Assessing Circular Economy Ecosystems through i* Model Analysis

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Abstract
Our world is currently facing the reality to make better use of our limited earth resources. This requires the transition from a linear to a circular economy with the wise use of information systems. In this paper, we explore how to support this transition in a specific domain by assessing the quality of its ecosystem and information sharing capabilities using i* for the modelling and analysis of material collected through circular business model and value chain canvases. Our approach is illustrated and discussed on a case study from the construction sector.

Keywords
Organisation Modelling, Ecosystem Analysis, Circular Economy, Sustainability

1. Introduction

Since the industrial revolution of the 19th century, the world has essentially followed a linear economy with products either immobilised or thrown away at their end of life. This model obviously poses a sustainability problem in our world with finite resources and fuelled by the search of growth. The term circular economy (CE) emerged in 1990 with the idea of a product maximum value retention cycle, as illustrated in figure 1. It can be defined as: "an economic system aiming at the efficient use of resources and the reduction of the impact on the environment at all steps of the life cycle of a product (good or service), while allowing the well-being of individual". The development of CE is gradual, with the emergence of Cradle-to-Cradle (C2C) around 2002 and also driven by the Ellen MacArthur Foundation since 2009 [1].

Another transformation is also quickly reshaping our world through the exponential development of information and communication technologies. This Digital Transformation (DT) is causing a paradigm shift in economic and social activities [2]. In the context of the CE, digital transformation is part of *the problem*, because Information Systems (IS) mobilise multiple resources: production of equipment, design of software, energy consumption with greenhouse gas emissions, production of electronic waste, and so on. On the other hand, it also contributes to *the solution*, by supporting change towards EC by improving resource management and reducing waste production, knowing that any transformation will require energy.

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In a recent work, we have proposed an iterative methodology to help ecosystems operating in a specific domain to manage their transition to CE by relying of DT in a responsible way [3]. Our process is based on repetition of four steps: (1) maturity assessment, (2) capturing circular business model/value chains in the ecosystem, (3) defining strategies to be deployed (4) by relying on adequate digital technologies.

The focus of this paper is mainly to refine our second step starting from informal brainstorming canvases defined by the CIRCULAB [4]. For this, we identified i* as being very relevant for its ability to capture and analyse the structure of complex ecosystems, in terms of actors, resources, goals and various types of relationships and dependencies [5]. We use here version 2.0 of the language [6] to model a strategic rationale diagram with the piStar tool [7] and the help of a few enhancements to provide specific support for CE strategies.

The structure of our paper is as follows. Section 2 gives a quick background on CE to introduce the notion of loops of different types and related CE strategies. Section 3 introduces our case study in the construction industry and the initial value chain canvas for our ecosystem. Section 4 details the modelling and analysis of this material using i*. The results and lessons learned are then discussed in Section 5 before concluding and identifying future work in Section 6.

2. Background on Circular Economy

The "Butterfly" diagram developed by [1] is illustrated in figure 1. It makes a distinction between the *biological cycles* (on the left) with biodegradable elements, such as cotton, foodstuffs, wood, etc., and *technical cycles* (on the right) involving all non-biodegradable elements, such as metals and certain plastics. It is important to assess in which cycle(s) a company/ecosystem is involved as the strategies are different.

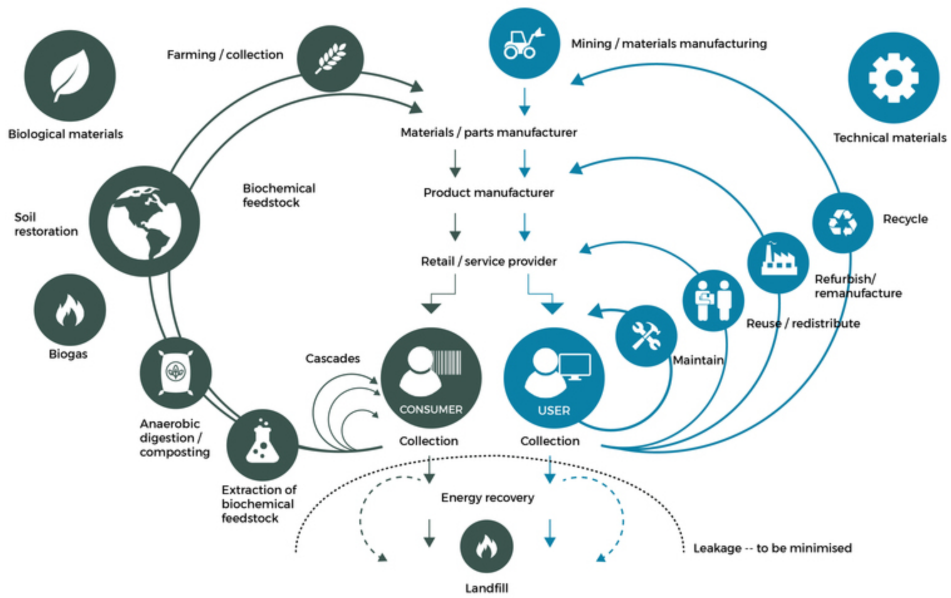

Figure 1: Butterfly Model of the Circular Economy

At the technical level, the shortest and most effective loops are sharing and then repair, while the longest are recycling of raw materials, which involves higher collection, sorting and processing costs.

