From Linear to Circular: A Holistic Framework for Sustainable Transition in the AEC Sector.

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Abstract

This research explores the transition towards a Circular Economy (CE) within the Architecture, Engineering, and Construction (AEC) sector, highlighting the significance of System Dynamics Modeling (SDM) to navigate the complexities of sustainable practices. By proposing the adoption of CE as a holistic approach to decline ecological imbalance, it addresses the challenges faced by the AEC industry, including material flow complexities, lack of awareness as well as systemic barriers to implementing CE practices. By leveraging SD's capability to model complex systems, this research aims to understand and optimize the interactions within CE, providing insights for long-term sustainable strategies and a system wide overview. The methodology includes a comprehensive literature review, stakeholder interviews, and a Use Case analysis. By identifying key elements, processes, and system-level, this paper outlines a framework for mapping CE onto SD. As a result, a High-Level-System (HLS) approach for policy adoption is developed. In a broader context this HLS is conceptualized in a Multi-System-Framework (MLF), to develop sustainable strategies and to smooth out and identifying horizontal and vertical bottlenecks in CE implementation.

KeyWords: Circular Economy, System Dynamics, Multi-method modeling, sustainability, Integrated Assessment Framework, DiCYCLE

Introduction

Since the initial observation of *Earth Overshoot Day (EOD)* on December 29, 1970, the date has progressively moved to earlier in the year, indicating an increasing demand on our planet's resources. In 2023, *Earth Overshoot Day* fell on August 2, reflecting our consumption of resources at 1.75 times the Earth's capacity to regenerate them annually. This consistent overshooting for more than half a century presents substantial dangers by disturbing the earth's ecological balance, leading to increased CO2 emissions and resource depletion (European Commission 2024). The shift in resource consumption by +75% from 2023 compared to 1970 indicates that countermeasures are necessary. Although the *EOD* for 2021 and 2022 has been pushed back by 6 and 5 days, respectively, this shift is negligibly small (Statistik Austria 2023). This is especially true considering the conditions of the global economy's downturn between 2020 and 2021, which was on average 30% during the worldwide Corona pandemic (IW 2022). This shows that economy and resource conservation are only partially correlated, and a reduction in economic growth do not determine a decrease of primary resource consumption. A concept is needed to close the loop of used and needed resources. This is pursued in the approach of the Circular Economy (CE). However, the implementation of a Circular Economy, especially in the Architecture, Engineering and Construction (AEC) sector faces challenges. Due to its nature of complex material flows (Charef et al. 2021), lack of knowledge and awareness (Minunno et al. 2018), supply- and value chain complexity and fragmentation (Hossain et al. 2020), a system-wide overview is a necessity. Additionally, current social behavior regarding CE practices, further complicate the adoption of sustainable methods and slowing systemic changes down (Joensuu et al. 2020). Moreover, the structure of the AEC industry causes communication and cooperation barriers as well as basic process flaws and overall systematic problems. In combination, hindering effective circular economy implementation (Govinda & Hasanagic 2018, Korhonen et al. 2018, López Ruiz 2020, Sigrid Nordby 2019, Tazi et al. 2020, Wahlström et al. 2020).

To overcome these challenges, System Dynamics (SD) can be introduced. Through its ability to model complex systems, identifying feedback loops, accumulation processes, and time delays, it comes in hand for concepts like CE. It offers insights into how changes in one part of a system can affect the whole system or blind spot over time. This approach is usable across various fields, to generate information and data, including business, public health, engineering, and environmental studies, to develop long-term strategies (Richardson, 2011).

By modelling different elements and their interactions, it is possible to understand how a system evolves over time, which is particularly important for long-term decisions such as those made for the CE. SD serves as a critical tool for understanding and optimizing long term systems, offering insights into the complex interplay between environmental, social and economic activities (Bossel, 2004). This approach facilitates the transition from traditional linear models to more sustainable circular practices by modeling its nature, behavior and possible outcomes.

