PATTERN CATALOGUE

# CIRCULAR BUILDING AND AREA DEVELOPMENT

LDE CENTRE FOR SUSTAINABILITY

**INTERDISCIPLINARY THESIS LAB 2022-2023**
CIRCULAR BUILDING AND AREA DEVELOPMENT

Universiteit Leiden
The Netherlands

TU Delft Delft University of Technology

Erasmus University Rotterdam
Making Minds Matter

**Centre for Sustainability**
Leiden-Delft-Erasmus Universities

# COLOPHON


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# CONTENT

# Introduction

This pattern catalogue is the final result of the Interdisciplinary Thesis Lab Circular Building and Area Development. It compromises the findings of all participating students and acts as a connector between all their theses.

## What is this thesis lab about?

What is this thesis lab about?
In the academic year 2022-2023 a group of Masters students from Leiden University, Erasmus University Rotterdam (EUR) and Delft University of Technology (TU Delft) joined in the Interdisciplinary Thesis Lab Circular Building and Area Development.
Cities are facing enormous challenges in terms of social, ecological and economic sustainability. In research and practice we are constantly focused on developing actions and knowledge that can help us to improve and safeguard the liveability of our cities. In our efforts to become resilient we focus on system change towards more sustainability and circularity and the optimal (re-)use of resources. The resource-intensive building and infrastructure sector plays a critical role in addressing urban sustainability challenges. At the same time, cities are an urban mine of materials and knowledge, that have the potential to develop a sustainable and circular system for the built environment.
This thesis lab addresses this interconnected challenge in the region of Zuid-Holland by focusing on assessing factors and conditions (e.g. technical, ecological, economic, locational, social, geopolitical, etc.) that influence the transition towards a sustainable and circular building, infrastructure and area development. This is related to the overall challenge: how can a system change towards more sustainable and circular cities and the optimal (re-)use of resources be achieved? This challenge was agreed upon among 5 different partners who are experiencing sustainability transition challenges in the built environment and who represent both the private, public and more hybrid perspectives. The coordination and organisation of this lab was facilitated by coordinators of the Leiden Delft Erasmus Centre for Sustainability and by an academic coordinator of the Faculty of Architecture and Built Environment of TU Delft.

## Who are the partners in this thesis lab?

### Municipality of Westland

The municipality of Westland is located in between Delft, The Hague, and the Port of Rotterdam. The municipality is mainly known for its horticulture landscape and the knowledge centres surrounding it. The horticulture sector of the future is ultra-sustainable and drives change, but realising this ambition is not straightforward. Research on energy usage, mobility planning and overall sustainable and green construction and area development is useful for realising this ambition.

### Antea Group

Antea Group is a global consulting and engineering firm with its origin and a large chapter in the Netherlands. It is a private sector organization that needs to be financially sustainable and that is concerned with ecological and social dimensions of sustainability and embraces the Sustainable Development Goals (SDGs). Antea Group is interested to learn more about how role of Antea Group in a new (circular) economy and about the economic dimensions of sustainability.

### The Bouwcampus

The Bouwcampus aims to start transitions within three complex, urgent societal tasks. (1) Replacement & Renovation Infrastructure, (2) Sustainability Buildings & Environment & (3) Redesigning the Urban Foundations. The Bouwcampus is interested in research about circularity in industrial building & construction, connections between circularity & other sustainable challenges in building and area development and in how transitions can be enabled by upscaling and thus going beyond pilots and experiments.

## Who are the partners in this thesis lab?

### Province Zuid-Holland

As a rapidly growing, highly urbanized province, South Holland faces a major housing challenge. The Province wants to build fast and in big numbers, but it is about more than that. Now more than ever it is necessary to build future-proof, in other words: climate-adaptive, circular/ biobased, energy-neutral, healthy, emission-free, and nature-inclusive. However, we do not yet know how to realise all those ambitions. It will help to learn more about factors and conditions that influence the transition towards future-proof housing; the role of different aspects of future-proof housing in area development in Zuid-Holland.

provincie Zuid-Holland

### Ministry of Interior and Kingdom Relations

The area of work of the ministry of Interior and Kingdom Relations is, among many other things, addressing the spatial challenges created by the shift towards a circular built environment, including a circular building sector. The concept of circular economy is about preventing the use of 'virgin' commodities and materials and closing loops in production and consumption processes. In relation to this, the ministry is looking at different scale levels at which used (building)materials can be re-used or recycled and at accompanying policies. Research themes that are of interest for the Ministry are: the spatial scale level of building sector related resource flows, reusing and optimising flows in building and area development projects and policy and knowledge as incentive.

