A regional remanufacturing network approach

Modeling and simulation of circular economy processes in the era of Industry 4.0

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1. Introduction

The natural resources on our planet are exhaustible and most processes in the creation and processing of products cause emissions. Furthermore, in many areas, including consumer goods, more products are currently being manufactured than are necessary (Marte-Wood 2018; Varga 2020). In design and production of goods, the focus is often still not on a long life of a good or a product or its individual components. This leads to several critical aspect on both, consumption and production side of goods. Waste of products by cause of e.g. optical reasons, leads to increasing market prices due to continuous – and mostly not necessary – scarcity of resources (see Barnett and Morse 2013), environmental pollution (Rathore, Kota, and Chakrabarti 2011), or increasing carbon footprint (Lewandowski and Ullrich 2022), to just name a few negative external effects. The concept of disposable products for single use violates the idea of sustainable behaviour and development - which guided humanity for thousands of years - and inherently weakens society. Of course, economical aspects of production such as value creation, securing employments, or filling societal needs cannot be ignored. However, economic growth against the background of resource depletion, environmental burden, and rising societal pressure demand a radical shift in market strategies and production/consumption behaviour of the actors (Rathore et al. 2011). On the other hand markets, legislation, and a growing societal awareness for responsible consumption and behaviour drive remanufacturing (Steinhilper and Brent 2003). Remanufacturing refers to a "life cycle renewal process that is recognized as one of the most effective green strategies to attain sustainable manufacturing" (Ngu, Lee, and Osman 2020). Within this process, products that consist of assemblies or several individual parts can be disassembled and reprocessed and then refurbished and, if necessary, partially replaced so that they can be re-mounted to the finished product. This way, the entire assembly or dismantled individual parts can be reused. However, manufacturing companies still have relatively few points of contact with the circular economy and are unaware of its potential (Kumar et al. 2019; MacArthur 2013). Furthermore, often cost-efficient assessment of the condition of the individual parts is problematic and assessment procedures after individual part separation are technically complex (e.g., scanning and testing procedures) (Zhang et al. 2019). Furthermore, these assessment procedures are usually only

DOI: https://doi.org/10.30844/wgab_2022_8

available after the disassembly process has been completed. This is where conceptualization, data acquisition and simulation of remanufacturing processes can help. Advance information about product use via feasibility analysis can relieve the disassembly effort in advance and provide information about installed individual parts and their condition. Furthermore, advance information, if accessible, also enables the use of components from non-manufacturers, so that greater interoperability can be ensured. Advance information can thus make the remanufacturing process cost-effective and also provide information on future product design to facilitate the remanufacturing of new product variants. One major constraining aspect is reducing logistic efforts, since these also have negative external effects on the environment. Thus regionalization is an additional but in the end consequential challenge for remanufacturing processes and approaches. In accordance with the problem outlined, this article aims to fill a gap by providing an ex ante approach to local remanufacturing, in particular the design of local remanufacturing chains and the simulation of alternative courses of action, including feasibility study and economic assessment.

This chapter is structured as follows. Section 2 introduces and elaborates on circular economy in general and remanufacturing specifically, thereby, focusing on the remanufacturing circle and its phases. Section 3 presents the local remanufacturing network approach and its phases. The haptic scenario modeling approach and the Centre Industry 4.0 Potsdam (CIP4.0) that are used for scenario specification including feasibility and operating efficiency study will be introduced in Section 4 and 5 respectively. The application of both steps will be illustrated in Section 6, using the example of local remanufacturing of a trailer, instead of scrapping the existing and buying a new trailer. The focus lies on both, implementation of the haptic workshop and a requirement analysis regarding data that needs to be harvested and analyzed according to specific process steps. Section 7 provides a discussion and conclusions.

2. Theoretical Background

2.1. Circular economy

Circular economy is understood as an economic system that replaces the "end-of-life" concept through reduction, remanufacturing, recycling and recovery of materials in production/distribution and consumption processes. In the circular economy, a distinction is made between two types of basic principles (Kirchherr, Reike, and Hekkert 2017). There are the R-frameworks and the systems perspective. In practice as well as in science, different R-frameworks have been used for a long time, ranging from four over six to nine or even ten R (Fig. 1).

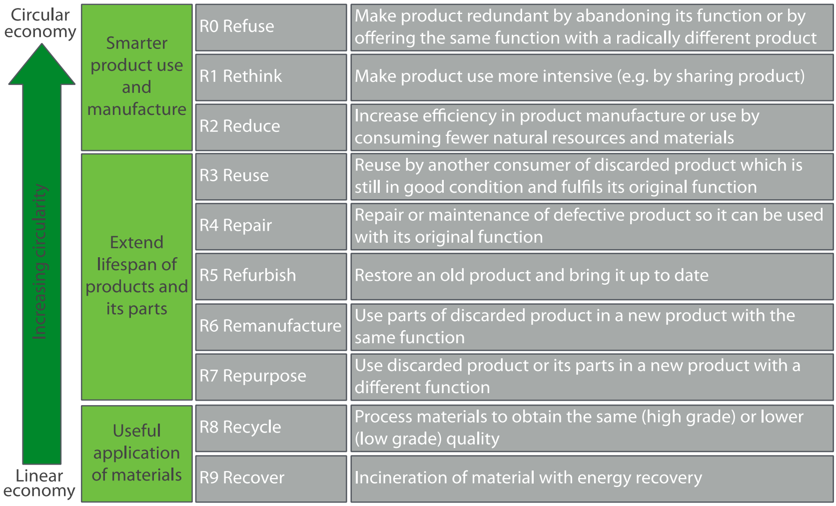

Figure 1: The 9R Framework (following Potting et al. 2017)

All variants of the R-framework have a hierarchy as a main feature, where the first R (which would be "reduce" in the 4R framework) is considered to have priority over the second R and so on (Potting et al. 2017; Sihvonen and Ritola 2015; Van Buren et al. 2016).