The problem addressed in this research deals with the scope a system-dynamic model should fulfill to be applied in the CE for AEC in order to test methodological approaches and develop sustainable strategies. By taking the various process chains, actors and the overall system into account, therefore criteria and basic requirements for the use of System Dynamic Modelling (SDM) in the CE for construction can be developed. Furthermore, simplifying the transition, by showing the possibilities and range of CE strategies trough a SD approach. The aim of this research is to propose a systematic approach and framework for using SD in CE in different granularity. This can provide researchers and decision-makers with a methodological principle for developing CE strategies and models. The research aims to increase the understanding and application for a combination of CE and SD and especially of the scope for CE transition.
Achieving a system equilibrium through an integrated pattern of adjustments among various factors, even those that appear to be in conflict, necessitates the consideration of the entirety of the situation. It is necessary to consider both quality and quantity, by including the conflict between the present and the future as well as the balance instant and partial interests against long-term sustainability (Huxley 1962).

Methodology

The presented research follows an integrated research approach, including a comprehensive literature review, interviews with 12 stakeholders, as well as a closed-loop Use Case analysis. To create the presented Use Case, a workshop was conducted, where the details of individual process steps were documented and the current challenges in CE, reading the Use Case, were discussed. By analyzing the Use Case and overlapping the findings within the literature review the development of an overarching approach for the translation of a CE processes into SD method is stated. By comparing different approaches for CE using SDM and utilizing the literature background, a schematic approach for mapping CE onto SDM is developed. In a final step the develop schema is elevated to a higher level, by generalizing CE processes to system dynamic principles (CE $\Rightarrow$ SD). Throughout this 3rd step, a generalized framework approach is developed. In combination with the previous developments, this research outlines essential properties and concepts for mapping CE processes onto SDM across various levels of detail.

Literature review of SD for AEC

Background

The current research in circular economy and construction waste demonstrates the benefits of dynamic modeling and systems-oriented methods for CE (Guzzo et al. 2020). Studies like Ding et al. (2018) show SD models effectiveness in assessing environmental benefits in construction phases. For waste management Marzouk and Azab (2014) research shows, that an SD approach is a useful tool to investigate waste management strategies. Yu-jing et al. (2012) illustrate SD's use in analyzing construction project complexity, identifying crucial loops and control mechanisms for better planning and control. Guzzo et al. (2022) propose similar SD based methods for evaluating circular economy transitions, assisting policymakers and businesses in understanding complex relationships for the electronic industry. Bassi et al. (2021) emphasize approaches in assessing the multifaceted impacts of CE regulations, including local dynamics and behavioral changes.
To summarize, the integration of systems-oriented, holistic, approaches, combing construction practices, life cycle analysis, waste management, social behavior and interdisciplinary methods, are a necessity to provide a comprehensive view of the industry's challenges and opportunities (Ma et al. 2022; Marzouk and Azab, 2014; Meshref et al. 2023; Sing et al. 2019; Thomassen et al. 2022; Alamerew et al. 2018, 2020; Ghosh et al. 2023; Zohu et al. 2020).

In the following literature review concerning CE and SDM an overarching approach was made, to explore the field and possibilities of SD inside CE and reverse.
The integration of SDM into CE development provides a comprehensive approach to manage the complexities involved in transitioning towards a closed loop economy. The study by Xu et al. (2009) illustrates this integration through the development of a SD Multi-Objective Programming (MOP) model (SDMOP) for regional CE planning. This innovative approach emphasizes risk analysis through sensitivity analysis, enabling the optimization of parameters critical for CE planning. By applying this model to a region, the researchers demonstrated its practical utilization in real-world settings, showcasing how SD can effectively manage the interlaced dynamics of CE initiatives on a territorial level.

