Regionaal Bouwen aan Human Capital: Employing Causal Loop Diagrams to Depict the System of Factors Characterizing the Construction Sector and its Digitalization

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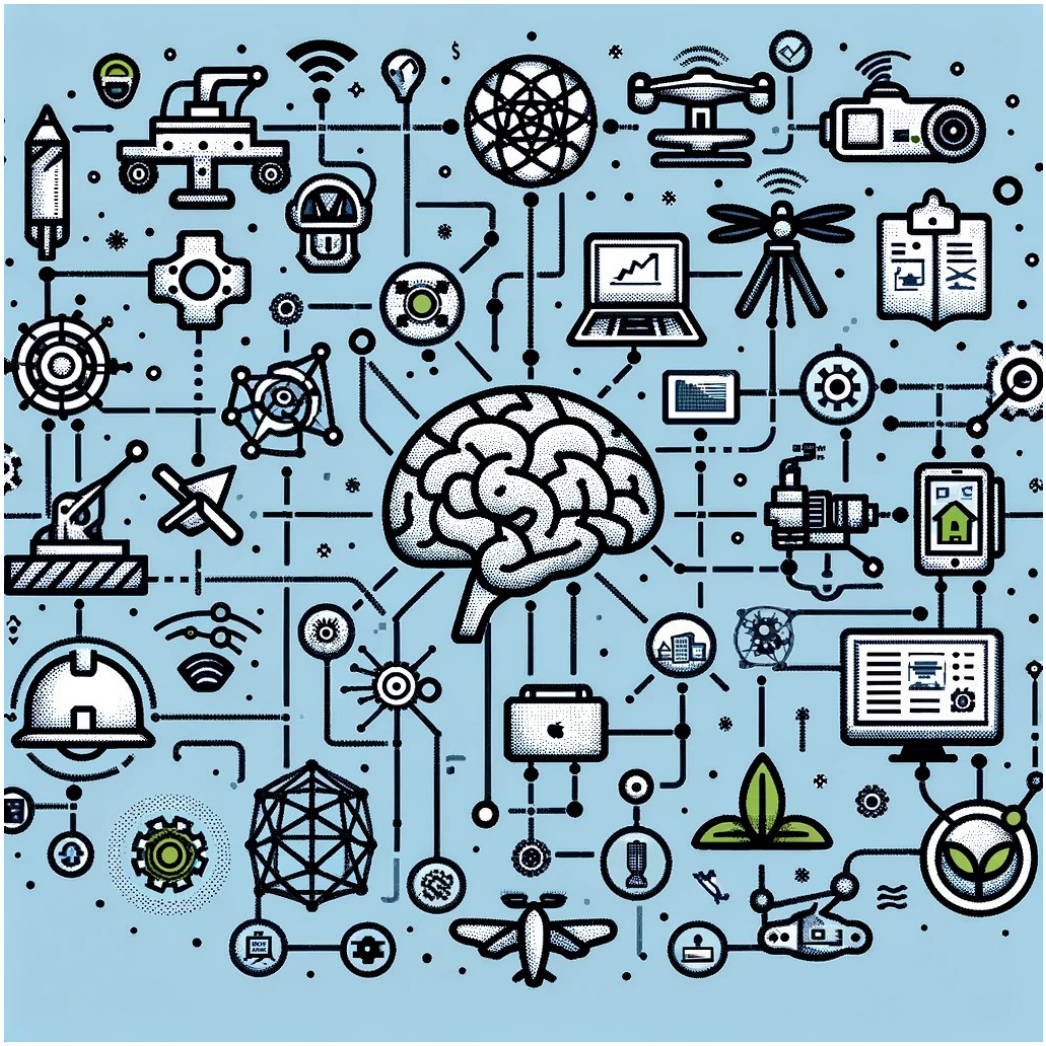

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Executive Summary

This report discusses the preliminary results based on the Causal Loop Diagram (CLD) that has been developed as part of a research study within the broader Regionaal Bouwen aan Human Capital (RBHC) project. The diagram was created with relevant stakeholders' direct involvement during a workshop on September 12th, 2023 (in 's-Hertogenbosch, the Netherlands). It depicts the most crucial factors characterizing the construction sector in the south of the Netherlands, its digitalization, and the relationships between them. The results presented in this report are partial. More work is still needed to explain the meaning of the CLD produced by stakeholders during this project.

