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The Use of System Dynamics to Verify Long-term Behaviour and Impacts of Circular Business Models: a Sharing Platform in Healthcare

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Abstract: Static approaches for business modelling cannot cope with the increased complexity commonly linked to Circular Business Model (CBM) innovation. In this research, we aim to investigate whether System Dynamics (SD) modelling is suitable to verify the long-term behaviour and impacts of CBMs by applying it to a particular case study. The dynamics of a closed sharing platform for healthcare institutions are modelled and simulated. The dynamics of sharing durables and consumables is represented through (1.) a causal explanation of the behaviour, (2.) the structure of stock and flows and (3.) verification through simulation. Results indicate substantial potential impacts for durable products. Products lifecycle time and the number of use cycles determine this behaviour. The use of SD enables experimenting with CBM in this case by connecting the dynamics of sharing to the use of resources and its impacts. Further research should verify the possibilities to design enhanced CBMs from interventions evidenced by modelling.

Introduction

Business model innovation is the bottom-up engine towards a Circular Economy (CE). Circular business models (CBMs) provide the rationale so that companies and individuals can consistently operate and benefit from value retained in products and materials (Bocken et al., 2016; Lüdeke-Freund et al., 2018). Increased complexity is commonly linked to CBM innovation. It arises from the need for collaboration in ever more complex networks of stakeholders (Geissdoerfer et al., 2018), the possibility of rebound effects (Bocken et al., 2016), and from increased risk due to capital tied up in resources and reliance in future people behaviour inherent to solutions of increased lifetimes (Linder and Williander, 2015).

Still, business modelling methods rarely focus on sustainability (Evans et al., 2017) and current research still offers a static view of business model innovation for sustainability (Roome and Louche, 2016). In this work, we aim to investigate whether System Dynamics (SD) modelling is suitable to verify the long-term behaviour and impacts of CBMs by applying it to a case study of a closed sharing platform for healthcare institutions. SD, a modelling paradigm used in environmental sciences (Meadows et al., 1972) and business management (Sterman, 2001), is used to demonstrate the potential impacts of CBMs while decreasing the efforts and risks of experimentation. Through modelling and simulation, the multiple parties involved in business model innovation can further understand the potential impacts and its reasons when aiming for long-term sustainability.

Background

System Dynamics (SD) is a continuous modelling approach capable of representing and simulating specific aspects of systems based on feedback-rich structures and delays among decisions and their effects (Sterman, 2001). Causal Loop Diagrams (CLDs) and Stock and Flow Diagrams (SFDs) are the two major diagramming conventions in SD. CLDs use variables and links to represent the feedback structure of a model (Lane, 2000). SFDs enable simulations of stock accumulations over time, according to structures of inflows and outflows (Lane, 2000).

While the former is effective in communicating and explaining the system's behaviour, the latter enables verification of behaviour through time.

The SD lenses can be used to make sense of the Circular Economy. The CE is a regenerative system where the flow of resources, waste and emissions are minimised through circular initiatives (Geissdoerfer et al., 2017). Stocks can be used to represent the many types of resources in a system. Products, parts, consumables constitute some of the stocks to be maintained in a CE. By contrast, flows depict the transformation processes that affect such stocks: extraction, manufacturing, discarding.

The circular initiatives, in fact, slow or narrow the flow of resources and closing their loops (Bocken et al., 2016; Geissdoerfer et al., 2017). In other words, the CE involves both creating mechanisms to delay flows of resources as to enabling outflows of a given stock to be used as inflow of a less aggregated one. In order to slow the flow of resources, delay systems can be conceptualised to decrease throughput, retaining the value of products. Maintenance services work as delays for functional products to become obsolete, increasing their lifetime as useful stocks. In order to close the loops, outflows of a given resource become inflow of a less aggregated one, retaining value in the parts or materials levels. Recycling makes use of the outflow of obsolete products to be used as inflow of material production.

This resource-oriented perspective, if connected to the dynamics of a given business model, enables the capability of verifying and potentially experimenting with the impacts of CBM implementation through the application of SD.

Research Methodology

A case study of long-term behaviour and impacts of the sharing platform provided by Company A for healthcare institutions was performed. The scope of analysis is the use of a sharing platform in a small-sized hospital with 400 employees.