Ministerie van Binnenlandse Zaken en Koninkrijksrelaties

## Lab Program

The Circular Building and Area Development lab had a biweekly program where students from the lab came together to follow in-depth lectures and workshops related to their sustainability challenge. During these sessions, the students discovered and discussed the interdisciplinary aspect of this challenge. At the end of the program, they developed one interdisciplinary result as presented in this booklet

## The booklet

Thomas van Daalhuizen developed the idea to work with 'patterns', an approach that originates from Christopher Alexander and described in his book from 1977. All participating lab-students developed patterns based on their individual thesis research findings and those patterns including their interconnections are presented in this catalogue. We, as coordinating team, are very proud that this group developed this informative end-product together. It shows the diversity of knowledge and insights that are all relevant for the transition towards a more sustainable and circular built environment. It offers insight in how we can make better use of the existing building stock and how we can (and cannot) transition towards the use of biobased materials in construction. It sheds light on how innovative approaches in terms of collaboration and experimentation mechanisms can result in innovation and in more stabilized and upscaled forms of change. Additionally, it questions what a more sustainable and circular built environment should encompass, going beyond buildings when looking at housing for the future and mobility as well as focusing on linkages between reducing the exploitation of various resources including raw materials, energy and water. Despite this broad coverage, many questions remain, and we look forward to doing more research and implement more actions to further enhance a transition towards a more sustainable and circular built environment.

## Enjoy reading this pattern catalogue!

Best wishes
Karel Van den Berghe, academic coordinator of the thesis lab; Assistant professor in Spatial Planning and Urban Development, Management in the Built Environment, Faculty of architecture and Built Environment, TU Delft.

Thomas van Daalhuizen, co-coordinator of the thesis lab; Student Assistant of Leiden Delft Erasmus Centre for Sustainability

Saskia Ruijsink, coordinator of the thesis lab; Scientific coordinator Cities & Regions theme of the Leiden Delft Erasmus Centre for Sustainability

# GOVERNANCE

# G1 LACK OF REGULATIONS AND STANDARDS

CURRENTLY, THE CIRCULAR ECONOMY OFTEN FALLS OUTSIDE REGULATIONS AND STANDARTS, AS IT IS STILL A NEW CONCEPT IN MANY AREAS

CONNECTED TO
D1, S8


## Theoretical Background

**There is high demand for government and policy support for implementing can CE in the built environment (Pomponi and Moncaster, 2017). Since there is currently no legislation for circular construction, the local government must be willing to apply it. This is factor that can hinder progress towards circularity. The construction industry is highly regulated, and new circular business models and materials may not yet be adequately covered by existing regulations. This can lead to uncertainty and hesitation among stakeholders, who may be reluctant to invest in new circular solutions without clear guidelines and legal frameworks. Therefore, it is essential to update regulations and standards to promote circularity and provide a level playing field for circular solutions.**

## References

Pomponi and Moncaster, 2017

## Recommendations

Avoid being overly constrained by existing policies and regulations; instead, examine the underlying reasons behind them. While implementing circular practices may not always align with the literal interpretation of current policies and regulations, it is essential to assess whether they achieve the same level of safety or strength. Given the novelty of many concepts in the circular economy, they often do not fit within the confines of established policies and regulations. However, it is crucial not to allow these limitations to hinder the adoption of circular approaches.