Here, we offer a tool to understand CLDs and some preliminary conclusions about the most crucial factors of the system that characterize the construction sector in the south of the Netherlands and its digitalization. Factors are the building blocks of loops. Connecting factors between each other according to existing causal relationships, each loop expresses a theoretical construct.

According to this study, the factors that are most crucial to the system are sustainability, (profit) margins, quality of planning, an innovation culture, investments in existing employees, long-term thinking, and rules and regulations. These factors are the most influential in composing the overarching narrative of the CLD, which will be explained with an in-depth analysis of the loops in the diagram.

1 Introduction

This report discusses the preliminary results of a study involving a Group Model Building (GMB) approach. During a stakeholder workshop on September 12th, 2023 (in 's-Hertogenbosch, the Netherlands) and a number of experts meetings after, we created a so-called Causal Loop Diagram (CLD). This CLD depicts the most crucial factors characterizing the construction sector in the south of The Netherlands, its digitalization, and the relationships between them. In this report, first, we explain the methodology employed to produce the diagram. Second, we describe the CLD, appraising its features. Third, we provide a preliminary interpretation of the diagram.

2 Methodology

To understand the system characterizing the construction sector in the south of the Netherlands and its digitalization, we collected relevant data using a Group Model Building (GMB) approach. GMB is an established technique defined as a process of involving stakeholders central to a sector or a field in developing a model to create shared insights and consensus for implementing a mental map of a system.[1] The GMB approach consists of uniting relevant stakeholders and asking them to conduct guided collective work to identify crucial factors to a system of interest and establish causal relationships between them. The final product of this activity is a Causal Loop Diagram (CLD).

A CLD is constituted of loops of variable size, from two factors affecting each other to a variably large number of factors involved in the same causal relationships. The causal relationships under examination can be both negative and positive. If we imagine that each factor is a "stock", we can see a relationship between two factors defined in two ways. First, if one factor positively affects the other, an increase on the first determines a proportional increase on the second. Second, if one factor negatively affects the other, an increase in the first determines a proportional decrease in the second. The example in Figure 1 can clarify this concept further.

In the loop on the left-hand side, we can see two factors, i.e., the amount of money in the bank and the interest earned thanks to it. They are both measurable stocks of money. When someone gains more money and puts in the bank, it is normal that the interest earned on it increases; this is a positive causal relationship. Also, earning more interest increases the money stored in the bank account overall. Hence, the loops close with positive relationships. Since these two causal relationships are both positive and depict a type of stock that keeps increasing, money in this case, we call this type of loop reinforcing.

The loop on the right-hand side of Figure 1 depicts two different factors, i.e., stress and coping mechanisms. Both of them are measurable and quantifiable. Hence, we can call them stocks of stress (quantity) and coping mechanisms (number of solutions adopted). If we see our level of stress increase, we look for solutions to reduce it. Hence, it is correct to say that higher stress increases the number of solutions we implement, for instance, taking time off and going for a walk. It is expected that the coping mechanism reduces the stress. Hence, this time, the relationship is negative. This loop type is called balancing since it ensures that the stocks reach a balance and stop the growth.

[1] P.S. Hovmand, Group model building and community-based system dynamics process Community Based System Dynamics, Springer (2014), pp. 17-30

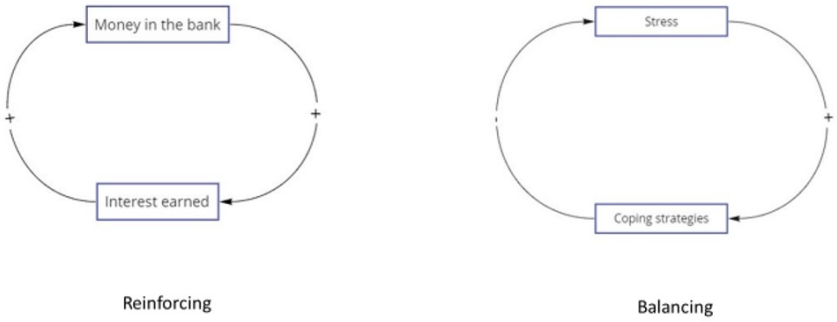

Figure 1: Example of positive and negative causal relationships between factors and the types of loops that they produce according to positive or negative causal relationships.