Various *maintenance/recovery strategies* feed into CE, notably the *R strategies* like *Reduction* to limit the quantity of resources needed for manufacture; *Reuse* during the life of the product to extend it as far as possible by re-affecting or repairing; or *Recycling*, at the end of the product life. This concept can be extended in other ways, such as ReSOLVE (Regenerate, Share, Optimise, Loop, Visualise and Exchange) [8].

To implement CE, extensions to classical business analysis tools exist, including a circular business model and value chain canvases [4]. They enable the identification of next use possibilities, circular flows, and positive/negative impacts at societal or environmental level, including possible "bouncing" effects.

3. Case Study of the Construction Industry

As case study, we considered the construction industry and more specifically a Belgian ecosystem composed of classical actors such as architects, contractors, material providers, building owners/operators, demolition companies. We also identified emerging and highly innovative actors such as Rotor DC, a company specialising in the dismantling and resale of materials, and Multipick, providing rapid and reliable automated waste sorting based on artificial intelligence. Figure 2 depicts the complex structure of this ecosystem captured through a circular value chain canvas following the building life cycle in a clockwise way from design to end of life.

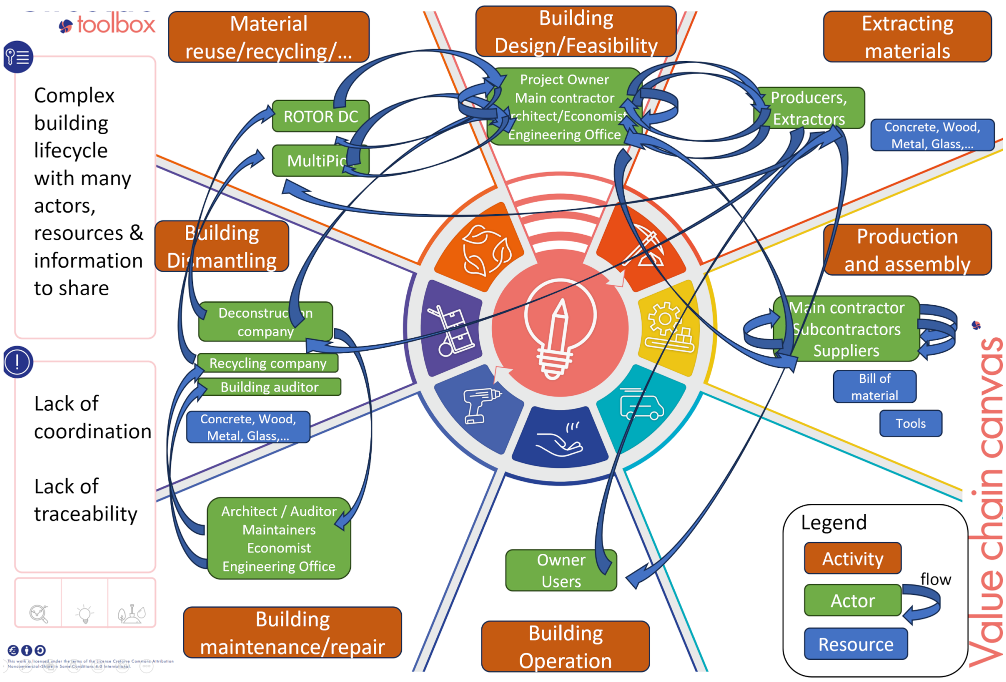

Figure 2: Ecosystem and data flow elicitation using circular value chain canvas (in French)

The construction industry is quite relevant to consider as it is estimated to be responsible for more than 30% of the extraction of natural resources and 25% of the world's solid waste. Most buildings cannot be easily deconstructed to recover materials resulting in unusable materials at the building end of life. In the European Union, 5 to 12% of greenhouse gas emissions come from this area, making it a sector with a high potential for reducing emissions [9]. Moreover, the CE awareness is still emerging and evolving at a slow pace in this sector given the long time scale and various obstacles related to the complexity of the ecosystem and of its regulations. However, it is possible to envisage more effective R strategies in terms of better reuse of building elements at different levels of deconstruction and considering the buildings as material banks. This comes at the price of specific IS to be deployed, which is hampered by the low maturity of this sector w.r.t. digital technologies.