Medical devices contribute to the high use of resources and waste generation in diverse ways (Moultrie et al., 2015): through recyclable uncontaminated devices ending up treated as hazardous waste, the release of toxic substances from the end-of-life of PVC-based devices, and the Waste Electrical and Electronic Equipment (WEEE) from electromedical equipment. Sharing assets is one of the CE strategies that can be applied to the medical industry towards a more sustainable healthcare system.

A protocol using the SD modelling process proposed by Pruyt (2013) was applied. The following steps were employed: problem identification, model conceptualisation, model formulation and model testing. The sustainable business model canvas presented in Bocken et al. (2015) was applied in order to set the scope of inquiry. Interviews (four) with the platform co-founder, press releases and secondary sources as research papers from the medical and SD knowledge areas were used for model conceptualisation and testing. Stock and Flow Diagrams (SFDs) were developed to simulate model behaviour over time. Causal Loop Diagrams (CLDs) were employed to highlight the structure originating such behaviour. The reasons for the simulated long-term behaviour are discussed. Recommendations for intervention in the real system and initiatives for model enhancement are pointed out. These are derived from the increased understanding enabled by modelling and simulation.

Results

Problem identification: articulating the issue to be addressed

In the platform, different types of resources can be shared: from low-value single-use products to highly complex electromedical devices. Two types of sharing platforms are available: (i.) Closed sharing platforms - where customer companies pay a tailoring fee and annual maintenance fee for a platform to be used by internal teams, and (ii.) Open sharing platforms - where customer companies pay a monthly fee to access products from a network of healthcare institutions. Following five years of market experience, where they mainly acted as evangelists of Circular Economy and Sharing Economy to clarify their business model, Company A is focusing on implementing closed sharing platforms in Hospitals.

Their current challenges towards expansion are:

- Understand the dynamics of sharing in a closed platform;
- Connect the dynamics of sharing to potential environmental impacts of platform use;
- Identify levers so that the potential positive impacts of sharing can be consistently improved.

Model conceptualisation: a theory of behaviour

The model structure about the dynamic aspects of product use dealt by the sharing platform is represented in Figure 1.

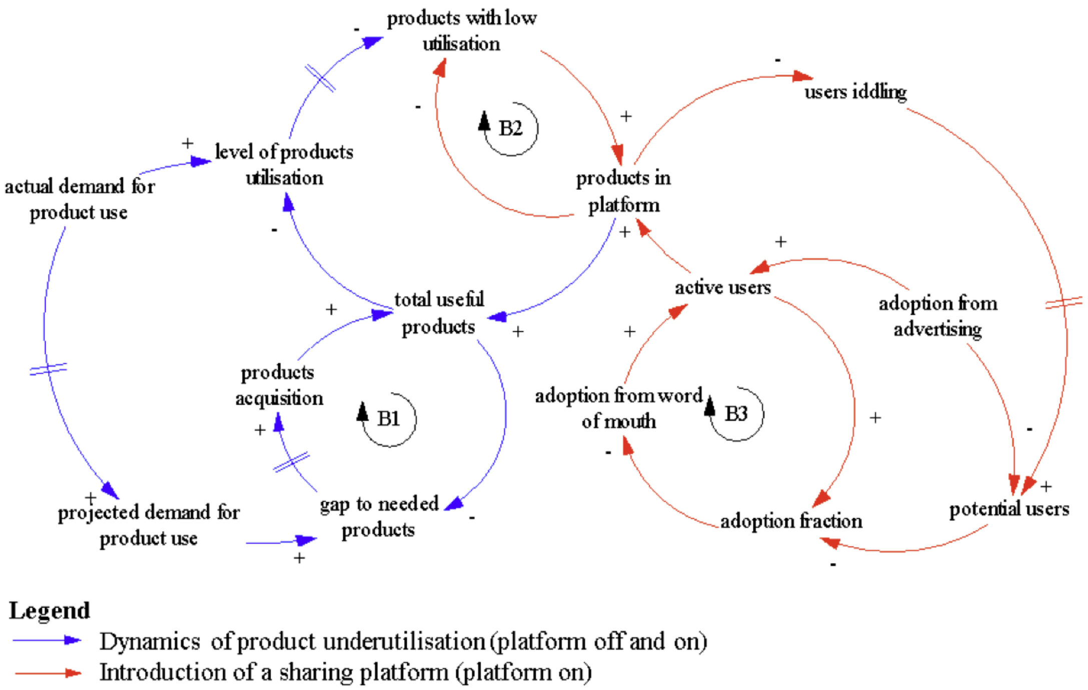

Figure 1. Causal Loop Diagrams (CLD) of sharing platform use.