From the systems perspective, three systems are identified within the circular economy. Fang et al. (2007), Sakr et al. (2011) and Jackson et al. (2014) differentiate the macro, the meso and the micro system. The macro system responds to the industrial composition and structure of the entire economy. From the meso system perspective, industrial parks are identified as systems or regional level systems (Shi, Chertow, and Song 2010). Here, the process is specifically optimized to increase the local circular economy. Within the micro system perspective, on the other hand, products or individual companies are considered (Jackson et al. 2014; Sakr et al. 2011).

2.2. Remanufacturing

Remanufacturing refers to the repair or replacement of worn-out or "no longer in use" components and modules. According to Johnson and McCarthy (2014) it refers to "the rebuilding of a product to specifications of the original manufactured product using a combination of reused, repaired and new parts". In general, it is the industrial reprocessing of used end-of-life parts and is uniformly defined in the literature in terms of its essential characteristics. Remanufacturing can be characterized by four major aspects (Lange 2017):

(1) The term refers to an industrial remanufacturing process of used parts.

(2) An end-of-life part is remanufactured using standardized process steps, and its original function is restored to it.

(3) The product performance added back to the old part is equal to or of an equivalent to new production.

(4) The same quality assurance measures as in the production of new parts and a guarantee ensure that the remanufactured product or the remanufactured product unit corresponds to the quality of a new production.

Sundin (2004) summarizes the remanufacturing process as an industrial process, through which end-of-life parts are refurbished for reuse. At the end of the process, it must be ensured that the remanufactured product meets the standards of the remanufacturing originals. Remanufacturing is described as a physical measure that restores the function of a defective unit (component, device, subsystem etc.) (Ijomah 2002). In comparison to remanufacturing, the wear stock is not renewed. The term "defective unit" describes the condition in which a unit is incapable of fulfilling a required function.

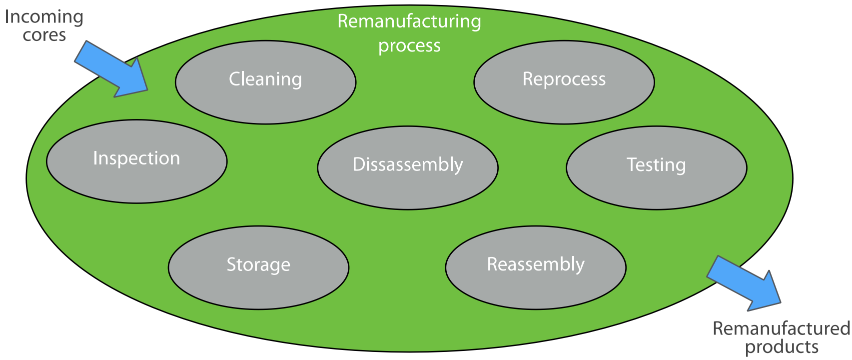

Figure 2: The generic remanufacturing process (Sundin 2004, p. 61)

Figure 2 summarizes the individual steps of the remanufacturing process. The used product that is to be remanufactured usually goes through 7 steps. The sequence of the remanufacturing process depends on many factors such as product design, working environment, volume etc.

Remanufacturing does not start with the product itself, but with the selection of cooperation partners and the organization of work to remanufacture the product. A particular challenge is when remanufacturing is to be established as an element of a regional closed-loop system and when it relies on distributed competencies. This is because it is an ideal and special case if a company can implement all remanufacturing sub-steps efficiently (time, cost, quality) on its own. This is probably only true for very specialized equipment or for large companies. At the same time, it is possible that several regional companies with different competencies can mutually establish a remanufacturing process regionally. This should at least be the goal if one wants to achieve remanufacturing as a standard for many products and not only for a few.

For the diverse and cross-company dissemination of remanufacturing, it is necessary to identify regional networks that can map and embed the regional process for a specific product class. In the case of new initiations, a large number of actors will be relevant who are not aware of the feasibility and economic viability. At this point, participatory group processes are (unusually) suitable to demonstrate the interaction of subtasks distributed among different actors in a remanufacturing process.

3. A regional remanufacturing network approach

The process model for a regional remanufacturing network (RRN) must cover tasks that go beyond the generic remanufacturing approach. The intention is that the remanufacturing is carried out by and with actors from a specific region. For this, the right competencies and respective specialists have to be identified. Specialists and customers must be convinced to participate in such a network by demonstrating feasibility and economic viability. The actual remanufacturing process is embedded in a joint planning for the entire regional network. The process model (see Fig. 3) thus includes tasks of production planning, supply chain management, quality management and stakeholder management, which are ensured by a company in the role of a network manager.

1. A potential trigger for the regional remanufacturing process can be a customer request. Her request is evaluated along with all other requests to identify trends or acute focus orders that should be prioritized or handled with particular systematicity. The customer contact can be initiated at any partner company in the network. Likewise, the needs analysis is shared by all partner companies. The network manager is responsible for the central maintenance of customer data, customer inquiries and analysis routines.

