtual communities are a good method for introducing knowledge management processes and principles into SME organisations, which may often find it difficult to structure a knowledge management infrastructure (Du Plessis 2008). SMEs can utilise CoPs for controlling the knowledge management lifecycle, ensuring that knowledge generates value through which innovation can take place and also as a communication tool especially if their communication strategies are inadequate (Desouza and Awazu 2006). Virtual communities can support SMEs in the prediction of work activities and provide them with current information on market trends and technological advancements (Du Plessis 2008).

There are unique challenges for SMEs in the development of virtual communities. SMEs deal with information that can be very specialised and they do not manage knowledge in the same way as larger organizations therefore, scaling down knowledge management in practices found in multinational organisations to suit SMEs, is not appropriate because of financial and resource constraints. This requires that SMEs be more creative in working around these limitations in order to manage knowledge (Desouza and Awazu 2006). A significant number of SMEs do not have the network infrastructure, technological tools, ability or economics to establish a virtual community. In addition, their computer-based systems may be more basic with limited functionalities or slower speeds for data retrieval when compared to larger organisations (Du Plessis 2008). The impact is that staff must keep up with changes in the rapidly changing industrial manufacturing markets, without the assistance of the necessary tools and equipment (Du Plessis 2008). However, one solution to the financial and resource constraints of an SME is to participate in a cross-industrial CoP where a number of industries can contribute to the development of the site, the resources and the content of knowledge.

2.4 *Communities of Practice and Cross-Industrial Knowledge Flow*

Cross-industrial virtual communities have the potential to traverse structural boundaries and promote knowledge flow between different organisations or from different areas of industry. Cross-industrial knowledge flow can highlight current principles and processes that can be transferred between industries such as novel approaches, techniques, tools and methodologies (Du Plessis 2008) and promotes the development of a common body of industrial knowledge between different industries by the sharing of information without the members necessarily needing to work together (Wenger et al. 2002; Hinton 2003).

The benefit of cross-industrial virtual communities include

- sharing of network technology and tools
- division of economic commitments
- working with others to improve processes and innovation
- collaboration with others that may have the relevant skills needed
- development of experts and expertise through collaboration (Du Plessis 2008).

However, industrial organisations are currently only doing this to a limited extent in certain areas, such as technical exchanges, joint ventures, and research and development partnerships. (Du Plessis 2008). The rarity of cross-industrial virtual communities is due to industries' knowledge being part of the asset that sets them apart from other organisations when competing for contracts. Industries protect their knowledge and are not disposed to share it, unless there is some kind of reward or incentive in place. In addition, cross-industrial virtual communities also face additional barriers such as cultures, customs, language and time constraints that inhibit individuals from engaging in knowledge exchange (Wasko and Faraj 2000).

Ultimately, it is the strength of relationships between co-workers that determines the operational potential of an organisation, with innovation, productivity and staff satisfaction, relying on the strength of these relationships. (Du Plessis 2008). CoPs have the ability to assist in the building of social networks including the strengthening of relationships, and the establishment of values and norms providing a platform for knowledge life-cycle management (Du Plessis 2008).

3 Form and Function for a Successful Virtual Community

This section aims to provide a broad guideline for creating and maintaining a self-sustainable collaborative virtual community. It discusses the requirements that need to be considered for an initial framework that enables information sharing and decision support across and between organisations. The section starts with a summary of the structure of all CoPs (including virtual communities) and how this supports the management of knowledge, followed by a discussion on the challenges for a successful virtual communities are explained including guidelines concerning the purpose, content, context, conversations, connections and technology that should be employed for the general development of the UIW-virtual community.

UIW's cross-industrial virtual community aims to support a framework for cross-industrial knowledge management. It not only faces the same limitations of any other CoP, but also specific challenges that facilitate knowledge exchange across different industries. Developers of the community not only have to deal with communication, motivation and leadership issues but also take into consideration the different interests and expectations of the community and the interoperability of the communication technology, that each industry employs (Koh et al. 2007).

3.1 Structural Characteristics of a Community of Practice

While CoPs including virtual communities, come in many forms, three structural characteristics have been identified as being central to the framework of all CoPs. These are a domain, a community and a practice (Wenger et al. 2002). Within this structural framework, major factors for a successful community include a clear and focused purpose, high quality content, correct context, meaningful conversation, relationship-building connections and high performing technological tools (Wenger 2009). The structural characteristics of a CoP are discussed first, followed by a review of the major factors.