On the consumer side, the research conducted by Kuah and Wang (2020) investigates the acceptance of CE practices. They highlighted the vital role of consumer engagement in the success of CE, pointing out concerns regarding product reliability and quality. Despite these challenges, there is a notable willingness among consumers to support CE practices, driven by environmental and cost considerations. Therefore, underscoring the necessity for targeted strategies to enhance consumer trust and acceptance.
From a business perspective, Geissdoerfer et al. (2018) explored the sustainability performance of circular business models (CBMs) and supply chains. They propose an integrated framework that combines CBMs with circular supply chain management to foster sustainable development. This framework highlights, how different business models can affect different circular supply chains across various loops by closing, slowing, reinforcing, balancing or narrowing them. These different possibilities of supply chain loops illustrate the complex interplay between business strategies and CE

implementation among processes, as well as the interplay among them self.

Coming from a business perspective, the conceptual foundations and application of CE tries to combine economic activity with environmental wellbeing, focusing on process redesign and the circularity of materials. Nevertheless, current approaches tend to neglect the challenges related to the social dimension and potential unintended consequences (Murray et al. 2015). Furthermore, a crucial inside can be gained by the comparative analysis of CE policies in China and Europe by McDowall et al. (2017). The study reveals different priorities and approaches for the implementation of CE, underscoring the critical importance of developing CE policies that are both tailored to regional specifics but also align with broader sustainability goals. It also highlights the importance of comprehensive policy frameworks that address not just waste management and recycling but also innovation, consumer behavior, and business models in a broader spectrum.

Addressing the broader challenges and limitations of the CE concept, Korhonen et al. (2018) provide a critical analysis from the physical perspective on resources. They identified significant challenges, such as the laws of thermodynamics and system boundaries, arguing that while CE has the potential to attract business and policy development, more conclusive scientific research has to be conducted, to ensure that contributions, towards sustainable practice, are based on physical aspects. This critique calls for a more organized scientific basis for CE, emphasizing the need for a comprehensive understanding and overview, to tackle the key factors for the physical implementation of CE.

Key Values

An overview for essentials and key values as well as parameters for a SD approach in the AEC sector is necessary. Additionally, to the pervious mentions papers, specific work on SD integrated into CE, are reviewed, to gather the key elements for an SD approach in the industry.

Firstly, it is necessary, that all key stakeholders and input parameters within industries are identified, to tailor system dynamics models effectively to circular economy practices (Guzzo et al. 2022). By doing so the interactions of actors and there surrounding can be pictured (Stermann 2002). Tapia et al. (2019) and Bossel (2004) further enrich this integration by emphasizing the importance of considering territorial dynamics as well as adopting a future-focused approach to problem solving, instead of a historical-focused approach.

Based on that, the importance of revisiting traditional linear relationships to uncover potential indirect connections between stocks, stakeholders or parameters is crucial for a holistic understanding of the system, to reveal hidden dynamics that could significantly impact the CE's effectiveness (Guzzo et al. 2022; Bossel 2004). Especially important for such hidden dynamics, is the awareness for interventions and their outcomes across social, economic, and environmental indicators (Bassi et al. 2021).

Babader et al. (2016) discuss the integration of behavioural theories into SDM, which provides a more nuanced understanding of the factors that drive social change and are essential for the success of CE initiatives. As Bassi et al. (2021) point out, new dynamics may emerge as a result of social interactive change, emphasizing the evolving patterns that must be considered in system dynamics models to accurately predict the outcomes of CE interventions and policy design. Therefore, integrating Cognitive Behavior Theory (CBT) with the Theory of Planned Behavior (TPB) into SD in CE is necessary (Babader et al. 2016).

From the perspective from CE onto SD, material flows and usage efficiencies, can enhance the visibility and focus on quantifying the interactions among different elements and processes, therefore enhancing the understanding of their dynamics and impacts (Alamerew et al. 2020, Jacobi et al. 2018). As a result, feedback loops can be identified, allowing for the recognition of patterns and the influence of different elements on each other. (Guzzo et al. 2022). To detect these patterns, a counterintuitive approach as well as focusing on long-term outcomes is often a necessity (Sterman 2002), especially, in open and closed loop processes. This long-term stimulation is crucial, to learn from their development and utilize this information in policy development (Franco 2019; Pfaffenbichler 2011). Regarding this information Forrester (1962) emphasizes the importance of information-feedback control trough an iterative process.