2. Maintaining and expanding contacts with partner companies for the network is another central task for the network manager. The network checks whether the necessary competencies are available to fulfill acute or potential orders. The later planning and execution is not self-organized. The individual business objectives and framework conditions of the participating companies are too dominant for this. Central planning works on the basis of the data that the network participants in turn provide to the network in a self-organized manner. Each company must be aware that involvement in a remanufacturing job is more likely if the information about its own availability and performance is better updated. The network can focus, for example, on specific industries, fail-safety and regional self-sufficiency. These strategic considerations must be understood and supported by all partner companies. For this reason, special network

meetings are held to run through various scenarios and actor constellations. Here, new potentials and effective relationships within the network are uncovered and discussed. The network manager maintains the provided master data of the partner companies and initiates strategic networking.

3. In the feasibility check phase, the technical implementation of the remanufacturing process is reviewed. Central questions concern the correct decomposition of the remanufacturing process and the necessary product and actor data to make this process controllable at all. The verification is carried out by means of a simulation. In the case of a cyber-physical simulation, partner companies are shown directly what workload they have to adjust to or what information still has to be supplied. In addition, problems in the network can be simulated and it will be determined whether they can be handled with the information available in each case. Partner companies should gain confidence here and recognize the need to exchange information with companies that may be competitors beyond and within the network. If it turns out that a certain product cannot be remanufactured or cannot be remanufactured economically, it is jumped back to the first phase. The customer need and the network setup are considered again by the partner companies, so ideally new and missing competencies and information are shared. The network manager organizes the feasibility check and is responsible for monitoring and reworking orders that cannot be implemented.
4. In the distribution phase, the basic feasibility of the remanufacturing process is confirmed. Here, concrete process planning and optimization is carried out. Again, this is done with information about capacities, availabilities and costs from the partner companies. As a result, a concrete remanufacturing process and offers for the workpiece, specifying the companies involved, quality standards, total costs and total completion date will be presented to the customer. If no solution can be created or the offer is not accepted, it is jumped back to phase 1 so that the partner companies can revise the performance of the network.
5. The execution phase includes the actual remanufacturing process. The subtasks will most likely be spatially distributed and processed over several network partners. Thus not only the subtasks but also the transports of the disassembled workpiece must be coordinated. This is done by the network manager.
6. Finally, the delivery and the evaluation of the distributed overall performance in the remanufacturing process take place. Here also the phases 1 to 4 are considered. The compliance and adequacy of costs, times and result quality are checked and considered for future processes.

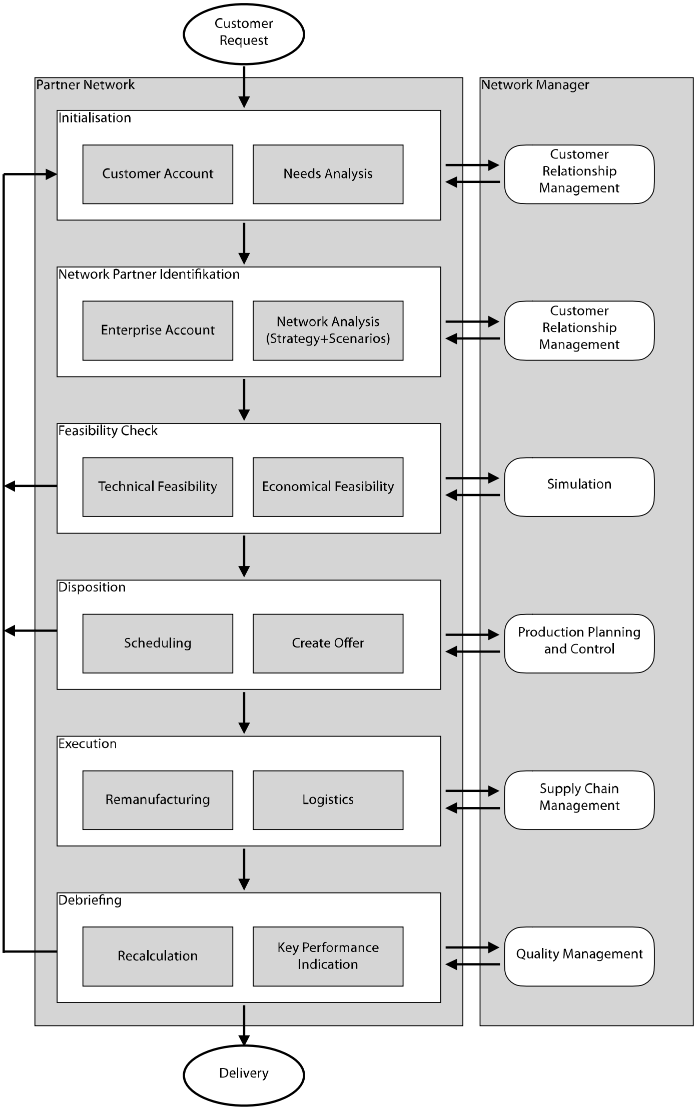

Figure 3: General procedure model for the regional remanufacturing network

The network manager is responsible for operating the application systems required by the network partners in the remanufacturing network. S/he integrates functions and data for the overall process. In operational terms, this means that s/he ensures the availability of data and the executability of the subtasks by the network partners. The network manager is not the central decision-making authority. The initial customer contact goes through the network partners. The network manager only ensures a central customer database and enables evaluations of products and competencies in demand. S/he requests and maintains relevant data from the network partners. The companies themselves decide which data is made available to the network. The same applies to feasibility analyses, scheduling and execution. Many of the network manager's tasks can be automated: Renewal of analyses, data exchange, reminders, scheduling, cost calculations, and performance metrics reporting. Thus, customer contact does not normally have to exist at all. Intensive contact with network partners only takes place in the "Feasibility Check" step. These are strategically important tasks (simulation workshops) in which the network partners, under the moderation of the network manager, determine the partner structure (scenario modeling) and the technical feasibility of the remanufacturing. This sub-step is only complex if new product categories or new partners are included by the network. The network manager is needed as an independent and autonomous actor in the network. S/he has no personal interests in the actual fabrication process and can ensure that critical data from partner companies is used only for planning but not passed on directly to the other network partners.