The first structural characteristic is the domain. The domain represents the shared interest that unites the members of the community (Wenger 2009). Relevant domains of knowledge where experiences of the individual members can be communicated include particular hobbies or interests or work-related activities such as research projects, business activities, technological advancement, training and educational methodologies (Wenger et al. 2002). The domain can be local or global, with some communities meeting face-to-face, while others mostly interact online. It is not a community grouped by geographical location such as a neighbourhood or workplace, but is defined by membership and commitment to the domain and to the development of a shared understanding, resulting in the creation of personal meaning and strategic knowledge (Gunawardena et al. 2009).

The community defines all the members that interact and learn from each other. As the members of a community interact, they build relationships through dialogue and conversation, resulting in an environment of trust, from which they can learn from each other (Wenger 2009). It is not a community grouped by shared characteristics such as age, gender, ethnicity or religion but is a system of knowledge, beliefs, behaviours, and customs, which serve as the basis for further interaction (Gunawardena et al. 2009). The community can be small or large, often with a central group and many peripheral members and may contain individuals from the same organization or from different institutions (Wenger 2009).

The practice is a result of sustained mutual engagement in the community over time, with members being jointly responsible for the development of knowledge and learning (Wenger 2009). The time spent building relationships and collaborating is vital in the development of a practice and also allows for the repetition of circumstances, situations, and events, resulting in a commitment to the engagement for shared knowledge. This provides the conditions for setting down new cultural norms and conventions within the practice and the development of a common history (Eckert 2006).

The multi-industrial element of the Use-it-Wisely virtual community requires the consideration of these structural characteristics. The domain has to be general enough to encompass the different industries and their external stakeholder partners while being specific enough to encourage a commitment to the community, allowing personal meaning and strategic knowledge to be formed. The community needs to develop trust and confidence within and between the industries, so that relationships can be built and members can learn from each other. Finally, the practice needs to be flexible enough to cover all the industries and provide an environment that develops new cultural norms, conventions and a common history.

3.2 Major Factors for a Successful Virtual Community

Although the number of virtual communities has increased, there appears to be a limited consensus within the literature on the factors which underlie a successful practice. However most of the research agrees that the success of a virtual community relies on its members having both the opportunity and the motivation to participate and contribute knowledge (Rothaermel and Sugiyama 2001; Ardichvili et al. 2003; Koh et al. 2007; Wenger 2009). The factors for any successful CoP, including the UIW-virtual community are dictated by the community itself and usually evolve over time. However, major factors for consideration in the initial design stage of a virtual community include the purpose, content, context, conversation, connections and technology.

3.2.1 Purpose

All the shared ideas, interests and common goals of the members of a virtual community constitute its purpose. A shared purpose is essential for a successful collaborative environment because it unifies everything that occurs within the virtual community. Furthermore, clarity of purpose is also important because it creates energy and interaction, generating trust and connections between the members (Hoadley and Kilner 2005). However, it can be difficult to reach a consensus that clearly defines the shared purpose, especially when members come from different professions or industries (Koh et al. 2007). Establishing and developing good community leaders and leadership roles that can identify and act upon the needs of the members, is important for the generation and clarity of a shared practice (Koh et al. 2007). Nevertheless, even when a shared purpose is clearly defined, the actual purpose will evolve through the content, conversations, and connections, of its members, with every contribution either reinforcing or disrupting the stated purpose (Hoadley and Kilner 2005).

For the UIW-virtual community a clear, focused and shared purpose will increase interaction and collaboration. However, the different requirements from the industry partners may hinder the chances of establishing a specific shared purpose. Initially, a more general purpose may be more appropriate, which over time, may be defined more clearly by its members as they form connections, establish trust and share knowledge.

3.2.2 Content and Context

The content of the virtual community refers to the contributions the members make in relation to their experiences, understanding and development (Eckert 2006), while context refers to the known information about the origin of the knowledge posted and how it has been previously applied (Hoadley and Kilner 2005). Both are vital for a sustainable virtual community.

The continuous delivery of good quality content is important because it supplies a basis for conversation and attracts new members by communicating a clear purpose (Hoadley and Kilner 2005). Generating quality content is a major challenge when establishing a virtual community, but the reasons why members contribute content is not clear, although a number of processes have been proposed that can assist in its generation (Ardichvili et al. 2003). Requesting specific contributions from members will stimulate content as individuals are more inclined to contribute when they are asked (Hoadley and Kilner 2005). Reviving conversations that have been posted about a particular topic into, for example, a new format or from a new point of view can stimulate new objectives and ideas and generate fresh content (Hoadley and Kilner 2005), and introducing an evaluation system that filters out redundant or obsolete postings based on periodic examination, ensures that high value content is maintained (Koh et al. 2007).