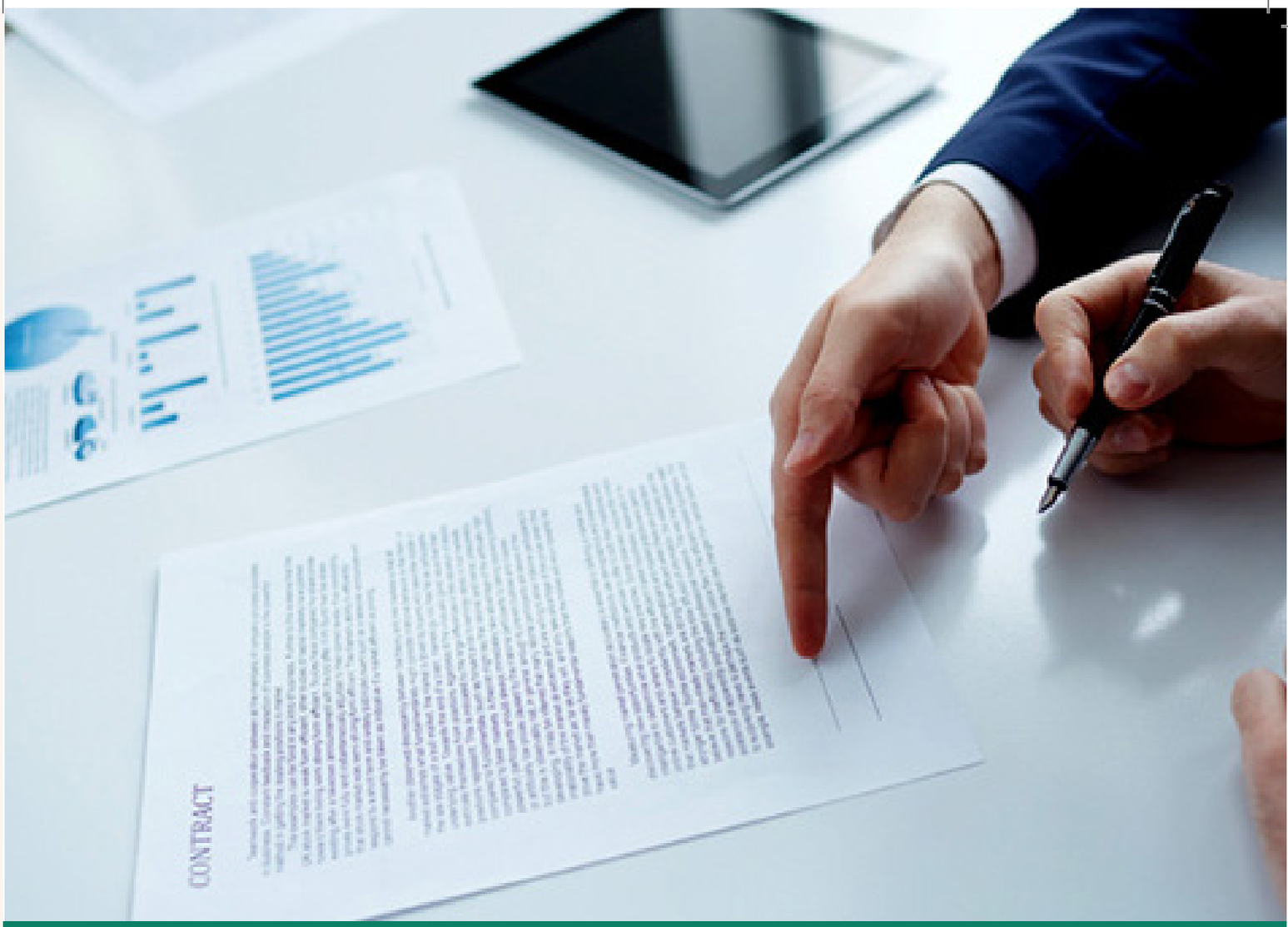
## Methods

Literature, Interviews

# G2 IMPORTANCE OF CONTRACTS

CONTRACTS SHOULD SUPPORT IMPLEMENTATION OF CIRCULAR ECONOMY

CONNECTED TO
S2




## Theoretical Background

The contract's role in circular projects is also crucial. The contract should be designed in such a way that it values circularity and allows the project team the freedom to implement circular practices. When contracts do not provide adequate flexibility, circularity becomes difficult to implement, even with the best intentions of individuals.

## References

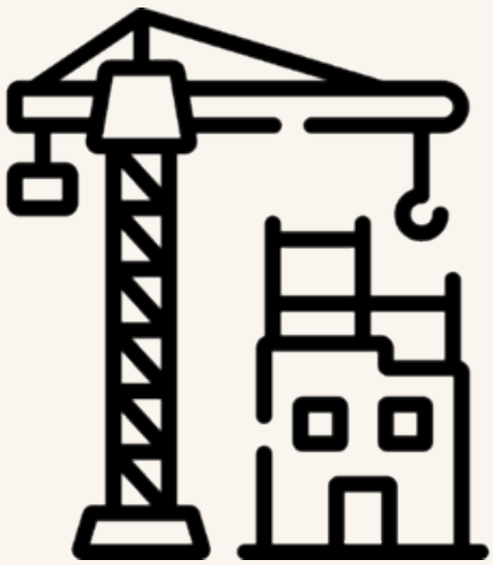
Interviews

## Recommendations

The choice of contract format is a significant decision that can greatly impact the success of a project. Traditional procurement methods may not always be suitable for circular initiatives. Therefore, it is recommended to explore alternative approaches such as a construction team or creating a learning environment. These contract formats can provide the necessary flexibility and support for circular practices to thrive. It is important to align the intentions of all involved individuals, but without contractual provisions that accommodate circularity, even the best intentions may lead to failure. Therefore, the company should prioritize selecting a contract format that fosters collaboration and allows for the effective implementation of circular principles.