3 Describing the CLD

During a workshop that took place on September 12th, 2023 (in 's-Hertogenbosch, the Netherlands), five groups (of 4-6 people each) created five different CLDs following the GMB protocol. The five diagrams have been merged into a unified one with the help of the so-called expert reviews. The final CLD outputted from this process is displayed in Figure 2. The diagram consists of 76 factors connected with 226 causal relationships. Of these 226 relationships, 84.5% are positive causal relationships, whilst the remaining 15.5% are negative. The factors were classified into the following seven thematic categories during the expert reviews: 1) Stakeholder/ecosystem; 2) Written rules and regulations; 3) Unwritten rules, culture of the construction sector; 4) Organizational skills; 5) Individual skills and expertise, quality of human capital; 6) Boundary conditions of output; 7) Societal output. Figure 3 gives a legend of the categories.

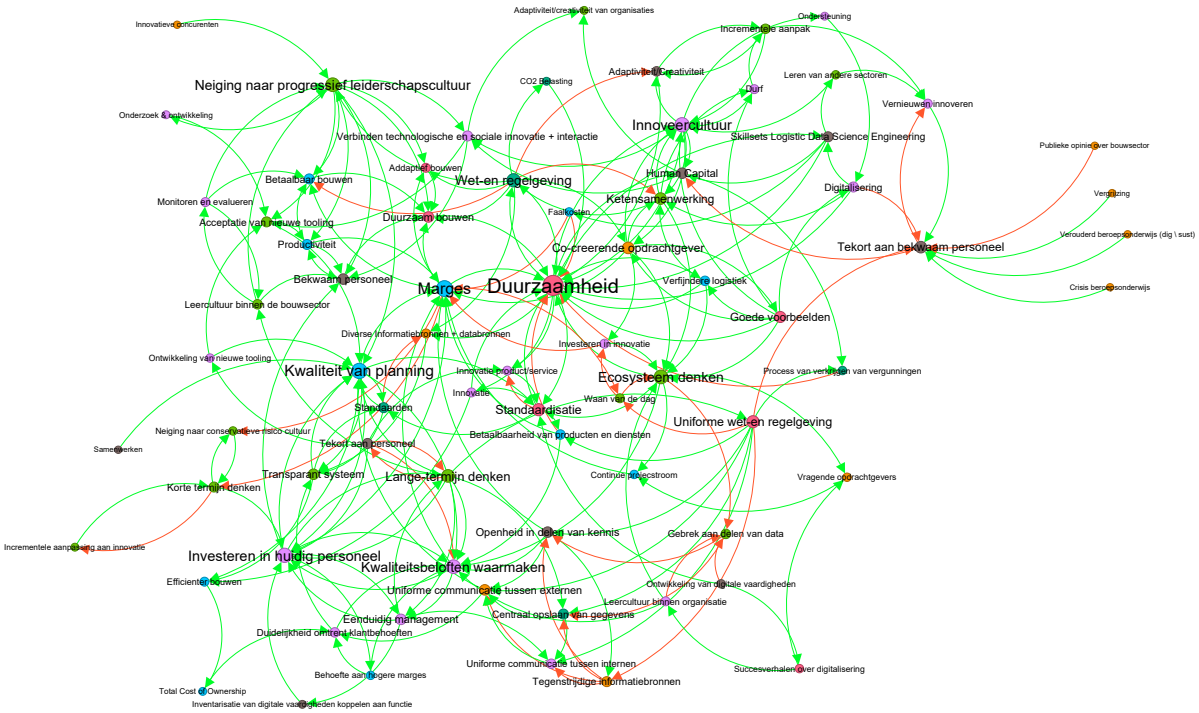

Figure 2: CLD of digitalization in the construction sector.
Green edges indicate positive causal relationships, **red** edges indicate negative causal relationships.

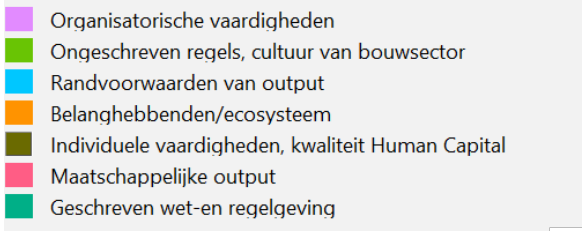

Figure 3: Legend for node categories in CLD

4 Interpreting the loops

The causal relationships that compose CLDs can be analyzed in loops like we did with the examples in Figure 1. A loop is defined as a path through the CLD that defines causal relationships with a certain number of factors. Every loop can be either balancing or reinforcing according to the type of causal relationship, either negative or positive, respectively. Let us now disentangle one of the loops in Figure 2. This loop consists of four different factors and is reinforcing, since all the relationships between the factors are positive.