Lastly, Tapia et al. (2019) published the ESPON Report, in which the 10 R’s for CE are overlapped with a territorial system behaviour, showcasing the possibility of interlinking CE principles with a basic SD approach.

The combination of SD and CE represents an opportunity, to linking the interlaced modelling capabilities of SD with the resource efficiency and sustainability goals of CE. By deep diving into both fields, they can complement each other, therefore enhancing our understanding and implementation of sustainability practices across industries.

Use Case

The Use Case of “re:parkette”, as a part of the ongoing research project DiCYCLE, started with the removal of large sections of parquet flooring from the old Vienna Directorate. In combination of a following project, which involved installing approximately 1200 square metres of parquet flooring for a construction company in Austria. The project of “re:parkette” was developed. The idea of mechanically treating and refurbishing individual strips of parquet for reuse in new construction projects accrued from this project. This concept was taken to the product development stage through a partnership with a flooring manufacturer. Additionally, a specialized flooring company played a crucial role in the process by collaborating on the removal and installation of the flooring, completing the product lifecycle. To effectively organize the dismantling process, the three companies involved - the 'circular design' company responsible for evaluating and collecting reusable parquet, the flooring manufacturer, and the parquet installation company -

collaborated to produce a manual. The manual aimed to incorporate a standardized method for collecting the flooring into their business operations. In April 2022, the first example of remanufactured parquet was presented to the public, indicating its readiness for market launch. Efforts are currently underway to expand the distribution network to different areas, demonstrating a scalable approach to integrating sustainable practices into the construction and renovation sector. This case study exemplifies the potential of collective innovation in advancing CE principles within the AEC industry.

Use Case analysis:

The process starts when an order is placed for the dismantling, recover, or refurbishment of old or used parquet floors. Builders, floor layers, or property owners request the expertise of a the 'circular design' company. Additionally, the 'circular design' company, searches for potential stockpiles, them self. In the following, a comprehensive and expert assessment of the potential or existing stockpile of flooring is then conducted to evaluate the parquet's current state. An expert compiles data on the parquet's quantity, quality, and additional attributes, which are recorded on a datasheet. Moreover, third parties can contribute their datasheets for potential stockpiles of recyclable parquet floor to the online platform, which is incorporated into the 'circular design' company database for further verification and processing.

Based on the gathered data, a decision is made on whether the parquet floors should be renovated in place, removed for reuse, or discarded. If in-place renovation is deemed feasible, there may be a change of plan, where the flooring is removed and reused due to an initial misjudgement or a change in the owner's plans. However, this approach can sometimes result in inadequate removal by untrained individuals due to time or budget constraints, which reduces the amount of material available for reuse.

The 'circular design' database with all relevant information about the disassembled parquet flooring, including its quality and quantity etc. is then transferred into the manufacture data system. However, it is currently not possible to establish an automated digital data exchange between the source database and the refurbishing manufacturer, which is a critical next step, due to the absence of a viable solution.

Upon receiving details about the quality and availability of the flooring, the manufacturer integrates this data into its Enterprise Resource Planning (ERP) system. The system is then used to assess market demand for the product and plan production and sales strategies accordingly.

In conclusion, the decision to demolish or dispatch to the manufacturer depends on the preceding stages outlined by the 'circular design' company. For existing structures, either demolition is initiated, or the stockpiled inventory is sent to the manufacturer for further processing. The manufacturer manages the dismantled product within its facility, with the aim of restoring or refurbishing it. The product is then either stored in the warehouse or sold directly to consumers, depending on the alignment with sales strategies and production capacity.

Results

The results are divided into 3 parts. The first part presents the findings in relation to the Use Case. In the second part, these conclusions are combined with the findings of the SD/CE literature research (background and key values) to develop an overarching process framework. In the final step, the framework developed in step 2 is further adapted to a holistic approach in CE.

Results Use Case

Through the evaluation of the Use Case process as well as the conducted interviews, the first part of the results can be presented as the following.