## Methods

Interviews



# G3 CAPITALIZING UPON GOVERNMENTAL SUPPORT

GOVERNMENTAL SUPPORT AND REGULATIONS CAN BE USED TO HASTEN THE SYSTEMIC TRANSITION BY IDENTIFYING LEVERAGE POINTS AND PROMOTING TRANSPARENCY

CONNECTED TO
G1, G2, G4, D2, S8


*Image: The hand in this image represents the government will the person represents the industry: close collaboration is required (Bing, n.d.)*

## Theoretical Background

The Netherlands has been at the forefront of circular building due to numerous initiatives which have been carried out across the country. The Dutch Government has set a goal for its economy to become completely circular by 2050 (Hanemaaijer et al., 2021). To successfully adopt circular building, the required collaboration should encapsulate direct and indirect stakeholders in the construction sector who are interconnected through the convolution of social, political and economic aspects (Williams et al., 2017). A wide-scale systemic transition such as circular economy requires the simultaneous movement of large parties or sectors towards the desired outcome since the system is the result of the dynamic interactions between parts of said system (van der Steen et al., 2022) – changes within elements or interrelationships will have ensuing effects across the entire system. For the circular economy specifically, there exists a direct interaction between governments and proactive entrepreneurs/companies, and the implementedgovernance strategy must consider the structure, strategy and culture of these companies (Oudega et al., 2022). Accordingly, an adequate governance scheme should focus on deploying and expanding capacity within the ecosystem and creating a steppingstone basis for the rolling out of the desired state of circular building (Oudega et al., 2022).

## References

Hanemaaijer et al., 2021
Williams et al., 2017
Van der Steen et al., 2022
Oudega et al., 2022

## Recommendations

Policymakers should be involved at the start of pilot projects, safeguarding transparency on all accounts. Such a stream of communication will clarify and ease matters for both ends: the companies will witness the difficulty in updating legislation, and the government will see firsthand the struggles that the companies face. A working group should be formed to converse the challenges and collectively discuss methods to overcome certification difficulties and develop clearer material tracing mechanisms. Simultaneously, the government should slowly use legislation to promote circular building through tax incentives – making uncircular materials more expensive and giving tax breaks/subsidies on circular projects. Eventually, circularity should become obligatory in the built environment, without gray areas which the companies can oversteer. The government is expected to lead the change by adopting a facilitative position in steering for the transition. This can be done by pinpointing and grouping successful companies with established innovations – creating working groups and frontrunner networks where ideas can be
shared, and accountability can be increased. Similarly, the government should apply circularity inwards – adapting all their owned buildings to be circular, thereby decreasing the associated risk in the public eye. These recommendations of course complement the required preliminary role of funding before normalization.

## Methods

Literature review and data analysis (13 semi-structured interviews)

# G4 UPGRADING THE ETWORK FOR A SUSTAINABLE BUILT ENVIRONMENT

CURRENTLY, MORE THAN 9 DIFFERENT NETWORKS IN THE NETHERLANDS ARE WORKING AROUND CIRCULARITY IN THE BUILT ENVIRONMENT (CIRKELSTAD / HET NIEUWE NORMAAL, CITYDEAL CIRCULAR AND CONCEPTUAL BUILDINGS, LENTEAKKORD 2.0, CIRCULAIR BOUW 23, BUILDING BALANCE, WE GROW, BIOBASED BUILDING ZUID-HOLLAND, THE GREEN VILLAGE AND TOEKOMST BESTENDIG BOWEN). BY INTEGRATING THESE NETWORKS, THE GOVERNANCE OF THE TRANSITION TO A CIRCULAR BUILT ENVIRONMENT COULD BE SIGNIFICANTLY ENHANCED. THERE IS AN OPPORTUNITY TO FOSTER CIRCULARITY IN THE BUILT ENVIRONMENT IF THE STRATEGIES OF CONNECTING AND EXPLORING CONTENT ARE PERFORMED REGULARLY BY A NETWORK MANAGER.

CONNECTED TO
G3, G5, K3, M4, S3

*Image: lorem ipsum*

## Theoretical Background

Klijn and Edelenbos discuss that there is a statistically significant relation between the use of Network Governance Strategies (NGS) and Outcomes in Environmental Projects. In this literature the use of the strategies Process Agreement, Exploring Content, Connecting and Arranging are positively related to the Perceived Outcomes in the participant's perceptions. Therefore, it is hypothesized that if more of those strategies were used in the Netherlands, the general progress towards a circular built environment would improve.