4. Modelling and Analysis in i*

This section shows the contribution of i* modelling across the four steps of our methodology sketched in the introduction. It mainly relies on the i* strategic diagram although alternative goal-oriented modelling notations could also be considered as discussed in Section 5.

STEP 1 - Maturity Assessment. In this step, the main stakeholders are informally identified as well as their goals and capabilities. This also enables to roughly estimate how mature the ecosystem is compared to others both for CE and DT.

STEP 2 - Circular business model and value chains. In this step, the as-is situation of the ecosystem is captured along with some potential for evolution, e.g. through emerging actors. This is managed first through brainstorming CIRCULAB canvas such as described in Figure 2, then i* modelling comes into play to model more precisely the ecosystem using the following refinement process:

- the same global clockwise layout is used to structure the traditional actors.
- flows of information and resources are represented using dependency links.
- steps that should be reduced in order to improve circularity are highlighted in orange, e.g. injection of new materials and disposal in landfill.
- emerging actors enabling new loops for reusing materials are positioned in the middle of the diagram. Those loops are also highlighted with a dark green.

The resulting model is shown in Figure 3. Its analysis revealed many interesting points:

- traditional actors were captured as roles while innovative actors are very specific and captured as specific agent.
- tracking the information revealed key models present in this sector: the Building Information Model (BIM at design time), the BAM (Building Assembly Model, at construction time) and the BOOM (Building Owner Operator Model, at operation time).
- Information is however lost in the long term process. Two strategies are present. At short term, for existing building the information can be recovered through a dedicated actor (ROTORDC) through specialised audits. At longer term, another strategy is to introduce a specific actor acting as a memory to ease the deconstruction process.

- the other emerging actor is in charge of the automated sorting of valuable materials with the qualities of being local and automated, while sorting tends to be outsourced to low cost countries with strong environmental and social impacts. However, this comes at the cost of robotisation and IA training.