Low utilisation occurs when the actual demand for product use is lower than the total amount of useful products. Products become underutilised after a while in that condition. It is worth distinguishing durables and consumables. Durables may not be used often – way less than their capacity, and consumables may be kept away from use while approaching the end of their shelf life.

In a hospital which does not use a sharing platform, these underutilised products become obsolete after little use, and the number of total useful products is balanced by acquiring new products to meet projected demand – see B1 in Figure 1.

By contrast, in a hospital with a sharing platform in place, products with low utilisation can be turned into useful products for users that otherwise would not have been able to access them. This mechanism is of limited impact because it is a balancing loop – see B2. Active users in the platform register products and make use of them. The mechanism of internal user acquisition is thus critical. Users adopt the platform through two mechanisms: word of mouth and advertising. Adaption through advertising occurs mainly exogenously. Word of mouth is a powerful mechanism, which is balanced when the adoption fraction is high – represented by B3. Finally, users may get idle and stop using the platform for some time when they have a negative experience, i.e. when they cannot find products they want in the platform. Some idle users may never try the sharing platform again because of the bad experience.

Model formulation: a simulation model of the theory of behaviour

Towards simulation, the model is organised into four sub-models on the sector diagram represented in Figure 2. Sub-models are parts of the model that could be conceptualized and tested separately, so that modelers could deal with less complexity before assembling the full model. It helps to provide a general description of the Stock and Flow Diagram (SFD) model. Sub-models are: 'use of resources', 'users in platform', 'sharing within a platform' and 'KPI system'. Variables that connect sub-models are made explicit.

The 'use of resources' connects the model to the CE framework by making the stocks the and flows of resources explicit in a healthcare institution. It contains the total stocks of functional, underutilised, and obsolete resources. Acquisition, obsolescence, utilisation and discarding are the main flows.

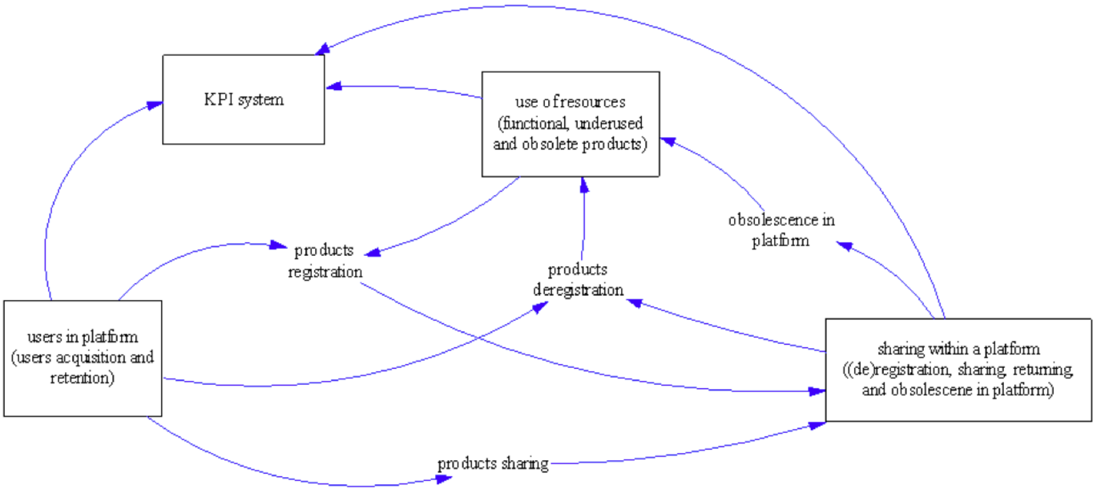

Figure 2. Sector diagram of the four conceptualised sub-models and relationships among them.

The 'users in platform' represent the mechanisms for user acquisition and retention in a closed platform. The Bass diffusion model (Borshchev and Filippov, 2004; Sterman, 2001) is applied to represent the mechanisms of word of mouth and saturation in such a process. Advertisement efforts pushed forward by Company A are used to initiate/reinforce such dynamics.