## References


Klijn et al., 2010
Klijn et al., 2010
Klijn & Koppenjan, 2016


## Recommendations

Integrating the different existing networks for circularity in the Built Environment can aid in developing a single vision of what the transition to a circular/ sustainable Built Environment means, how it should be done, and what is the role of different actors in the process. These  ntegrated networks should advance in developing this vision and selecting the indicators to measure success, to allow for further policies to be developed.

## Methods

Literature Review, Interviews

# G5 NEED FOR REGULATORY CHANGES

NEED FOR REGULATORY CHANGES, MATERIAL BANK, AND INFORMATION FLOW, TO SPEED UP HIGH-VALUE REUSE OF COMPONENTS.

CONNECTED TO
D1, D3, G1, G3, G4, F1, T6, S6

*Image: Pixabay*

## Theoretical Background

Research outcome validated literature recommendations including high-value reuse of material stock (building and structural components and products) in the built environment (Rios et al., 2019), value capture (Hopkinson et al., 2020), identity retention (Hansen et al., 2020), emission reduction, waste minimization, prolonged resource depletion, and possible cost saving potentials over the life cycle (Cooper, T., 2020). Challenges include lack of market mechanisms (Adams et al., 2017c), unawareness of demolition contractors (van den Berg et al., 2020b), transportability of components (Coenen et al., 2021a) and demand supply mismatch (Brissaud & Zwolinski, 2017). Standardization (Hart et al., 2019a) was difficult to achieve due to the unique context of each project

## References

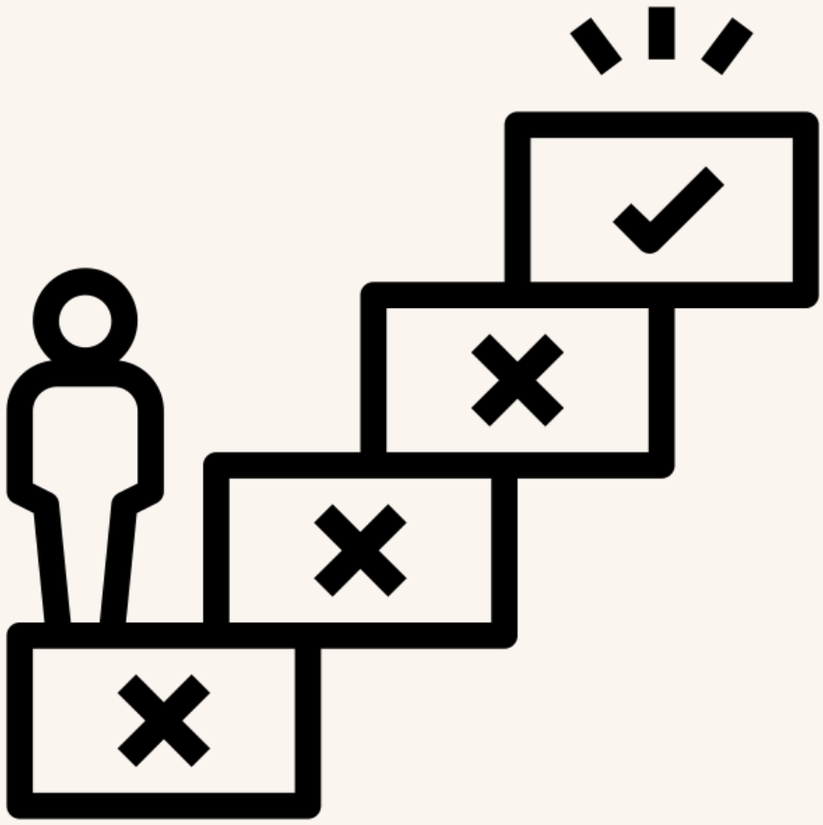
## Recommendations

- Banning the demolition of viaducts to encourage deconstruction, hence key to faster circular transition
- Stimulating design with available elements
- Avoiding duplication of design work with readily available components
- Matchmaking was found to be key to success
- Storage like a material bank (beam bank) is a challenge and holds potential pportunity for faster circular transition in the viaduct projects

## Methods

Interview
Secondary Data
Qualitative Analysis

# KNOWLEDGE



# K1 EXPERIMENTATION AS A DRIVER OF INNOVATION

BY EXPERIMENTING, YOU GAIN MORE KNOWLEDGE AND FIND OUT WHAT WORKS WEL AND WHAT DOESN'T WORK WELL.