Posting is central to the quality of the content but viewing is just as important. Koh et al. (2007) reported that there was an increase in viewings when the content of a virtual community were perceived to be valuable or useful. Therefore collecting and displaying good quality content, which is updated regularly, is important for promoting the viewing activity of community members (Hoadley and Kilner 2005). Posting and viewing are so important for the development of a sustainable virtual community that they must always be taken into consideration when any changes are made (Koh et al. 2007). A key finding in the study by Koh et al. (2007) was that postings were influenced by offline events while viewing was influenced by the quality of the technological infrastructure and the usefulness of the community. The size of a community can be an important element in the sustainability of a community because the amount of a community's posting and viewing is related to the number of members (Koh et al. 2007). Therefore, it is essential at the formation of a virtual community to actively recruit and include community members. However, there are limitations to the amount of time people can devote to a community and as the commitment and energy of members decreases, so does the quality of the content (Koh et al. 2007).

Providing the right information context to enable members to learn more effectively is also an important factor for a productive virtual community. Context helps a community member know the source of a piece of knowledge and how it has been applied in the past and might consist of information about the author and their situation, including details, cross-references, and stories (Patel et al. 2012). Knowing the context of a piece of information contributes to the applicability and understanding of the members of a community in the communication (Hoadley and Kilner 2005). When conversations reinforce a community's purpose in their content, the result is a clearer context for everyone involved. In addition, when members are connected through a relationship, they gain access to context about contributions to the community. However, the challenge for virtual communities is to situate the knowledge context through conversation and connections among members who are geographically distributed (Hoadley and Kilner 2005).

Posting and viewing are major factors in the sustainability of any virtual community and the UIW-virtual community needs to establish good quality content presented in the right context at an early stage of development. This will provide a basis for each of the industries to connect and converse, to build trust and learn from each other.

3.2.3 Conversation and Connections

Conversation and connections are the fundamental elements for establishing confidence and trust among the members of a virtual community. Conversation in a virtual community, relates to any communication including electronic interaction such as video conferencing, text messaging and emails that relay knowledge. Connections relate to the relationships made within a virtual community that enable members to build relationships and share knowledge (Hoadley and Kilner 2005). Both the conversation and the stability of the connections made are primary factors for a productive virtual community.

The transfer of knowledge is most easily generated through conversation. Conversation offers a personal connection to members of a community and supplies the content for the domain and the context for the information. Without efficient forms of conversation, community members from differing geographical locations will not benefit from the knowledge transfer processes (Jin et al. 2010). The challenge within a virtual community is to generate dialogue that elicits meaningful conversation, which is focused and relevant to the community's purpose (Hoadley and Kilner 2005). Effective conversation can be stimulated by social presence, however within virtual communities the dominant communication channel is the exchange of text messaging, which is low in social presence (Fulk et al. 1990). To overcome this challenge it is important to support community members with relevant graphical and video interfaces such as video-conferencing and avatar chatting and to integrate ways to strengthen social identity by linking offline meetings to online activities (Koh et al. 2007).

Making connections within a virtual community involves forming relationships between members to facilitate the transfer of knowledge (Jin et al. 2010). Stable relationships contribute to a culture of trust in which members feel safe to contribute knowledge content, challenge assumptions and propose unconventional ideas (Hoadley and Kilner 2005). In a virtual community, the lack of social connections can often result in an evolution of the site into either an online document repository or a chat room. Having a clear purpose so that members are aware that they all share a common interest, quality content and conversation that facilitates dialogue, all reduce barriers so that connections can be made. In addition, linking member profiles with their knowledge contributions facilitates connections, as other members contribute to the conversation (Hoadley and Kilner 2005).

Providing an environment that allows connections and conversations between the members of the UIW-virtual community is a fundamental element that can facilitate interaction and collaboration. Interactions between the members from different areas of industry can promote diverse relationships and comprehensive processes that can lead to innovative practices. However, there are many barriers to generating conversation and establishing connections over geographical distances and between differing industries including language, culture, background and organisational principles.

3.2.4 Technology

The advancement of web-based technology has facilitated the integration of knowledge and networks of individuals, to such an extent that they have transformed the concept of CoPs, allowing them to effectively become virtual. New web-based applications break down the geographical barriers of traditional CoPs, with virtual communities extending over a variety of contexts and geographical areas (Wenger et al. 2009). The ability of virtual communities to transverse geographical distances allows for communication and interaction between members of differing cultures, disciplines and backgrounds, who can work from anywhere with mobile or internet coverage (Wenger et al. 2009).