4. Scenario development workshop using haptic modelling

In the network identification phase, an exchange of knowledge takes place with and between the actors from the region. The aim is to identify potentials and effective relationships. A common understanding of the production network and the various roles of the partner companies involved and to be involved will be generated. To ensure that individual perspectives, concerns, unique selling propositions, advantages and disadvantages can be worked out transparently and presented in a comprehensible way for all participants, a system modeling will be carried out. For this purpose, a participatory approach and a haptic type of representation will be used (Hoffmann 2020). This is based on a synthesis of current methods of haptic thinking (Grunwald 2009).

4.1 Haptic modelling in general

Haptic thinking and modelling methods are hands-on methods in which tacit knowledge and skills are brought into 3D space by modeling with the hands (Harrigan, Kues, and Weber 1986). Lego® Serious Play®, PlaymobilPro®, Design Thinking, Rapid Prototyping and other new techniques are based on the principle of Haptic Thinking (Nerantzi, Moravej, and Johnson 2015).

Thus, the system under consideration is physically mapped so that spatially inspired changes in perspective can be made. Likewise, spatial relationships can be mapped more effectively. System or model elements can be moved or rotated in relation to each other without any problems in order to be able to observe dynamic changes even of actually static system structures. From an experienced-based learning perspective, this haptic modelling fosters a deeper understanding of both, the problem and the solution. The mutual discussions in each phase furthermore enable different ways of approaching the content and thus a deeper penetration of the content, which ultimately leads to internalization of the developed solution.

From a practical point of view, the following advantages for haptic modeling are mentioned (LEGO Serious Play 2022):

- New findings from psychology and neuroscience suggest that cognitive processes such as learning and memory are strongly influenced by how our bodies interact with the physical world.
- Through the creative process of modeling, the brain is enabled to work in a different way. This opens up new perspectives.
- Thoughts, feelings and experiences are made visible and comprehensible in order to recognize room for maneuver.
- Existing thought patterns and thought processes are broken up and questioned, allowing new or different information to rise to consciousness.
- The haptic modeling of contexts that are difficult to grasp can be an important aid in reflecting on difficult or particularly complex topics.
- Visual reminders of important aspects of an issue can support thinking skills.
- By creating objects that can be seen and grasped, the brain reduces the amount of things that need to be considered at the same time. Neuroscientists call this process "reduction of mental workload".

An important design feature of haptic modeling methods is the level of abstraction used. System properties, elements, and relationships can be represented concretely, figuratively, or strongly metaphorically. Model elements in a concrete figurative notation provide a direct recognition value of the modeled object (e.g. model cars for real vehicles). System models created in this way are easier to understand for people who only see the modeling result and were not involved in the modeling process. This usually involves working with predefined modeling elements. Metaphoric modeling makes it possible to create more profound model elements. These are only created during the modeling process and the modeler consciously or unconsciously provides the design features of the element. In order to understand these models, participation in the modeling process and in the accompanying explanation and discussion sessions is necessary. Uninvolved model viewers can only understand the sometimes complex metaphors and model evolution with a lot of effort. A simple, uncommented viewing of the model is not enough to be able to understand the embedded metaphors.

4.2 Concrete implementation

The modeling of regional remanufacturing networks focuses on regional settings. The existing infrastructure, spatial distribution of partner companies, the social environment and landscape specifics are relevant influencing factors for the integration of actors in regional networks. All these aspects are integrated into the model, layer by layer and step by step. The individual sub-steps are always subdivided by explanation and discussion phases of the system modelers involved, so that the group always continues to work with a common understanding and consensus of the scenario presented. As a result, the scenario developed provides all strategic information for a conceptual implementation of remanufacturing cycles in the region under consideration.

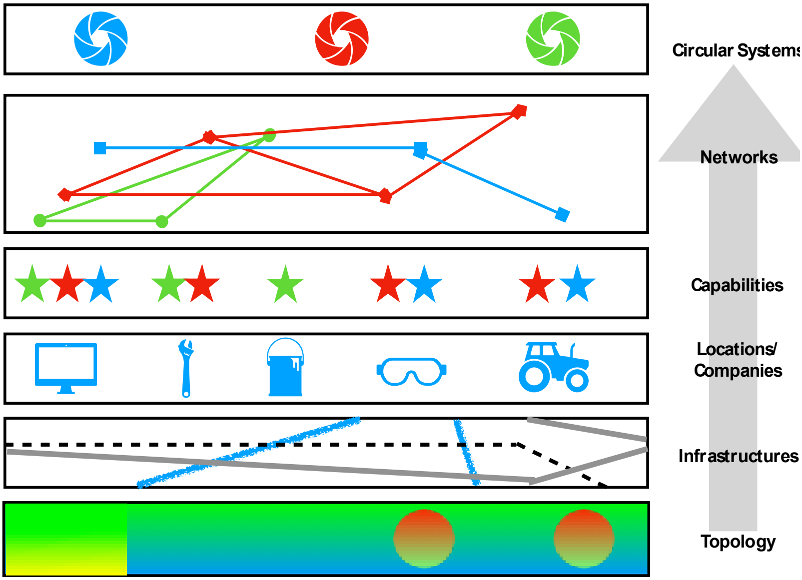

Figure 4: layers of the scenario model

Regional actors that the network manager considers relevant for the upcoming main topics are involved in the scenario modeling. They may be experts in the relevant technologies, people who know the region or those affected by the remanufacturing process. In turn, these can be manufacturing companies or craft enterprises that can technically carry out sub-steps in the remanufacturing process. At the same time, logistics service providers, trade, administration or potential/current customers can also be considered relevant and involved.