CONNECTED TO
M1, S3 , S8, D2


*Image: The Exploded View Beyond Building DDW 2021*

## Theoretical Background

The results of the study suggest that experimenting with new ideas and approaches is essential to drive innovation. Innovation often requires a willingness to try something new, and sometimes it may take several attempts to find a solution that works. It is importand to experiment and trying new approaches, even if it means that some experiments fail. It is better to try something three times and have two failed attempts than to spend a long time discussing how it should be done without actually taking any action. To implement the circular economy, it is advisable to develop best practices and guidelines through rapid collaborative experiments and the validation of underlying assumptions (Brown et al, 2019).

## References

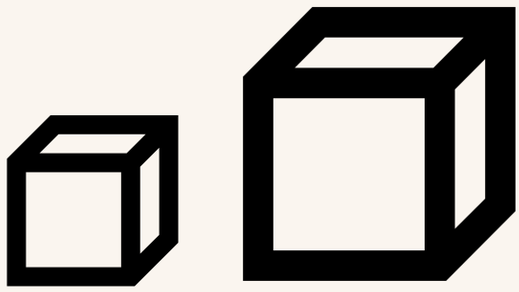
Brown et al, 2019

## Recommendations

Be open to trying and exploring new things. Each time something new is attempted, there is an opportunity to learn from the experiment, even if the desired outcome is not initially achieved. By repeating the process, the experiment can be fine-tuned until a satisfactory end product is achieved. This approach goes beyond innovation solely driven by meetings and discussions.

## Methods

Literature, interviews



# K2 START SMALL

START SMALL TO GAIN KNOWLEDGE FOR A LARGER SCALE.

CONNECTED TO
G1, S2, S3, G1

*Image: Fortbrug, Weesp*

## Theoretical Background

Innovation plays a critical role in developing circular practices. However, it is not enough to create innovative solutions without scaling them up effectively. There needs to be more focus on how to implement and scale circular practices across the industry (Zhang, 2020).

Try to innovate with small steps. By slowly demonstrating what is possible, you learn from the processes. The construction world is already complex enough and by taking small steps it is easier to apply circularity and find out what does and does not work within an organisation. This works better than applying an innovation to a large project all at once.

## References

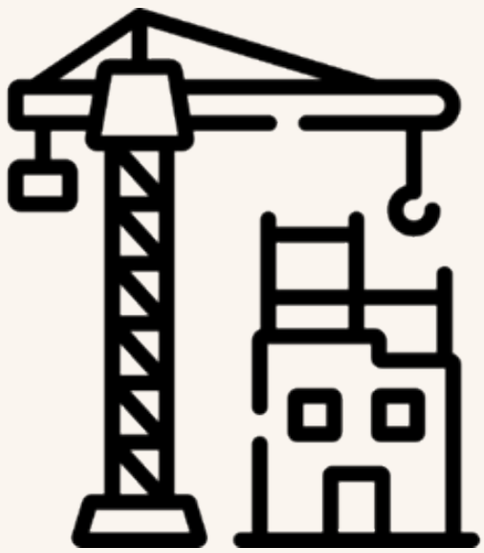
Zhang, 2020

## Recommendations

Try to initiate innovative circular projects on a small and simple scale. This approach allows for knowledge acquisition and identification of what works and what does not. Subsequently, the lessons learned can be applied on a larger scale.
While innovation is still necessary in certain areas, such as scaling up successful circular initiatives, it is critical to ensure that the innovations are integrated into the wider framework of the circular building economy. Ultimately, the success of circular projects lies in the effective implementation of circular principles at all stages of the project, including contract design, criteria selection, and collaboration.

## Methods

Literature, interviews



# K3 BARRIERS TO THE CIRCULAR BUILDING TRANSITION

THE CURRENT CAPACITY OF CIRCULAR BUILDING PROJECTS IS RESTRICTED FROM EXPANSION DUE TO CULTURAL, FINANCIAL,

LEGISLATIVE AND SECTORAL BARRIERS

CONNECTED TO
F1, F2, G5, S8

*Image: An image displaying how the current circular building barriers must be surpassed for continuation (National Elf Service, 2015)*