The 'sharing in platform' represent the flow of underutilised assets being registered in the platform and their consecutive sharing. It connects the two sub-models previously presented. Products registration by users into the platform work as a delay to products acquisition as it rapidly balances the total number of functional products. A balanced ratio of products per users is necessary to enable sharing. When users leave the platform, the products under their responsibility are automatically deregistered and become underused again.

Finally, impacts are represented by the 'KPI system' sub-model, which is fed by all the other sub-models. Total sharing events, total products acquired and discarded, and total unmet demand are some of the KPIs defined to assess resource effectiveness.

Model testing: assessing whether the model is fit for purpose

Table 1 shows the parameters used to model the behaviour of durables and consumables in the 400 employees hospital using a closed sharing platform. Durables account for electromedical machines like MRI, Computed Tomography, X-ray, and Mammography machines. Consumables are single-use devices such as sutures, syringes, and gloves. The variables and parameters used represent the demands and lifetimes of products – durables and consumables.

Durables hold a high lifetime. They get the status of 'underutilised' after 18 months of low utilisation level and the decisions involved in acquisition take longer. Consumables hold shorter lifetimes and a safety stock policy is maintained. Lifetimes of durables are drawn based on the age profiling of imaging equipment in Europe (COCIR, 2016).

Product acquisition is defined by the projected demand for product use. Random time series are used to simulate actual demand for product use. The projected demand is a delayed response to actual demand, considering the time to acquire the product. The actual and projected demands were defined based on a case study for demand forecasting in healthcare (Cote and Tucker, 2001).

For the sharing platform, registration relies on the density of underutilised products per users. Sharing relies on the probability of desired product availability, which depends on the types of products within a category – durables or consumables. Finally, only durables are returned as available products in the platform for further sharing events. Consumables are used only once.

Figure 3 and Figure 4 show the simulation runs for the input parameters for durables and consumables of a small-sized hospital. Two scenarios are presented for each type of product: one representing no sharing platform and another with the sharing platform in place.

Variables	Parameters for Durables	Parameters for Consumables
simulation time (Month)	120	120
hospital employees (People)	400	400
product lifetime (Month)	120	12
time to underuse (Month)	18	6
time to acquire (Month)	3	1
actual demand for product use (Product)	Random time series – mean value of 20, standard deviation of 4	Random time series – mean value of 3000, standard deviation of 600
projected demand for product use (Product)	Information delay of the actual demand for product use considering time to acquire	Information delay of the actual demand for product use considering time to acquire
initial Functional (Product)	19	2800
initial Underutilised (Product)	1	200
Safety stock (Product)	0	300
ratio of returning (Dmnl)	1	0

Table 1. Initial parameters to simulate the behaviour of durables and consumables. Further details on the model choices can be obtained by contacting the corresponding author.

For durables and consumables, the actual and projected demand is the same when the platform is on or off (see Figures 3.a and 4.a). Following Figures 3.b, and 4.b, when the platform is on, users become active, and after a while, an increasing fraction becomes idle. In both cases, when the platform is off, all types of users remain zero. As shown in Figures 3.c and 4.c, total useful products are higher when the platform is on for both cases. Nevertheless, it is more relevant for durables. The total number of acquired products is relevantly lower to durable products when the sharing platform is in place (see Figures 3.d and 4.d).

Furthermore, the sharing platform enables meeting some demand that would otherwise not receive treatment. The total unmet demand decreases when the platform is on. Potential increased capacity is, again, more significant to durable products than to consumables (see Figures 3.e and 4.e).

Based on the experiment, the potential impacts of implementing a sharing platform in the context of one small hospital are substantial. Impacts of sharing durables and consumables in hospitals vary according to factors such as demands for product use, lifecycle time of products and the number of use cycles. The potential is higher for the sharing of durables.

Discussion

The model can represent the long-term behaviour and impacts of sharing durables and consumables in the scope of one small hospital. It can, thus, influence the adoption of the sharing platform by a potential client. Also, it can assist Company A to communicate or even improve its solution. New mechanisms to improve environmental impacts of this CBM can be enabled by, e.g. expanding platforms for neighbour hospitals or improving the fit to demand by further understanding the reasons for underuse.

Nevertheless, some model limitations must be considered. First, we assume that products become useful as soon as they are added to the platform in the presented model. The actual stock of use cycles of products is not considered. Addressing this could provide a more accurate measure of the level of use for durables. Also, CO2 consumption during the use phase could be investigated.

Second, item degradation because of underuse or careless sharing was not considered.