Sustainability $\xrightarrow{+}$ Rules and regulations $\xrightarrow{+}$ Chain cooperation $\xrightarrow{+}$ Ecosystem thinking $\xrightarrow{+}$ Sustainability

According to this loop, an increased focus on sustainability leads to an increase in rules and regulations (for example, sustainability requirements). In turn, this is likely to lead to an increase in chain cooperation, i.e., closer collaboration between parties in the entire supply chain of a construction project (for example, to be able to meet the larger number of sustainability requirements). An increase in chain cooperation increases ecosystem thinking among the involved parties, which, closing the loop, determines an increase in sustainability (as ecosystem thinking is required for meaningful sustainability efforts).

This type of effect can be described as a virtuous circle that keeps increasing types of stocks that do not have tight material constraints. Ideally, sustainability should keep increasing, and the regulations should support sustainability during its development. This process should also foster the growth of chain cooperation, and when this happens, it implicitly develops ecosystem thinking that ultimately positively affects sustainability and is reinforced accordingly. This is just one of the many informative narratives we can highlight from the CLD in Figure 2. All of them should be put in the context of the other loops surrounding them.

Let us now focus on a balancing loop that consists of three factors.

Rules and regulations $\xrightarrow{-}$ Adaptability/creativity $\xrightarrow{+}$ Sustainability $\xrightarrow{+}$ Rules and regulations

From this loop, we learn that an increase in rules and regulations leads to a decrease in the sector's adaptability/creativity, since the new regulations bound these factors. Still, an increase in adaptability and creativity increases sustainability, and an increase in sustainability increases rules and regulations. This loop shows that a permanent growth of sustainability is not sustainable, since it involves the development of material constraints such as rules and regulations that are costly and determine the decrease of adaptability and creativity. We understand how sustainability cannot grow eternally through the decrease in adaptability and creativity. This process grows only until it reaches its natural balance. This loop also needs to be placed back in the context of the other loops by whom it is surrounded in order to appraise its entire meaning.

As we observed in these two examples, each loop describes a theoretical concept that belongs to the system. By interpreting all the loops (or the most meaningful ones), it is possible to understand the complex system described by the CLD.

In Table 1, we present an overview of the number of loops composed of a specific number of

factors. For instance, we observe 27 loops involving two factors, 32 loops with three factors, and 57 loops with four factors. We can see that the number of loops keeps increasing as the number of factors increases. This is normal, because if we keep moving in the diagram, we can see a path to reach every other factor, whether it is shorter or longer. Usually, the most meaningful loops are those with a relatively small number of factors since they are able to describe more specific concepts. Future work will carry out an analysis to establish the most meaningful loop sizes for this specific CLD.

Even if the CLD produced in this study might not seem so big, its interpretation is not so simple. Several different theoretical constructs are enclosed in those loops and they need to be disentangled and evaluated carefully.

Table 1: Summary of the typology of loops according to the number of factors and their count for each typology.

Number of factors	**Number of loops**
2	27
3	32
4	57
5	112
6	228
7	463
8	894
9	1,777
10	3,570

5 Most Crucial Factors

A CLD is a very specific type of diagram. However, it is possible to conceptualize it as a network of factors connected by causal relationships. By doing that, it is possible to benefit from the tools offered by a discipline called network analysis to understand better the parts of which the CLD is made. One branch of network analysis studies how important certain network parts are compared to others. We can use the so-called centrality measures to understand which are the most crucial factors that influence this particular system, i.e., the construction sector and its digitalization. We selected three centrality measures suitable for this CLD. Namely, degree centrality, betweenness centrality, and eigenvector centrality.