## Theoretical Background

There exist several barriers which impede the progress towards upscaling and should be tackled: cultural, regulatory, financial, and sectoral barriers (Hart et al., 2019). Cultural barriers include resistance within the value chain: companies may not want to undergo circular building projects within a value chain which only provides linear logistics in opposition to the required circular mechanisms (Kirchherr et al., 2018). The existence of fierce horizontal competition within the construction sector fails to stimulate collaboration, rather only encouraging vertical integration which does not necessarily facilitate knowledge transfer (Hart et al., 2019). Furthermore, regulatory barriers exist due to unclarity upon the required legal approach: ministries do not always agree on a concrete steppingstone plan – causing confusion among the public (Hart et al., 2019). There also exist high financial barriers against the adoption of circular building. Due to the business requirement of reaping profits, the long-term outlook and returns of circular building pilots are not appealing to private businesses – decreasing cross-sectoral and society- based collaborations (Carra & Magdani, 2017). Circular building requires high levels of upfront investments specifically to improve the logistics across the value chain – discouraging businesses from becoming first-movers in the market (Hart et al., 2019; Hopinkson et al., 2018)

## References

Hart et al., 2019
Kirchherr et al., 2018
Carra & Magdani, 2017
Hopinkson et al., 2018

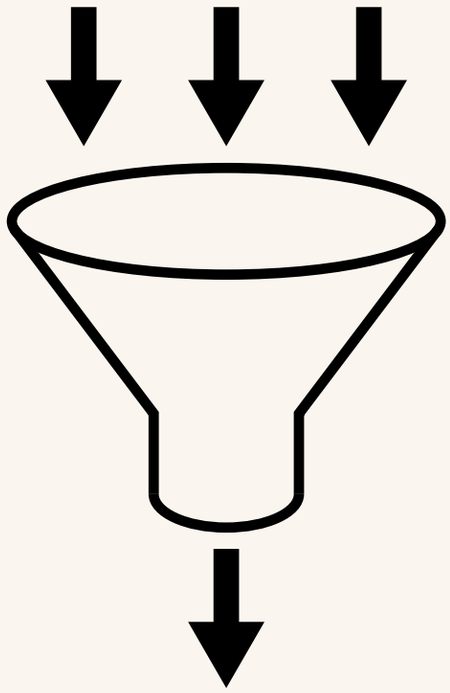
## Recommendations

While the technological knowledge is well-established, there is a difficulty in achieving certification or surpassing the legislative requirements to apply it in real-world settings. This is due to the lack of material passports and the usage of bio- based materials within circular buildings, which may in some instances pose a threat to the safety and wellbeing of the residents. Consequently, both legislation and certification have proven to be prominent barriers in the field – albeit legislation being sometimes utilized as an easy excuse. The cost of circular building is not profitable and there is yet to be a dependable business case developed. However, the interviewees stressed that this is the case with all innovations, giving numerous references to the energy transition and the cost of solar panels at their initiation versus their current cost. Thus, the time perspective should be long- term – incorporating the environmental cost into the equations. There is a need for novel business models to overcome the current risk aversion. Circularity needs to be exhaustive – not only do all new buildings have to be circular, but the old ones need to be modified to become circular as well, which will consume a lot of time.

## Methods

Literature review and data analysis (13 semi-structured interviews)

# FINANCIAL



# F1 COST OPTIMISATION

COST OPTIMISATION THROUGH SIMPLIFIED PROCESSES AND ACCOUNTING TRUE ENVIRONMENTAL COST FOR COMMERCIAL VIABILITY

CONNECTED TO
K1, G5, T6, S6

*Image: pxhere.com*

## Theoretical Background

Circular viaduct project witnessed attractiveness, reuse of components (girder), hence preserving material, and functionality of components, also due to implied avoidance of waste handling and associated fee (Rakhshan et al., 2020c) and implied reduced energy consumption (Bilal et al., 2020). A contradiction from literature was found in terms of cost saving potential of circular construction projects compared to conventional projects, (Dantata et al., 2005b; Dantata et al., Dantata, Touran, & Wang, 2005c; Tan et al., 2018), as the Hoog Burel project didn't make a strong financial case as indicated in literature (Adams et al., 2017c)

## Recommendations

- Looking for avenues to minimize cost and time,
- Taking into account real environmental costs
- aking a lifecycle perspective
- Intrinsic value gain

## References

## Methods

Interview
Secondary Data
Qualitative Analysis

# F2 A “CHEAPER” GREEN ROOF LIFECYCLE

EVEN THOUGH THE INITIAL COST OF BOTH EXTENSIVE AND INTENSIVE GREEN ROOFS IS HIGHER THAN CONVENTIONAL ROOFS, WHEN SOME OF THE ENVIRONMENTAL BENEFITS OF GREEN ROOFS (ENERGY SAVING, CARBON STORAGE AND RAINWATER STORAGE) ARE QUANTIFIED AS COSTS, THE LONG-TERM COST PERFORMANCE WILL BE BETTER THAN CONVENTIONAL ROOFS.