Web 2.0 is the term that describes the second generation of development for the World Wide Web (Hossain and Aydin 2011). It refers to the transition from static HTML Web pages to more dynamic user-generated tools, resulting in increased collaboration and communication speeds. By utilizing the different tools made available by Web 2.0 technologies, knowledge sharing and communication capabilities of virtual communities is enhanced (Hossain and Aydin 2011).

The rise of Web 2.0 technologies has provided the tools to shape the scale and scope of the UIW-virtual community, providing new sources of knowledge on real world activities. This allows the members to situate themselves within the context of the knowledge and link it to the practices performed in everyday life. However, technological advances can only be effective if the correct applications for the right situation are applied in a structured and systematic way (Boulos et al. 2006).

Every virtual community encounters technological challenges and a wide range of user requirements that cannot be met, which can restrict community activity. In addition the diversity of technological skills among members creates further challenges (Koh et al. 2007). A rapid system response time is a necessary requirement in any virtual community, along with user-friendly interfaces and system reliability, all of which facilitate the relationships within the community and the level of activity (Koh et al. 2007).

3.3 Current Collaborative Tools

The rapid increase in the use of Web 2.0 applications includes a number of on-line platforms that have characteristics that align with the concept of virtual communities. These include Social Network sites such as Facebook, Twitter, Flickr and Google+, Apps, Wikis, and blogs. Their ease of use and speed at which they can distribute information, makes them powerful tools for obtaining knowledge (Boulos et al. 2006).

By definition all virtual communities are Social Networks, in that they involve making connections and establishing relationships between the members of the community. The members of Social Network sites form social relationships despite geographical distances and can obtain, interact, contribute and reshape knowledge in a way that is consistent with the norms and standards of their social group (Office of Educational Access and Success 2012) although, virtual communities are distinguished by having a domain as a source of identification, which is not a requirement of a Social Network (Jin et al. 2010). However, social networks can provide a valid and appealing tool that could be incorporated into a virtual community either directly or indirectly as a link, to form connections and stimulate conversation.

Web Apps are mobile applications that use HTML-based software to provide interactivity through portable devices such as smartphones and tablets (Godwin-Jones 2011) and support the idea of '*anytime, anyplace*' learning (Corbeil and Valdes-Corbeil 2007). Recently developed Apps, such as Instagram (www.instagram.com) and WhatsApp (www.whatsapp.com), support photo and video sharing and mobile communication networks (Gachago and Ivala 2015). These apps make connections between broad ranges of motivated individuals and have the potential to establish a collection of knowledge. They are affordable and easy to use and the speed at which they can circulate knowledge, due to their mobile nature (Newman et al. 2012), makes them ideal tools for virtual communities.

A Wiki is a web-based platform whose members can contribute to articles and share dialogue using simple editing tools while contributing to the development of a collection of knowledge (Boulos et al. 2006). The best example of a Wiki is Wikipedia, an online encyclopaedia that can be used a source for obtaining knowledge, allowing members to obtain expert knowledge and engage in learning, although they do not provide the opportunity to establish relationships as social network sites and specific Apps (Office of Educational Access and Success 2012). The ability of Wikis to facilitate the development and transfer of knowledge makes them a potentially valuable inclusion into a virtual community (Office of Educational Access and Success 2012).

A Blog is a contraction of the term '*Web Log*', and is an on-line journal that offers an information-sharing environment using multimedia technology. Blogs feature posting tools, archives of previous posts presented in reverse chronological order, and standalone Web pages with their own unique URL address, to provide an information-sharing tool for deliberation and discussion around a specific topic.

A single user can write them or they can be written by a group of individuals, with entries usually containing dialogue, images and links to other Web sites (Boulos et al. 2006). While the specificity of the topics often results in a limited number of contributors the ease at which Blogs facilitate the linking of knowledge to a potentially global audience through the World Wide Web (Boulos et al. 2006), makes them ideal features to include within a virtual community.

Social networks, apps, wikis, and blogs have the potential to be effective tools for the UIW-virtual community. They are all simple to implement and use, and many are Open source or free of charge, which may be one reason for their popularity (Boulos et al. 2006). Although, none of these tools constitute a virtual community, the context to which they are applied has the potential to facilitate the transfer of knowledge, providing opportunities for virtual collaboration from a wide range of members, who have different needs and preferences of communication. The integration of these applications as part of a framework for learning within the UIW-virtual community has the potential to improve the knowledge sharing experience by facilitating interaction and collaboration (Boulos et al. 2006).