By analysing the process sequences, the participants, the upstream and downstream processes as well as the product itself, individual levels have been identified. At a higher level, three layers can be recognized, consisting of Element, Process, and System, which are, as seen in Figure 1, encompassed within their hierarchy. These layers showcasing the fundamental parts of a closed loop framework, which have to be considered in the development of a CE/SD model.

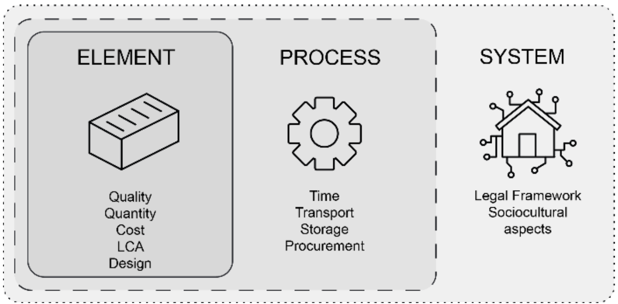

Figure 1. Levels of Reuse

Considering these levels separately, the following definitions apply:

Element: The element-related category refers to the properties and characteristics of the element itself. A element is the smallest unit in the loop and the foundation to creating, maintaining and enhancing the circularity of a system. The element is a discrete component which is the subject to an action. In a CE the goal is to keep an element as long as possible in the loop. It is the part of the CE that is subject to disassembly, recycling, remanufacturing, refurbishing, and reuse strategies. In short terms, it is the smallest subject answering to the 10 R’s in the CE.

Process: The process-related category refers to the various processes and procedures associated with the manipulation of elements or execution of an action. It is a systematic series of actions within a system. Subject to a process can be manifold. A process is used to transform a current sate into another, including data transfer, material manipulation or other activities. A process is defined by time consumption, manipulation or action in any way. It is the carrier or initiator for the element and related actions. A process in CE can be divided into sub processes from one stakeholder to an overall process, where all stakeholder interconnect with each other.

<u>System:</u> The system-related category refers to the overarching systems and frameworks within the reuse of existing elements. It refers to the interconnected and interdependent network of processes, stakeholders, policies, technologies, and practices. It involves a wide range of actors, including businesses, consumers, governments, and non-governmental organizations. The System encompasses the entire lifecycle of an element and provides the boundaries and rules for the process.

As a result of these levels, the following criteria and parameters have been defined for each level. These criteria are crucial for the development of SD models in the context of CE, as they make it possible to identify and consider both direct and indirect influences, as well as the resulting mechanisms and delays in the system. The criteria are to be understood as those that must be systematically and mentally run through when mapping a CE process onto a SD model. This ensures that the influences within the system boundaries are considered.

<u>Element-Related Criteria</u>

- Quality Determination: Rapid and effective assessment of the quality of elements for decision-making.
- Construction Details and Methods: Knowledge of construction methods and details.
- Documentation and Plans: Presence of detailed plans or spec sheet to simplify the evaluation.
- Material Characteristics: Assessment of materials in terms of their suitability for reuse, e.g., strength, weight, chemical properties, etc.
- Dismantling Ability: Ability of disassembly and removal of elements.
- Availability and Quantity: Accessibility and quantity of available elements.
- End of Life: The possibilities for reuse, recycling, thermal utilization, or disposal
- Additional Benefits and Applications: Creative rethinking in reprocessing materials on an element level → Consideration of the 10 R's for possible material flow opportunities

<u>Process-Related Criteria</u>

- Access and Inspection Opportunities: Long-term and unrestricted access to elements for assessment and extraction.
- Storage and Logistics: Planning and coordination of transport and storage, aligned with the characteristics of the elements (e.g., weight, size).
- Time and Coordination: Synchronizing reuse with schedules such as demolition or construction site timelines as well as overall time delays.
- Decision-Making and Risk Assessment: Rapid and partly intuitive decisions, considering logistical and material constraints.
- Distribution and New Material Flow: Consideration of new ways of distribution- and utilization possibilities.
- Economic Value Chain: Monetary evaluation of processes and its impact on individual process steps.
- Stakeholder and Relations: Interconnection, responsibilities and relationships among stakeholders involved in a process.