Third, the parameters and dynamics of user acquisition need to be further investigated in practice. Nevertheless, the diffusion behaviour works similarly to research pieces used as references, i.e. Borschev and Filippov (2004) and Sterman (2001).

Fourth, the model is still not connected to Company A's operations, costs and revenues. These aspects of the company might influence the overall dynamics of sharing, and these processes should be explicitly considered in the model. This is key to understand the path to enabling the scale-up of Company A's business model. The dynamic business modelling approach presented by Cosenz and Noto (2018) can help in that direction.

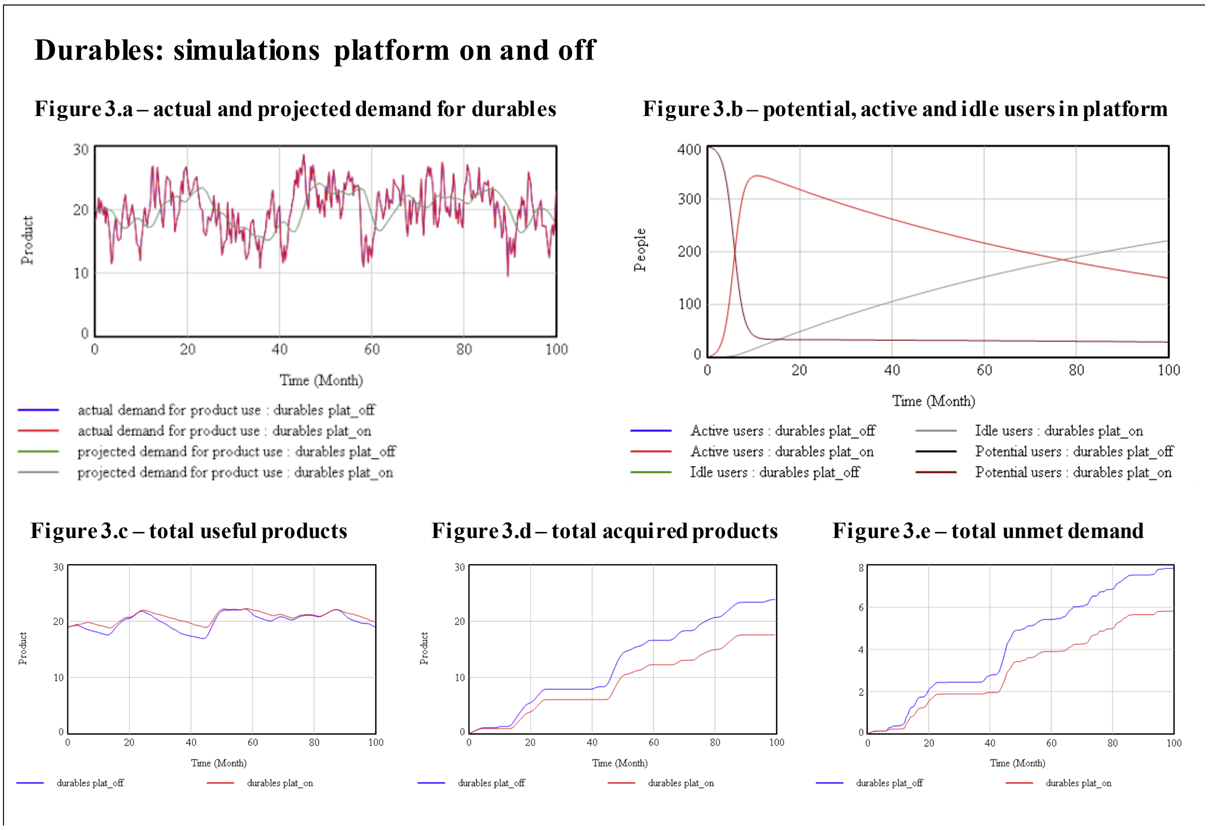
Durables: simulations platform on and off

Figure 3.a – actual and projected demand for durables

Figure 3.b – potential, active and idle users in platform

Figure 3.c – total useful products

Figure 3.d – total acquired products

Figure 3.e – total unmet demand

Figure 3. Simulation of durable products in a small hospital with and without sharing platform.