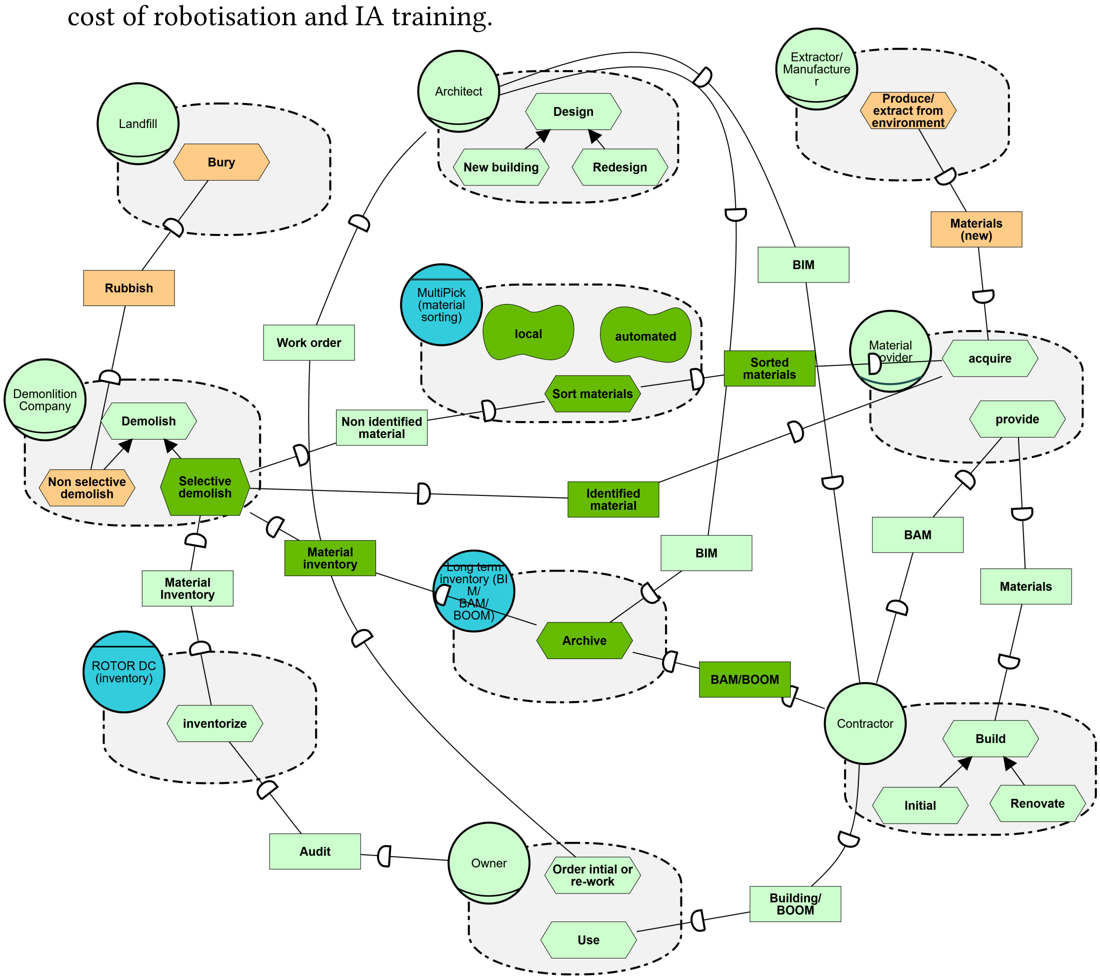

Figure 3: iStar modelling of the case study of our building ecosystem

STEP 3 - Selection of strategie(s) to deploy. We move here to the to-be system by considering how new flows and more efficient/shorter loops can be activated in the ecosystem at different time scales. In our case, we can engage in the short term re-inventory when needed and also start a process leading to the availability of long term inventory.

STEP 4 - Mobilising DT for implementation of strategie(s). A technological selection process is made by considering the possible impact of the technology itself. In our case, the long term inventory could use a blockchain providing decentralisation and integrity but at a high energy operation cost, or a more centralised and energy efficient solution operated by a trusted neutral actor. The i* diagram can also help support this analysis although it is not covered here.

5. Discussion and Some Lessons Learned

Although this work in progress was developed on a specific case, it has a good potential for a wider application for modelling and analysing CE ecosystems. We discuss here some lessons we learned so far as well as current limitations we plan to investigate.

On the modelling side, as already mentioned, the approach to refine a business value chain canvas into a strategic i* diagram is domain independent and can be applied to other domains, for example for agriculture, electronic devices, car sharing, etc. In terms of resources, an interesting distinction we make is between the information flow and the physical resources which require more specific typing. The integration of this notion into the Butterfly model could also be considered. Currently it discriminates biological and technical flows without making explicit the underlying information flow to manage them. Another modelling attribute we capture is the value of the resource or processing activity either as contributing to circularity or not (which can also be assessed by the fact they are within some loop or a "dead end" flow). Our current modelling is rather intuitive using a colour convention which can we related to a more quantified attribute. At first, we intended to use contribute links to capture positive or negative support to circularity. However such links have to remain inside an actor and this would require to relax the language which we did not consider here, although the piStar tool allows this quite easily. We believe it would be interesting as it can bring such diagram closer to system dynamics diagrams and enable related system level analysis [10].

Regarding the modelling language, while iStar 2.0 fitted our need, other goal-oriented modelling languages can also be considered. The main language features used are the ability to capture per agent goals/tasks and relate them through resource dependencies in order to build chains and loops. This means that other i* variants like Tropos [11] or GRL [12] can also be used. KAOS [13] could also be used by relying on monitor and control relationships. However as KAOS agents lack the container capability, the layout would be less readable.

On the analysis side, there is also a good potential for generalisation on different topics such as tracing the value of resources inside the various flows and identifying how emerging actors can close different loops, also considering and comparing or combining different alternatives. Interesting related metrics could be identified to make a more quantitative analysis, e.g to measure the complexity of the ecosystem and interactions (# of actors, loops, variety if information exchanged, etc). However, as already highlighted above, this would require to formalise the way the resource value and contribution information are captured. For the analysis itself, rather than developing specific tools, a smarter option is to rely on system dynamics analysis and simulation by translating the i* model to that formalism and use a related tool [14].

At this point, our modelling focuses on actors, tasks and resources but it also captures goals which help to assess how well each actor is aligned with sustainability goals. Goals are also useful to anticipate the level of difficulty to build new collaborations required between specific actors. Based on this, specific adaptations can be designed to remove barriers (e.g. standards for material description) or enforce collaboration (e.g. regulation). The ability to capture and trace goals and policies inside system-level models would also help in driving the management, evolution and optimisation of such models. Such approaches are actually being considered for oil field production (in contrast with the sustainability oriented goal we consider here) [15].

6. Conclusion and Perspectives

In this paper, we detailed how to model and analyse a circular economy ecosystem starting from a circular value chain canvas typically produced as output of an elicitation workshop. Although developed within the construction domain, the proposed approach has to potential to cope with other domains. It also provides a strong basis to deploy our method for helping in the transition to circular economy through the wise use of digital transformation.

In addition to the validation in other domains, our research agenda is to investigate how to formalise more our approach, identify key metrics relating to CE, investigate the mapping with system dynamics analysis while using goals to better drive the CE transition process.

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