<u>System-Related Criteria</u>

- Contract and Agreement Design: Development of contracts and agreements.
- Community Engagement and Local Distribution Channels: Involvement of local communities and use of local distribution channels.
- Supportive Policy: Consideration, development or adjustment of a regulations, policies and overall framework.
- Stakeholder and Relations: Interconnection, responsibilities and relationships among stakeholders involved in a superior system regarding the sum of processes.

This list of criteria do not represent all factors that should be considered for mapping a CE process on SD. This requires further Use Case analyses and research. The criteria listed here are based on the "re:parektte" Use Case and the conducted literature research.

Higher-Level System and policy adoption

Building up on the Use Case analysis and in order to capture and relate the different levels and stakeholders in the construction industry, a schematic approach is required. The following schema links the levels developed from the Use Case with the findings in the literature. This has allowed a schematic illustration of how the different levels and stakeholders are interrelated and how policies evolve over time. Based on Bossel (2004), Figure 2 was developed.

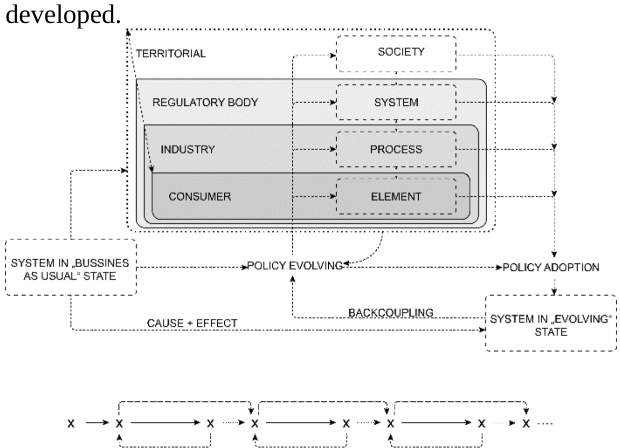

Figure 2. High-Levels-System in CE

The conceptual framework outlined in Figure 2 illustrates the interlaced hierarchy of relationships and levels that define the surrounding for SD in a CE. Starting point is the System in a *business as usual* sate, which has to transferred in a System in *evolving* sate over an *cause and effect* pathway. However, between these states, a process trough different levels and feedback loops has to be run trough. In this system, four main levels have emerged, which are the *Territorial*, the *Regulatory Body*, the *Industry* and the *Consumer*. In this context, they are described as objects. These objects influence each other in a bottom-up, as well as a top-down approach. As Figure 2 illustrates, starting by the level *Consumer*, each object is encompassed by the next higher level, resulting, that the *Territorial* contains every sub layer. To fully address CE every layer has to be included in the development of a system to model CE in the AEC industry.

Furthermore, each Layer has a subject implied. The subject's *Element, Process, System* and *Society* are describing the impact subject for the correlating object. As previous described, the subject's *Element, Process* and *System* are crucial to model a CE approach. Additionally, system dynamics are influenced by regional specificities, as highlighted by Tapia et al. (2019), underscoring the importance of adapting CE strategies to local and social dynamics. Therefore, the subject *Society* is crucial as a factor, to measure or model territorial influences and behaviour changes in a CE System. At the societal level, the integration of Cognitive Behaviour Theory (CBT) with the Theory of Planned Behaviour (TPB) emergences, to developing future-oriented problem solutions as contrary to the development of strategies of historical problem solutions and behaviour. Based on new dynamics related to behavioural change in the current society. The combination of territorial and behaviour results in an overarching level, *Territorial*, as they are both regional specifics.

As illustrated in Figure 2, the *Society* influences the *System*, as well as vice versa, yet in a weakened from. On layer deeper, the *Regulatory Body*, determining the *Industry*, reflecting the influence on industry practice trough legislative framework, that encourage or mandate circular processes. Therefore, simulating the effect of legislation on industrial actions presents a significant challenge, while also serving as an influential stepstone to estimate the impact of particular laws or strategies. In combination with the interplay of different characteristics of the *Industry*, such as the material flows and the identification of feedback loops, based on repetitive steps, CE strategies can be made quantifiable. Enabling a deeper understanding of the industry's circular transformation and repercussions, based on real data feedback and process evaluation.