4 Conclusion

The development of the UIW cross industrial virtual community stems from the requirement to engage a wide range of potential members. These include designers, engineers, trainers, managers, directors, support staff, affiliated organisations and customers, that need support in different areas such as community development, communication, collaboration, and sharing of practices. This chapter has identified and described six elements that need to be considered when developing the UIW-virtual community: a clear purpose, quality content, situated context, meaningful conversation, stable connections, along with a stable, high-speed IT infrastructure and web-based tools that promote discussion. Intertwined within these elements are a number of factors that also need attention, including good community leadership and member roles, viewing and posting activity, size, technological tools and applications and offline interaction to strengthen connections. In addition, it is also important that the platform is secure, easily maintained, and easy to use. Nonetheless, virtual communities are only sustainable when they provide benefits that surpass the costs of membership in relation to time. It is important for all members to be proactive at the beginning of a development to establish communication and interest. This may be time consuming especially when recruiting and instructing new members.

This chapter has taken into consideration the requirements of the UIW-project and suggested a potential guide to facilitate the first step towards understanding the basics factors for a successful virtual community platform. However, virtual communities evolve in a natural way over time and cannot be forced into an organisational structure. Changes will take place as the individuals, goals and objectives change within the community. In addition, a change in industrial culture, economic climate or organisational strategy, will also contribute to the evolution of the virtual community (Du Plessis 2008).

References

Allee, V. (1997). 12 principles of knowledge management. *Training & Development*.

Andrews, D. C. (2002). Audience-specific online community design. *Communications of the ACM, 45*(4), 64–68.

Ardichvili, A., Page, V., & Wentling, T. (2003). Motivation and barriers to participation in virtual knowledge-sharing communities of practice. *Journal of Knowledge Management, 7*(1), 64–77.

Boulos, M. N., Maramba, I., & Wheeler, S. (2006). Wikis, blogs and podcasts: A new generation of Web-based tools for virtual collaborative clinical practice and education. *BMC Medical Education, 6*(1), 41.

Brown, J. S., & Duguid, P. (1991). Organizational learning and communities-of-practice: Toward a unified view of working, learning, and innovation. *Organization Science, 2*(1), 40–57.

Brown, J. S., & Duguid, P. (2001). Knowledge and organization: A social-practice perspective. *Organization Science*, *12*(2), 198–213.

Chiu, C. M., Hsu, M. H., & Wang, E. T. (2006). Understanding knowledge sharing in virtual communities: An integration of social capital and social cognitive theories. *Decision Support Systems, 42*(3), 1872–1888.

Corbeil, J. R., & Valdes-Corbeil, M. E. (2007). Are you ready for mobile learning? *Educause Quarterly, 30*(2), 51.

Cox, A. (2004). What are communities of practice? A critical review of four seminal works. In *Fifth European Conference on Organizational Knowledge, Learning, and Capabilities*.

Cox, A. (2005). What are communities of practice? A comparative review of four seminal works. *Journal of Information Science, 31*(6), 527–540.

Cox, A. (2007). Reproducing knowledge: Xerox and the story of knowledge management. *Knowledge Management Research & Practice, 5*(1), 3–12.

Davenport, T. H. (1996). Some principles of knowledge management. *Strategy & Business, 1*(2), 34–40.

Davenport, T. H., & Prusak, L. (2000). *Working knowledge: How organizations know what they know*. Boston, MA: Harvard Business School Press.

Desouza, K. C., & Awazu, Y. (2006). Knowledge management at SMEs: Five peculiarities. *Journal of Knowledge Management, 10*(1), 32–43.

Du Plessis, M. (2007). The role of knowledge management in innovation. *Journal of Knowledge Management, 11*(4), 20–29.

Du Plessis, M. (2008). The strategic drivers and objectives of communities of practice as vehicles for knowledge management in small and medium enterprises. *International Journal of Information Management, 28*(1), 61–67.

Dubé, L., Bourhis, A., & Jacob, R. (2006). Towards a typology of virtual communities of practice. *Interdisciplinary Journal of Information, Knowledge, and Management, 1*(1), 69–93.

Duguid, P. (2005). "The art of knowing": Social and tacit dimensions of knowledge and the limits of the community of practice. *The Information Society, 21*(2), 109–118.

Eckert, P. (2006). Communities of practice. *Encyclopedia of Language and Linguistics, 2*(2006), 683–685.

Fulk, J., Schmitz, J., & Steinfield, C. W. (1990). A social influence model of technology use. *Organizations and Communication Technology, 117,* 140.