The step-by-step scenario modeling takes place in eight phases, of which one is a preparation and introduction phase and another is a post debriefing phase (cf. Fig.

4). Thereby, modeling materials are used in all phases, which allow a most direct figurative representation (cf. Fig. 5).

- Briefing: Begin with an introduction of the participants. This is intended to make transparent the expertise, perspectives, and interests present.
- Phase 1 (topography of the region): In this step, participants create literally the underground for the model. It represents a shortened image of the given topological situation in the considered region. Landscape and agricultural areas, settlement and commercial areas, forest and water areas are designed. It should not and must not be a direct image in the form of a true-to-scale map. It is only concerned with aspects of general land use, the degree of development and urban sprawl, and special natural features in the region.
- Phase 2 (infrastructure of the region): In this step, the main transport routes are added: roads, railways, waterways. Likewise, enterprises and institutions of generally great importance for this region can be added (large enterprises, administration, universities etc.).
- Phase 3 (commercial landscape of the region): In this step, companies are placed in the scenario which, in the view of the participants, may be of importance for remanufacturing work. Prepared overviews with companies from the region are suitable for this. The participants decide for themselves how many companies are to be modeled. Additional modeling can be carried out in later phases.
- Phase 4 (capabilities of the regional companies): In this step, the necessary competencies and capabilities are placed in the scenario that are required for the remanufacturing of specific products. The participants select a product or a product class and analyze its components. The relevant technical competencies are identified for each component. The identified competencies are assigned to the previously modeled companies. Competencies can be modeled redundantly. Unplaced competencies are noted as services to be sourced supra-regionally.
- Phase 5 (networking): The relevant competencies are now networked to a concrete processing sequence. Logistical aspects must be taken into account (transport, intermediate storage, assembly stations). Alternative networking can be designed to optimize routes, fail-safety or work distribution.
- Phase 6 (cycle extraction): In this step, the enterprise network developed for the product category under consideration is transformed into a separate model. The generic remanufacturing cycle (cf. Fig. 2) is applied. If the participants recognize that central actors, competencies or connections are missing, the scenario model can be improved.

- Debriefing: In this step, the modeling process is reflected upon. Participants consider the resilience and practicality of the model created. This can result in measures that the network manager has to implement: active integration of relevant companies into the real partner network, inclusion of the product group in the remanufacturing portfolio of the partner network, elimination of unsolved competence gaps.

By jumping back into phase 4, more than one product group can be worked on within one workshop and in one scenario model.

Figure 5: Modelling material

A landscape modeling technique was developed that uses inexpensive, easily procurable materials on the one hand and self-designed special building blocks on the other (see Figure 5). With the help of a laser cutter, for example, transport elements such as cars, ships, airplanes, and trains are provided. When selecting the different materials, it was important on the one hand that the materials fit coherently into the design of the model. On the other hand, the materials should inspire the participants to model, by being of high quality and therefore pleasant.

Certain technical and interdisciplinary concepts are introduced into the model development process via predefined special elements. This modeling approach fulfills the essential requirements such as modeling speed, expressiveness, traceability, material availability, haptics, modeler interaction and systematic procedure.

Due to the fact that all participants model simultaneously, there are no dominating actors in the designing phases who can drive the entire model in a certain direction. And in the concluding explanation rounds, each participant gets similar time shares to present their ideas and model extensions.

5. Scenario specification in the Centre for Industry 4.0 Potsdam

5.1. Centre for Industry 4.0 Potsdam

The *Centre for Industry 4.0* comprises a hybrid simulation environment, which combines the benefits of virtual and hardware simulation and components in order to design or analyse industrial manufacturing processes or value-adding networks (Lass and Gronau 2020; Teichmann et al. 2018). The main physical components are the work pieces and the machine tool demonstrators as well as transport lines which connect various machine tool demonstrators. The demonstrators with their ability to communicate in different ways and the flexible transport system provide an effortless integration of hardware components into the overall system. Additionally, digital technologies and Internet of Thing (IoT) devices such as AR/VR glasses, tablets, smartwatches, robots, smart products and machines are integral elements (Ullrich et al. 2019). The software is designed for a quick integration of sensors, actuators, and other devices using standard communication protocols such as OPC UA. The hardware components provide the interfaces for an easy connection and integration of new hardware. This simulation environment is used to investigate process layouts and identify alternatives (Gronau, Theuer, and Lass 2013; Lass, Theuer, and Gronau 2012) or as teaching and learning environment in which workers can experiment with new processes, new technologies, and thus acquire new skills (Gronau, Ullrich, and Teichmann 2017; Teichmann, Ullrich, and Gronau 2019). Learning scenarios can be implemented via process models (Thim, Ullrich, and Gronau 2020) and are used to convey skills and competencies (Gronau et al. 2017; Ullrich, Teichmann, and Gronau 2020; Vladova et al. 2022).