The *Consumer*, in this context, is the "user" of an element, which is a product of a series of processes from the *Industry*. Therefore, the *Consumer* is the first one "using" an *Element*, maintaining the *Element* and finally discarding the *Element*. Consequently, the *Consumer* is the Object, which keeps the *Element* in the cycle. As a result, each level above sets the framework conditions and prerequisites so that the *Customer* keeps the *Element* in the cycle for as long as possible. A Consumer can be an individual with a single element, as well as a building-owner holding a assembly of Elements (Building). Crucial to mention is, that the *Society* consists of individual *Consumers,* therefore the levels are indirectly linked, resulting in the pervious mentioned possibility of a bottom-up as well as top-down approach.

Figure 2 shows, that the four layers with their objects and subjects are encapsulated, functioning as a Higher-Level System (HLS) for the underlying process of policy evolution. The HLS is the main channel, decision making should go through. Simultaneously the HLS influences the evolving police throughout its behaviour, both direct and indirect. This feedback loop is illustrated by the dashed arrow pointing towards *policy evolving*.

The System in *business as usual* represents the current CE with the current HLS. Trough continuous feedback loops the hole system evolves based on a changing HLS and therefore changing policy, resulting in *policy adoption* and finally in a System in an *evolving* sate. The HLS with its underlaying process of policy development is in a constant iterative process through feedback loops and adoption and therefore in continuous *backcoupling* with *policy adoption*. This iterative process of the whole system is illustrated in the lower part of Figure 2.

Figure 2. postulates that the CE can be transformed with the help of proper strategies and regulations but with society and its behaviour and regional circumstances as the main influence.

Multi-System Framework

By combining the findings from the Use Case, interviews as well as the HLS, a second, more holistic, framework can be developed. Throughout the analysis of the Use Case it became clear that the process of an element is not proceed in an encapsulated system. It is subject to upstream and downstream conditions. In the Use Case for example, it is the conditions under which a building is dismantled, or how the parquet flooring is ultimately distributed. It can be concluded that in a functioning closed-loop economy, a number of different processes must be interlinked. Resulting in an overarching "process" in the AEC sector, which is divided into many individual processes with respective process steps. Furthermore, these processes are forming a system in which they take place or are regulated. If this is combined with the complexity and fragmentation of the AEC and the iterative processes evaluated in HLS, a Multi-System-Framework (MSF) can be postulated. This MSF, as illustrated in Figure 3, shows that a functioning CE must be orientated towards a large number of processes. At a superior level, multiple processes can form a system, as previously mentioned. Therefore, the transitions from System 1 to System 2 to System N are essential interfaces which have to be addressed in CE. In particular, the transition from one subsystem to the following. Based on this, the problematics of bottlenecks (BN) can be introduced. As shown in Figure 3, the bottlenecks are located at the transition between the systems. They

represent the changes, obstacles and junctions which have to be address and considered in a boarder context to set the course on a functioning CE, without encountering unbearable challenges or reaching a point where progress is exponentially hard. This is also based on the characteristics, that a circular economy can only function in a cycle where all elements and processes are maintained, as the failure of one component affects all downstream elements and processes as well as the future upstream, due to the loop nature of CE.
This MSF intends to illustrate that the overall system must always be taken into account when developing solutions and strategies for isolated processes, to minimize the risk of misleading strategies.