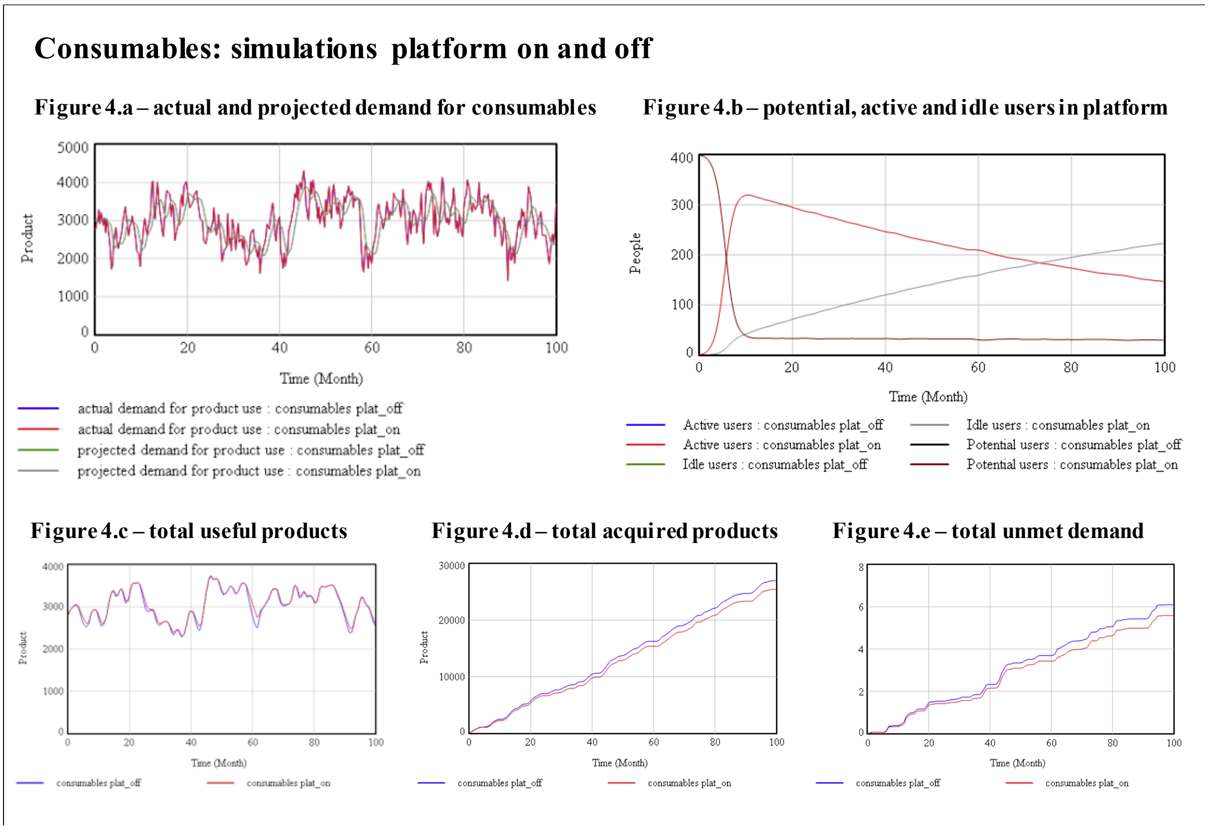
Consumables: simulations platform on and off

Figure 4.a – actual and projected demand for consumables

Figure 4.b – potential, active and idle users in platform

Figure 4.c – total useful products

Figure 4.d – total acquired products

Figure 4.e – total unmet demand

Figure 4. Simulation of consumable products in a small hospital with and without sharing platform.

Finally, while better impacts can be expected when two or more hospitals are connected by a single platform, a limitation of scope is that only the dynamics of sharing within one hospital was modelled and analysed.

Conclusion

In this work, we have experimented with a CBM in healthcare to verify its long-term impacts. Through the case study of a sharing platform, the dynamics of sharing durables and consumables is represented through (1.) the causal theory of sharing, (2.) a stock and flow model and (3.) verification through simulation. Scenarios based on a plausible set of variables lead to increased understanding of the CBM under research. A contribution of this research is thus to provide evidence that SD modelling and simulation can inform decisions i the adoption of business models aiming for long-term sustainability. The method presented in this research is useful to conceptualise a Circular Economy connected to the dynamics of business models. It can be used to verify the impacts of potentially circular business models in further applications. Directions to expand the model purpose are provided. It holds the potential to inform the design of CMBs by evidencing interventions for more positive impacts.

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