The CIP4.0 allows the design of different processes and scenarios that create the required learning situations with the help of the didactic concept and specifically promote the intended knowledge of the individual learning modules. If the hybrid model factory is now explicitly supplemented by a didactic concept, a flexible learning factory emerges which, as an immersive learning location, follows learning-theoretical methodology and greatly reduces the theory-practice gap for learners.

5.2. Simulation in the Centre for Industry 4.0 Potsdam

The simulation environment of CIP4.0 uses a hybrid approach for factory modeling. This approach combines a physical model factory with computer-aided simulation. For each component of the simulation, the most suitable form of model implementation can be selected in each case. In this way, necessary production objects (machines, workpiece carriers, etc.) can be configured, which - regardless of whether realized as a physical original, as a physical model or in virtual form - are integrated into the necessary variant of the production process and provide the desired scenario in the model factory.

A practical implementation of this hybrid concept consists of physical and computer models, which form the main elements, the so-called demonstrators (Lass 2018). The interaction of demonstrators enables the construction and simulation of an entire production process. A demonstrator consists of a box configured with the parameters of a particular production object. Interface and communication modules enable interaction with other components and allow various additions, e.g. further modules (such as additional sensors or actuators). Figure 1 illustrates the basic structure. The visualization of the machining process takes place on both sides of the demonstrator. The user interface for human-machine interaction is located on the top of the demonstrator and displays relevant product, process and job information (Teichmann et al. 2022). The demonstrators exist in stationary form as well as in mobile design (Fig. 6).

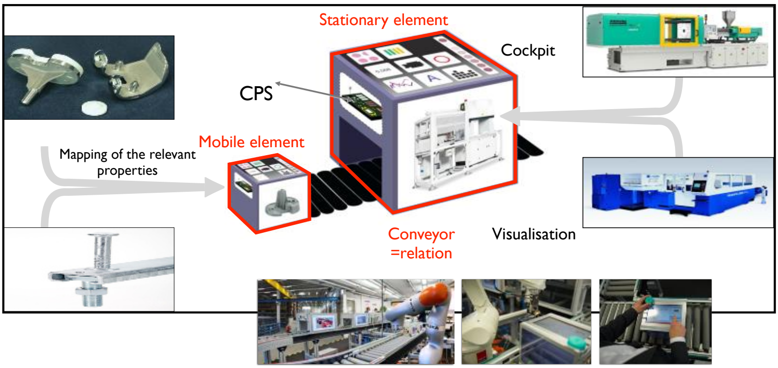

Figure 6: Principle of hybrid simulation

Using transport devices (e.g. roller conveyor) a real material flow in different layouts is possible. Experiences show that the transport by roller conveyor is perceived as very typical for a factory and has a positive effect on the immersion. Furthermore, numerous components from the Industry 4.0 toolkit are available as elements for modeling. For example, assistance systems can easily be configured that use mobile technologists such as tablets or AR glasses and allow the actors to experience the functions and advantages of modern and future production systems interactively in the middle of the production process or train them in their use.

The hybrid approach and its implementation in the CIP4.0 model factory have already proven themselves in competence and skill development (Vladova et al. 2022), testing of IoT-technologies (Bender, Teichmann, and Ullrich 2017) and have proven to be a suitable basis for use within continuing education (Gronau et al. 2017; Teichmann et al. 2019), simulation of production process alternatives (Gronau et al. 2013) or value networks (Lass 2012). Thereby, both general feasibility and economic efficiency of the processes can be investigated. For this purpose, feasibility studies can be conducted to assess the practicality of a specific process layout, configurations, or settings within a manufactory or within manufacturing networks, emphasizing especially respective strengths and weaknesses. Using distinctive manufacturing key performance indicators and realistic numbers for prices of refurbishing, replacement, and labour costs specific alternatives can be evaluated and therewith developed from conceived to feasible and lastly to economically efficient local remanufacturing alternatives. Therefore, the specific remanufacturing scenario is modelled and then simulated in the hybrid simulation environment, focusing on the good to be remanufactured and its components, all the associated actors in the remanufacturing process, their specific characteristics and relations.

6. The case of regional trailer remanufacturing

The strategic network planning and the work-preparing feasibility analysis represent the innovative methods within the general process model. Their application is therefore illustrated by a small case study on the remanufacturing process of agricultural trailers.

6.1. Specific haptic Workshop

The (fictitious) initial situation is that actors from a rural region want to ensure the remanufacturing of agricultural machinery. They do not want to rely on supra-regional manufacturers/ OEMs, but to use the competences and structures distributed in their own region. The method of scenario modeling is used to identify the necessary competencies for the remanufacturing of agricultural machinery and the corresponding partner companies. The remanufacturing process must be modeled technically and logistically in the region and with actors from the region.

According to the procedure model for scenario modeling, all phases have been conducted by the participants. Step by step, the scenario had developed. And at the end of each phase, there was an exchange of ideas on the newly added elements. As a result, a common understanding of the region and the remanufacturing network was successively developed (see Fig. 7).

After creating the overview of the remanufacturing cycle, the workshop participants discussed in detail the most effective and efficient process for remanufacturing the agricultural trailer, the consequences and results of which were then simulated haptically using scenario modeling.

- Through the modeling and discussion in the group format, new views and insights could be developed.
- Actors previously considered irrelevant could be identified as options for special tasks within the remanufacturing project.
- The spatial arrangement of the work sites could be directly included in considerations, so that alternative routes and sequences could be identified.
- The professional complementarity or redundancy of network partners could be structured.
- Experiences of cooperation among network partners could be exchanged.
- The regional distribution of workloads and tasks could be discussed.
- Technical competences that are missing in the region could be identified. Supraregional or alternative solutions could be discussed.