Gachago, D., & Ivala, E. (2015). Web 2.0 and social media: Essential tools for contemporary teaching and learning. In *Moving beyond the hype: A contextualised view of learning with technology in higher education* (p. 19).

Godwin-Jones, R. (2011). Emerging technologies: Mobile apps for language learning. *Language Learning & Technology, 15*(2), 2–11.

Gunawardena, C. N., Hermans, M. B., Sanchez, D., Richmond, C., Bohley, M., & Tuttle, R. (2009). A theoretical framework for building online communities of practice with social networking tools. *Educational Media International, 46*(1), 3–16.

Hibbert, K., & Rich, S. (2006). Virtual communities of practice. In *The international handbook of virtual learning environments* (pp. 563–579).

Hildreth, P. M., & Kimble, C. (2002). The duality of knowledge. *Information Research, 8*(1).

Hinton, B. (2003). Knowledge management and communities of practice: An experience from Rabobank Australia and New Zealand. *International Food and Agribusiness Management Review, 5*(3).

Hoadley, C. (2012). 12 What is a community of practice and how can we support it?. In *Theoretical foundations of learning environments* (p. 286).

Hoadley, C. M., & Kilner, P. G. (2005). Using technology to transform communities of practice into knowledge-building communities. *ACM SIGGROUP Bulletin, 25*(1), 31–40.

Hossain, M., & Aydin, H. (2011). A Web 2.0-based collaborative model for multicultural education. *Multicultural Education & Technology Journal, 5*(2), 116–128.

Jin, L., Wen, Z., & Gough, N. (2010). Social virtual worlds for technology-enhanced learning on an augmented learning platform. *Learning, Media and Technology, 35*(2), 139–153.

Koh, J., Kim, Y. G., Butler, B., & Bock, G. W. (2007). Encouraging participation in virtual communities. *Communications of the ACM, 50*(2), 68–73.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press.

Luen, T. W., & Al-Hawamdeh, S. (2001). Knowledge management in the public sector: Principles and practices in police work. *Journal of Information Science, 27*(5), 311–318.

Newman, G., Wiggins, A., Crall, A., Graham, E., Newman, S., & Crowston, K. (2012). The future of citizen science: Emerging technologies and shifting paradigms. *Frontiers in Ecology and the Environment, 10*(6), 298–304.

Office of Educational Access and Success. (2012). Development of virtual communities of practice to support programmatic efforts within university systems. Some considerations and recommendations. University System of Georgia in collaboration with Georgia Institute of Technology. OEAS Working Paper Series #12-01, Atlanta, Georgia.

Østerlund, C., & Carlile, P. (2003). How practice matters: A relational view of knowledge sharing. In *Communities and technologies* (pp. 1–22). Springer Netherlands.

Pan, S. L., & Leidner, D. E. (2003). Bridging communities of practice with information technology in pursuit of global knowledge sharing. *The Journal of Strategic Information Systems, 12*(1), 71–88.

Patel, H., Pettitt, M., & Wilson, J. R. (2012). Factors of collaborative working: A framework for a collaboration model. *Applied Ergonomics, 43*(1), 1–26.

Rothaermel, F., & Sugiyama, S. (2001). Virtual Internet communities and commercial success: Individual and community-level theory grounded in the atypical case of TimeZone.com. *Journal of Management, 27*(3), 297–312.

Scarso, E., & Bolisani, E. (2008). Communities of practice as structures for managing knowledge in networked corporations. *Journal of Manufacturing Technology Management, 19*(3), 374–390.

Stephenson, K. (1998). What knowledge tears apart, networks make whole. *Internal Communication Focus, 36,* 1–6.

Storck, J., & Hill, P., (2000). Knowledge diffusion through strategic communities. Sloan Management Review, 63–74.

Studer, R., Benjamins, V. R., & Fensel, D. (1998). Knowledge engineering: Principles and methods. *Data & Knowledge Engineering, 25*(1), 161–197.

Wasko, M. M., & Faraj, S. (2000). "It is what one does": Why people participate and help others in electronic communities of practice. *The Journal of Strategic Information Systems, 9*(2), 155–173.

Wenger, E. (1998). Communities of practice: Learning as a social system. *Systems Thinker, 9*(5), 2–3.

Wenger, E. (2009). Communities of practice. *Communities, 22,* 57.

Wenger, E., White, N., & Smith, J. D. (2009). *Digital habitats: Stewarding technology for communities*. CPsquare.

Wenger, E., McDermott, R. A., & Snyder, W. (2002). *Cultivating communities of practice: A guide to managing knowledge*. Harvard Business Press.