Table 2: The ten factors scoring highest for degree, betweenness, and eigenvector centrality

Rank	**Degree**	**Betweenness**	**Eigenvector**
1	Sustainability	Sustainability	Sustainability
2	Margins	Margins	Innovation culture
3	Quality of planning	Quality of planning	Margins
4	Investing in existing employees	Investing in existing employees	Rules and regulations
5	Innovation culture	Long term thinking	Quality of planning
6	Tendency towards progressive leadership	Innovation culture	Investing in existing employees
7	Delivering on quality promises	Delivering on quality promises	Ecosystem thinking
8	Ecosystem thinking	Ecosystem thinking	Standardisation
9	Rules and regulations	Human Capital	Co-creating client
10	Long term thinking	Rules and regulations	Delivering on quality promises

Degree Centrality: In a CLD, the degree centrality of a factor measures how many causal relationships the factor is involved with. Hence, it denotes the overall importance of that factor in the system. The higher the degree, the higher the number of loops a factor is involved in. If we think that each loop encompasses a theoretical construct explaining precious information about the construction sector and its digitalization, factors with a higher degree are the protagonists of a higher number of theoretical constructs.

Betweenness Centrality: In a CLD, the betweenness centrality of a factor measures how important a factor is in connecting different parts of the CLD. If the degree tells us how many theoretical constructs a factor is present, betweenness looks at the connection between these constructs. In fact, constructs are hardly isolated in a system, and betweenness identifies those factors that are able to embed different theoretical constructs in the same story. In other words, it shows how crucial a factor is in connecting different substructures of the diagram.

Eigenvector Centrality: Finally, the eigenvector centrality identifies factors that are connected to many other factors, which are, in turn, connected to many others, measuring how they are influential for the structure of the CLD as a whole. In the context of a CLD diagram, it shows how much a factor is influential for the concept mapped out in the substructure it is embedded in.

The top ten nodes for the three selected centrality measures are displayed in Table 2.[2] To start, we look at the degree of our terms.

Regarding degree centrality, as seen in Table 2, the factors embedded in more loops are sustainability, margins, the quality of planning, and investing in existing employees. These results are consistent for betweenness centrality. In this CLD, the four factors embedded in more theoretical constructs (loops) are also the factors with the highest ability to connect different theoretical constructs together in defining a system. Eigenvector centrality shows slightly different results. According to this measure, sustainability is also the most crucial factor, and it is able to influence the theoretical construct defined by the CLD the most. Margins also have a strong influence, but they are the third most influential, while the second most influential is innovation culture, which ranks fifth for degree and sixth for betweenness. Overall, the three measures show a coherent story since most factors score high in all of them.

[2]Original terms in Dutch.
Degree Centrality: Duurzaamheid, Marges, Kwaliteit van planning, Investeren in huidig personeel, Innoveercultuur, Neiging naar progressief leiderschap, Kwaliteitsbeloften waarmaken, Ecosysteem denken, Wet-en regelgeving, Langetermijndenken.
Betweenness Centrality: Duurzaamheid, Marges, Kwaliteit van planning, Investeren in huidig personeel, Langetermijndenken, Innoveercultuur, Kwaliteitsbeloften waarmaken, Ecosysteem denken, Menselijk kapitaal, Wet-en regelgeving.
Eigenvector Centrality: Duurzaamheid, Innoveercultuur, Marges, Wet-en regelgeving, Kwaliteit van planning, Investeren in huidig personeel, Ecosysteem denken, Standaardisatie, Co-creërende opdrachtgever, Kwaliteitsbeloften waarmaken.

6 Conclusions and Future Work

The findings presented in this report are partial. More time is needed to interpret the very high number of loops displayed in the CLD. Each of them describes a theoretical construct that helps in recomposing the picture of the complex system according to which the construction sector and its digitalization work. Still, this report presents the CLD produced within the broader Regionaal Bouwen aan Human Capital (RBHC) project and provides a concise explanation of the type of information that is possible to acquire from this CLD. Moreover, this report presents the most important factors of the system that characterize the construction sector in the south of the Netherlands and its digitalization.

According to this study, the factors that are most crucial to the system (i.e., in the top five according to the three measures employed) are sustainability, margins, quality of planning, innovation culture, investing in existing employees, long-term thinking and rules and regulations. These factors are crucial for a construction sector that works toward becoming more digitalized while keeping the (profit) margins positive. A focus on sustainability and quality of planning requires long-term thinking, and builds on companies' innovation culture and investments in their current employees. Rules and regulations only need to be put in place where they support the overall aims. This overarching narrative still needs to be specified with an in-depth analysis of all the theoretical constructs depicted in the diagram.