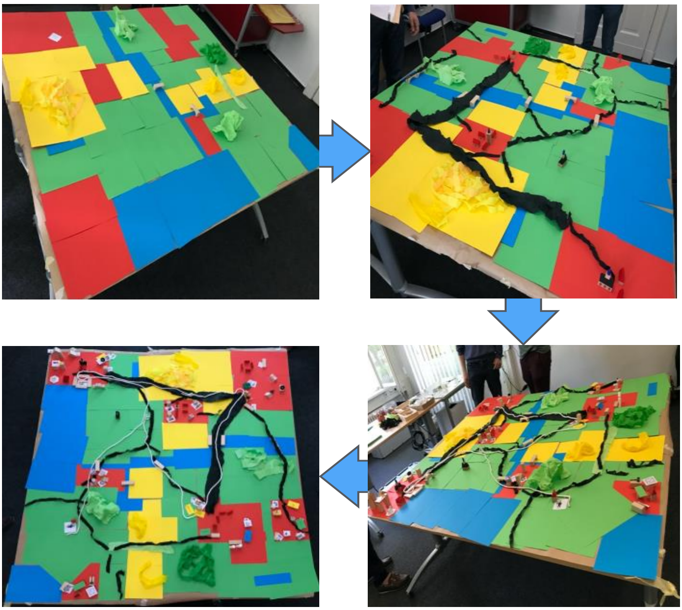

Figure 7: Insights into the haptic modeling workshop

Discussions on the aforementioned aspects were triggered by the scenario modeling. As a result, the participants additionally exchanged and linked their individually bound contextual knowledge about the region and its companies. A single network manager would not have been able to take these hidden potentials and sensitivities into account for a centrally implemented network planning.

6.2. Requirements for simulation in ACI4.0

How to plan a factory for regional remanufacturing networks when the network is not yet fully established? How to show the advantages and possible challenges to avoid a cost-intensive ramp-up phase? To answer these questions a simulation is the appropriate method of choice. Simulation as a method for mapping production processes and investigating effects that cannot be studied to the same extent in reality is widely used in engineering (Richter 2017; de Sousa Junior et al. 2019). There exist several requirements for simulation of regional remanufacturing networks (see Table 1).

The cyber-physical simulation of the remanufacturing network offers different insights into technical feasibility than classical planning systems. MES and production planning and control systems are designed to use provided order data to optimize overall planning. In regional production networks with several, loosely coupled players and constantly new product classes, optimization has a downstream significance. The focus is on the many imponderables which, unlike in a purely internal production line, cannot be controlled centrally. The danger of incomplete data from individual network partners, of failures of network partners and of technically induced changes in the remanufacturing steps primarily require confidence-building measures. The network actors (companies and customers) must be convinced that the network is sufficiently resilient or capable of change to be able to deal with such influences.

Requirements
Support of real-time decisions
Adaption to fast changing environments
Prediction of material flows
Usage of data from digital manufacturing systems (databases, traceability systems, process models)
Reusable generic remanufacturing algorithm

Remanufacturing information model
Access to data collected in manufacturing by sensors

Table 2: Requirements for the simulation of regional remanufacturing networks (Goodall, Sharpe, and West 2019)

Classical production assumes that all parts are in pristine condition. This is not given in remanufacturing processes. So the much higher degree of autonomy which comes with cyber-physical systems allows to flexibly reroute parts and assemblies according to their state and designation dynamically. This is where cyber-physical simulation concept can show its strength. Both purely virtual and cyber-physical simulation approaches initially require an internal model of the production process and a set of rules for controlling the production process. CPS approaches, however, have higher degrees of freedom in introducing disturbances. Disturbance scenarios do not have to be planned in advance and started according to schedule, but can be brought about at any time by direct physical interaction: Workpieces disappear, are delayed, are misrouted or are damaged; production facilities are overloaded, work incorrectly or fail completely. Network partners can jointly participate in such a hybrid simulation. In this way, each individual participant can act out his or her highest-rated hazardous moments. And the network partners together can see how the control concepts created for the production network independently deal with such disruptions.

The regional remanufacturing processes will not occur in large numbers and will always be carried out in different constellations. Thus, it does not make sense to learn exclusively from errors that have occurred. Structural deficiencies, faulty planning, lack of information and capacity bottlenecks can be largely uncovered by CPS simulation and eliminated before they actually occur.

We will collect data from exemplary remanufacturing processes and bring them together in a virtual remanufacturing network to show the advantages of this approach.

7. Discussion and conclusion

Inefficient production processes, the economical need of growth and throw-away society unnecessarily shorten limited natural resources. Globalization, additionally, has negative external effects on the environment. In semi-conductor industry e.g., a wafer is transported three times around the world before it is delivered to the customer. Such kinds of local optimizations of production processes in value creation networks lead to overexploitation of the environment. A promising and rising – yet the underlying principle is already hundreds of years old – approach is the remanufacturing of goods. Under the umbrella of circular economy, this approach allows for decreasing resource consumption. For being consequent, this approach needs however be implemented in a local context to decrease logistic efforts and thus negative effects on the environment.

In this paper, we presented a local remanufacturing approach that allows for reducing resource consumption, fosters local companies, and efficiently provides solutions for regional re- and further usage of goods. Therein, a particular focus was on identification of local networks and feasibility study of the remanufacturing process. Therefore, haptic modelling for identification and hybrid simulation in the Centre Industry 4.0 in Potsdam for feasibility study was presented. The approach to substitute a usually solely technical planning process with open workshop formats is new. This is, however, particularly helpful for the participants and affected persons to understand the existing complexity of such processes. Furthermore, the simulation of remanufacturing networks for conducting feasibility study and identify not just conceivable but practically implementable options in hybrid simulation environment is also new.