Wenger, E. C., & Snyder, W. M. (2000). Communities of practice: The organizational frontier. *Harvard Business Review*, *78*(1), 139–146.

Extending the System Model

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Abstract This chapter briefly reviews the state of the art in existing system modelling practice in support of project activities that span a product's lifecycle in different industry types (e.g., large series, small series, one-of-a-kind). Issues of collaboration, gaps in supporting the entire lifecycle and the advantages of defining (and sharing) semantics are discussed. The benefits achieved through the use of models to maintain control of system consistency are described, along with examples of the requirements for using this approach in practice and the potential impacts on company workflow. The maturity and expected advantages of known solutions and proposed extensions to current practices are also described.

Keywords Model-based systems engineering · Product life-cycle · Realizations modelling · Model-driven engineering modelling · Analysis and simulation

1 Introduction

Modelling can be defined as the definition of systems, processes and/or associated methods. Modelling requires dedicated processes, controls and resources. The modelling approach is not necessarily efficient; the associated effort may be lower

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or higher than the related savings or earnings due to improvement in quality, reduction of data exchange effort, reduction of programmatic and technical risks, prototype cost savings, easier feedback from stakeholders and provision of additional services regarding the physical or digital good produced.

The main objective of Use-it-Wisely (UIW) is to enable innovative continuous upgrades of high-investment product-services (see Granholm and Groesser in Chapter "The Use-It-Wisely (UIW) Approach" of this book), which requires:

(1) Customer involvement, including providing the required information, receiving and capturing their feedback and anticipating their needs (one of the seven challenges identified in Chapter "The Challenge").
(2) Understanding the customers' needs and transforming them into valuable innovative solutions through an adequate ideation and creativity process (see Chapter "Complexity Management and System Dynamics Thinking" for details).
(3) An industrial strategic approach to analyse, plan, simulate and anticipate the impacts of the upgrade at the company, market and environmental levels (see Chapters "Complexity Management and System Dynamics Thinking", "Managing the Life Cycle to Reduce Environmental Impacts" and "Collaborative Management of Inspection Results in Power Plant Turbines" for details).
(4) Efficient and effective improvement of technical work to rapidly analyse updates and product innovation from as-required status to realized status through design, verification and post-delivery activities, to provide adequate engineering services for the customer and enter the design, verification or operations loop (the main purpose of this Chapter is to provide the means to respond to this need through a system-level neutral layer for all stakeholders).
(5) Collaborative work between the project teams, customers and project stakeholders, supported by adequate approaches (see Chapter "Virtual Reality and 3D Imaging to Support Collaborative Decision Making for Adaptation of Long-Life Assets" for a potential solution for this need).

The complexity of these elements can be managed through modelling. This Chapter analyses modelling methodologies in the context of innovative upgrading of complex technical systems (e.g., space, airborne, heavy machinery, naval or energy systems).

How can issues related to the technical management of complex systems be handled efficiently? This question has already been answered: Through systems engineering and model-based approaches. Systems engineering is defined by the International Council on Systems Engineering (INCOSE) (Wiley and others 2015) as "an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem […]. Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs."

Systems engineering is not a self-standing activity; it is based on continuous consultation and collaboration with the other technical disciplines and with the program/project-level management. In parallel with this, system engineer activities rely on support from other SE activities for projects in different lifecycle phases.

Hence, an effective system approach relies primarily on the knowledge of those working on the team, a well-defined process, the collaboration, and the availability of required information.

Application of the systems engineering approach has led to the definition of various standards and methods to support all the perspectives that characterize a project. Different standards have matured to support systems engineering activities and reduce errors related to information exchange between different environments.

The model-based approach is a consolidated method to involve all the technical disciplines and relies on modelling to manage complexity and improve the effectiveness of the conception, definition, verification or operational activities using appropriate tools to improve efficiency.

Model-based approaches at the system level that replace or sustain the traditional document-based approach are applied or planned in many fields, such as military, space, transport, healthcare, robotics and telecommunications. This is revealed by the wide variety of universities, agencies and companies that are interested in the field and participate in projects and conferences worldwide (e.g., IEEE Systems of Systems Engineering Conference, INCOSE International Workshop and IEEE Systems Conference).

There are benefits to application of a model-based approach despite the limits to its current scope. The development of a transversal application that profits from modelling as much as possible throughout the entire project or product lifecycle and that unifies different disciplines and those beyond the company boundaries is still an open field of innovation.