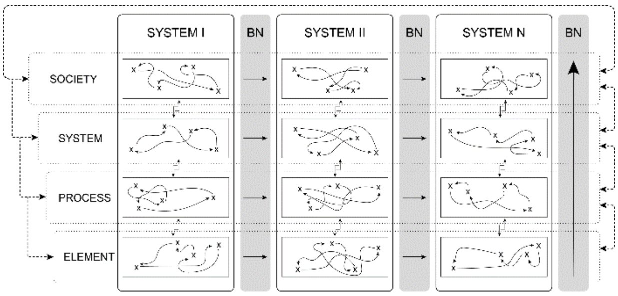

Figure 3. Mulit-System-Framework in CE

Based on the development of the HL-System the MS-Framework is as well a multi-layered system, including the four levels *Element, Process, System* and *Society*. As a result, the degree of granularity within the MS-Framework upholds the structure of the HLS in a vertical hierarchy.
Figure 3. illustrates that the initial obstacles to overcome are the horizontal BNs. Once these have been managed, a process - spanning several systems - can achieve its goal of CE. Once this process is complete, the issue of vertical BNs arises. The issue addressed here, is to elevate the system encompassed in one layer, to the next level to proceed the CE concept of the underlaying layer to the next higher sequence of processes and system. Based on this schematic, the circular economy requires passing through each level to benefit from the next. This approach can vary between top-down and bottom-up, depending on simultaneously development or achievements in a different layer, system or process. Therefore, a continuous feedback loop in horizontal as well as vertical direction is possible. Thereby, again, the crucial aspect is an iterative process and knowledge exchange through all layers and Systems. This process is necessary to establish a functional circular system in the construction industry that integrates all actors, processes, and elements in an economic, social, and politically regulated and balanced process.
Overall, this schematic serves as a conceptual model for understanding the flow and transformations in a CE, highlighting the interconnectivity of processes and potential bottlenecks that need to be managed to achieve an efficient and sustainable system and to prevent silo thinking.

Conclusion

In conclusion, this research highlights the importance of adopting a System Dynamic approach to effectively navigate through the complexities inherent in transitioning towards a Circular Economy in the AEC sector. By conceptualizing CE as a dynamic, multifaced and adaptive system, supported by a interrelated network of stakeholders and processes, it underscores the need for a holistic SD model. Thereby combining network- and dynamic thinking to capture the characteristics of CE. Such a model not only enhances our understanding of CE but also serves as a vital tool for decision-makers in the industry, political, and economic spheres, enabling them to handle the transition's complexity through closed-loop thinking and simulation-based experimentation.

Furthermore, the aim of this research was, to underscore the significance of a supportive environment that evolves through learning, iteration and interaction with the system over time, to shift from the current *business as usual* practices to an *evolving* state that embodies the principles of circularity step by step. Further, SD can be utilized for CE to coupling various research methodologies and fields, thereby promoting an interdisciplinary connection. By the development of certain constraints and conditions, this paper tries to lay the groundwork for further research, to develop a holistic SD within a defined system boundary. Throughout such a model, the illustration of the CE-system can be made possible, resulting in a more accessible approach for the public to understand and see the needs of CE. This can influence society's behavior towards a greater form of an intrinsic motivation to achieve Circular Economy.
This research tried to provide a comprehensive framework, capable of capturing the full spectrum of development and interference possibilities in CE transitions, serving as a base layer for future research. Further research directions can include the evaluation of bottlenecks, quantifying CE processes, evaluating the impacts and solutions through scientific quantitative simulation and Use Case analysis, as well as the continuing unravelling of the processes and influencing parameters in CE.
Throughout continuing exploration and refinement of integration from SD in CE, we can create more resilient, sustainable strategies that benefit society as a whole. As a result of such a strategy, the cyclical characteristic of CE can progressively synchronize with the structural setup of our built environment and therefore pave the way for an economy, that is both sustainable and structurally steady. This synchronization can happen by merging SD and CE principles enables the testing and refinement of approaches within CE to provide tools, theories and perspectives to tackle the complexities of sustainable development.
The overall aim for SD in CE should be to develop a robust model for a more comprehensive understanding of our complex world and dealing with it sensibly. Therefore, an increased focus on systems thinking, prioritizing the core issues of *Elements*, *Processes,* overarching *Systems* and *Society* within the CE

framework is needed. The utilization of both panoramic (MS-Framework) and granular perspectives (ML-System) as well as each process by itself, is necessary to address the multifaceted challenges and opportunities that define this transition, to gradually bent the linear economy into a functioning loop without running into a bottleneck or dead end.

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