In principle, the RRN approach is suitable for a wide range of products. In particular, however, this is strongly dependent on both the regional demand and the existing competencies. If there is a large regional demand for a certain product category, it makes sense to build up an RNN, even if supra-regional competencies have to be included. If there are good regional competencies, an RRN can be created, even if the demand for this product category comes less from the region but supra-regionally. Example of extreme cases are cheap mass-produced appliances (e.g. coffee machines) on one side and large custom-made products (e.g. production equipment) on the other side.

That the competencies are composable within an RRN is a necessary criterion. The sufficient criterion is then the economic efficiency. The challenge of the network manager is to fathom out over time how large the order volume and the product complexity must be or may be in order for the network to cover its costs.

The RRN approach can be scaled down, so that production networks for certain product categories are not elaborately simulated, but are implemented directly without any claim to profitability. However, this only works if there are network partners who carry out certain activities on a voluntary basis (e.g. small equipment remanufacturing in open workshops).

Especially if the CIP4.0 approach is realized, it probably makes sense to start with large, medium-complex products. As experience is gained, the RRN can then be extended to more complex items or to mass-produced items. For both orientations, it makes sense to also consider non-economic remanufacturing scenarios (reprocessing of low-cost items for citizens with the primary goal of waste avoidance. Or reprocessing of special machines that are existentially important for the regional economy). This would then even be an advantage for regional resilience, so that one can help oneself better in extreme situations.

A detailed listing of the potentials and challenges of regional remanufacturing networks is shown in Table 2.

Potentials	**Challenges**
Strengthening of regional economic and business relations	Additional coordination effort
Independence from supra-regional supply problems (material, knowledge, transport)	Additional IT infrastructure is required
More transparency in value creation	Sometimes too close interdependencies
Regional ties as a performance incentive	Regional performance (quality, costs, capacities) usually lower than that of supra-regional companies
RRN experience remains in region and grows	In case of small markets there is only little demand
Better traceability of costs, deadlines, and quality	Each region needs a method-competent network manager, if central RRN services are to remain regionally located
Process experience, methodology and IT architecture can be transferred to other regions and does not need to be rethought	Willingness of network partners to communicate necessary information
Networking of regional partners to remanufacturing services with supra-regional unique selling point	Dependence on good data from network partners
Uncovering regional synergies and emergences	Network partners need infrastructure to be able to transmit data

Systematic collection of experiential knowledge	Sensitivities in regional competitive situations have a greater impact
New business models for regional companies	Exposure of company internal key figures and structures to other network partners
Independence from supra-regional manufacturers / OEMs	Dependence on IT and network managers to manage complexity efficiently
Potential to integrate semi-professional actuators (hobbyists)	
Scalable for many/few products and for large/small products	
Degree of own contribution can be determined and implemented	
Regional optimum is in the foreground	
Existing organizational concept, in case supra-regional supply totally fails or is overloaded (e.g. emergencies)	

Table 3: Potentials and challenges of regional remanufacturing networks

Haptic modeling of socio-technical systems is not the norm in business informatics or production science. However, it offers several advantages over digital models and two-dimensional representations, which can be directly experienced in any modeling workshop. These advantages could also be confirmed for the application context of remanufacturing.

- Scenario modeling is a strategically significant negotiation process. There are individual interests and personal sensitivities. Personal presence of the actors involved is thus basically advantageous. Points of view, ideas and opinions are not only expressed through words, language and facial expressions. The way in which certain aspects of the model are designed with the hands also sends out tacit signals to the other participants.

- Because placing elements and establishing supply connections implies affirming business relationships, working with haptic elements is analogous to making "tangible" statements that are placed in the model.

- Modelers can change geospatial perspective at any time. Models have a different effect on the viewer depending on the angle of view or distance. Zooming in digital models does not correspond to the usual physical, intuitive movements and then distracts from the object of observation.

- Likewise, conflicts (technical but also economic) between the actors are directly revealed and dealt with in a playful context. More formal meeting scenarios tend to escalate opposing positions.

- Since regional networks are involved, the balanced selection of the involved competence carriers also plays a role. Their appropriate spatial distribution in the region can be a key acceptance factor in ensuring that this service model is perceived and used by customers from the region. This is because each network partner acts as it were for customer acquisition.

- The modelling process is immensely efficient and effective. This is because all actors work on the model at the same time and initially no time has to be invested in negotiating design decisions.

- Model creation is not dominated by those who have the writing cursor, greater market power or rhetorical competence. In fact, the model becomes useful only when the smaller companies or niche competencies are integrated into the model.

- These workshops are about a service from the region for the region. Even independent of this business model, the network partners form an economic community due to their spatial proximity to each other. Bringing regional companies into conversation with each other is always a sensible measure. This also initiates other opportunities for cooperation. From the point of view of the remanufacturing network, these meetings and the "playful" cooperation are an important measure for making the players personally known to each other and building trust.

Future research activities comprise modelling and simulation of further goods to enrich the process library, the implementation of a deeper detail planning to also assess intra logistic and remanufacturing process variants within the network participants.

Acknowledgements

This research was conducted as part of the junior research group ProMUT "Sustainability Management 4.0 - Transformative Potentials of Digitally-Networked Production for People, Environment and Technology" (grant number 01UU1705B), which is funded by the German Federal Ministry of Education and Research as part of the funding initiative "Social-Ecological Research".

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