This Chapter analyses some of the fundamental aspects of reaching such a vision. Section 2 provides a brief overview of the main types of modelling. Section 3 provides an analysis of the practical implementation of some models, proposes extensions and changes to available models and describes visions for the future before summarizing the conclusions in Sect. 4.

2 State of the Art in System Modelling for Systems Engineering and Technical Simulation

Systems engineering is currently gaining an increasing role in the design process for complex products. System modelling is a multidisciplinary approach that addresses the development of balanced solutions for different stakeholder's needs. This balance involves both management and technical processes, with the main aim of reducing the possible risks affecting the success of a project. Management activities mainly address monitoring development costs, schedules and technical performance, ensuring that the project objectives are met. These processes are related to risk management and decision making activities. Some of the most important activities performed at different levels of system development are:

- Elicit and analyse stakeholder needs
- Specify the system
- Synthesize alternative system solutions
- Perform trade-off analysis
- Maintain traceability

Two of the most interesting and challenging phases are synthesizing alternative solutions and performing trade-off analyses. A clear understanding of stakeholders' needs is crucial because the decisions made during this early definition process can affect the effectiveness of the final product. It is extremely important to understand how the external systems, users and physical environments interface with the system to clearly define the boundary of the system and the associated interfaces. This process is often characterized by the definition of the functions and related non-functional requirements that must comply with the customer requirements (functional analysis), specifying their sequence and ordering. After the functional analysis is performed, development proceeds with the design and testing of components, providing feedback to the specification process. In this manner, the design evolves iteratively towards the definition of the final system solution.

During this process, it is important to clearly define the information flow from the stakeholder needs to the component requirements. The system representation often includes broad stakeholder perspectives and involves the participation of many engineering and non-engineering disciplines. A typical systems engineering team should include viewpoints from each of these perspectives. Teams from different domain-specific fields must work together in a complex environment in which all the disciplines are deeply integrated.

The complexity of the systems drives the definition of a system of systems (SoS) structure in which an individual element is part of another system with a higher level of definition. The appropriate management of system complexity has led to the definition of various systems engineering standards to support different perspectives on the same project. Reduction of as many data exchange errors as possible is one goal of the standards. An overview of some of the most relevant systems engineering standards is available from (Friedenthal et al. 2014).

System modelling aims to define the processes and components that characterize a product through the entire lifecycle and across different domains. The main objective of the modelling standards is the identification of a common language for describing physical system architecture, behavioural models and functional flow.

Model and data exchange are among the most challenging and critical activities during development, especially when different domain-specific tools must interact for data sharing. Different modelling approaches and protocols are currently available in the context of systems engineering. The XML Metadata Interchange

(XMI) specification is an example of such a standard for facilitating model data exchange. In the same manner, the model-driven architecture (MDA) paradigm addresses the definition of standards, ideally enabling the transformation between models and different modelling languages. These efforts address improvement of tool interoperability, modular modelling processes and re-use of system design products, reducing the time and costs of implementing defined components.

Interdisciplinary communication is essential in establishing stakeholder needs. The integration of system modelling environments and frameworks for technical simulation is often affected by the communication between domain-specific disciplines. Communication among those with different backgrounds is challenging but critical for the effectiveness of the developed system. The use of different tools, procedures and formats to model and analyse the same product must be properly coordinated. A common conceptual infrastructure can improve the effective exploitation of simulation environments to support system modelling, ensuring a seamless exchange of data across disciplines.

2.1 Model-Based Systems Engineering

The model-based systems engineering (MBSE) methodology is one of the most interesting approaches in the system modelling domain and shows promising capabilities for management of the phases that characterize a project. The application of the MBSE methodology to support the design of complex systems has been assessed through different research initiatives such as in Space Engineering, a domain characterized by a high level of complexity in which the number of products, people, disciplines and processes leads to an environment that is difficult to manage and control.

The increasing number of variables and stakeholders, often from different backgrounds, make the task of properly managing a complex product very difficult. MBSE provides the basis for a rational organization of work with respect to traditional approaches. MBSE has been defined as (Technical Operations International Council on Systems Engineering (INCOSE) 2007):

> Model-based systems engineering (MBSE) is the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing through-out development and later life-cycle phases.

One of the key concepts in the MBSE approach is Architecting, which is strictly related to the process that drives the identification of design solutions starting from system objectives. This process is characterized by the analysis and technical simulation necessary to evaluate system performances. During this phase, systems engineering work is also affected by policies, principles, procedures, budgets, reviews and other activities. Under these conditions, the system design process can be potentially characterized by omissions, misinterpretations and inconsistencies