CONNECTED TO
F1 T2, K1, T7, T1

## Theoretical Background

Green roofs are often thought of as long-term investments with short-term returns(Bianchini et al,. 2012). To be precise, the installation of green roofs requires a significant investment, the cost of which varies depending on the type of green roof, its location, labour and equipment, and in addition to these costs, additional costs are incurred for operation, maintenance and eventual disposal(Vijayaraghavan, 2016). Few studies have been conducted to analyse the costs of applying green roof systems in cities. As a result, the return on this investment is either unknown or very difficult to understand. Most studies ignore certain aspects of the cost-benefit analysis, which leads to a bias in the final observations. It is absolutely needed as a part of the decision-making process. From author's perspective, the potential profit of a green roof is much higher than its potential losses. (Vijayaraghavan, 2016).

## References

Vijayaraghavan, 2016
Bianchini et al,. 2012

## Recommendations

Even though, after calculation, many of the environmental benefits are quantified so that the life-cycle cost costs of both green roofs are lower than those of conventional roofs, there are certain budgetary constraints that allow interventions at different stages of the green roof life-cycle process based on the calculated cost hotspots, but there are conflicting cost hotspots when combined with the environmental hotspots of green roofs, such as the use of more sustainable layer materials that increase costs. However, in order for Campus to become the green lung of Westland in the future, the government should develop corresponding policies so that environmental performance is not heavily sacrificed for the sake of cost reduction.
(Vijayaraghavan, 2016).

## Methods

Literature review; Life Cycle Cost Analysis

# SYSTEM CHANGES

# S1 SHARE RESOURCES

DESIGNING FOR RESOURCE AND SPACE SHARING AMONG OCCUPANTS.

CONNECTED TO
G2, G7, R1, R2, R6

## Theoretical Background

In circular building design, resource sharing aims to operationalize multiplicity in the use of assets in order to maximize the efficiency of resource utilization (Hamida et al., 2022). Resource sharing can be promoted in different ways, including the provision of multipurpose facilities and sharable assets (Askar et al., 2021).

## Recommendations

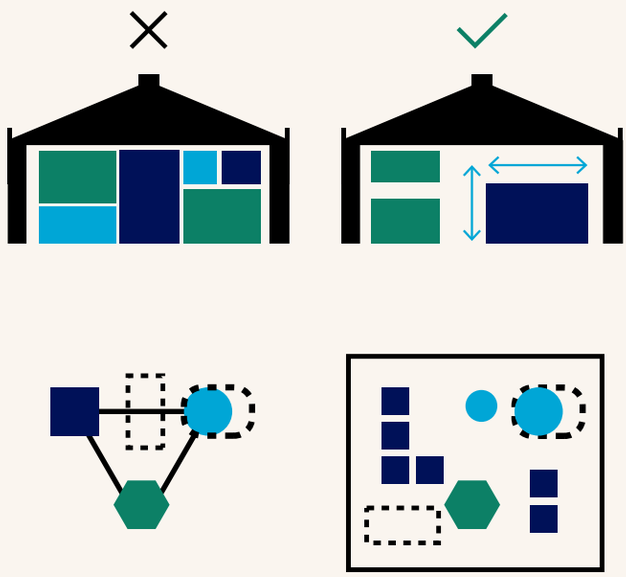
For instance, designers can configure buildings with adaptable and flexible spaces, provide multifunctional spaces that can be used for multiple purposes (Ness and Xing, 2017), and incorporate systems for sharing information digitally (Dewagoda et al., 2022).

## References


Askar et al., 2021
Dewagoda et al., 2022
Hamida et al., 2022
Ness and Xing, 2017


## Methods

Literature Review



# S2 CREATING FLEXIBILITY

TO FACILITATE RECONFIGURATION OF CIRCULAR ACTIVITIES, OFFER FLEXIBLE CONTRACTS & FACILITATE FURTHER DEVELOPMENTS

CONNECTED TO
G2, D5, S3, S8, M3


*IMAGE:*

## Theoretical Background

Flexible accommodation does not only allow for a diversity of use and growth of the companies, but also facilitates the uncertainty that many companies and (urban) developers face about their future requirements. As companies develop, their requirements do as well and new companies can be introduced in a different economic context, which also requires accommodation that can adapt to these requirements (Groeneveld, 2016) Some buildings, such as industrial heritage, often offer this by default due to overdimension and size and structure of these buildings (Dell'anna, 2022; Tennekes et al., 2022), while new buildings are often much more tailored to a specific use. In addition, industries do not only grow, but scale. down sometimes, especially in on-demand produc-
tion, which should also be facilitated by the building (Hill et al., 2020)

## References

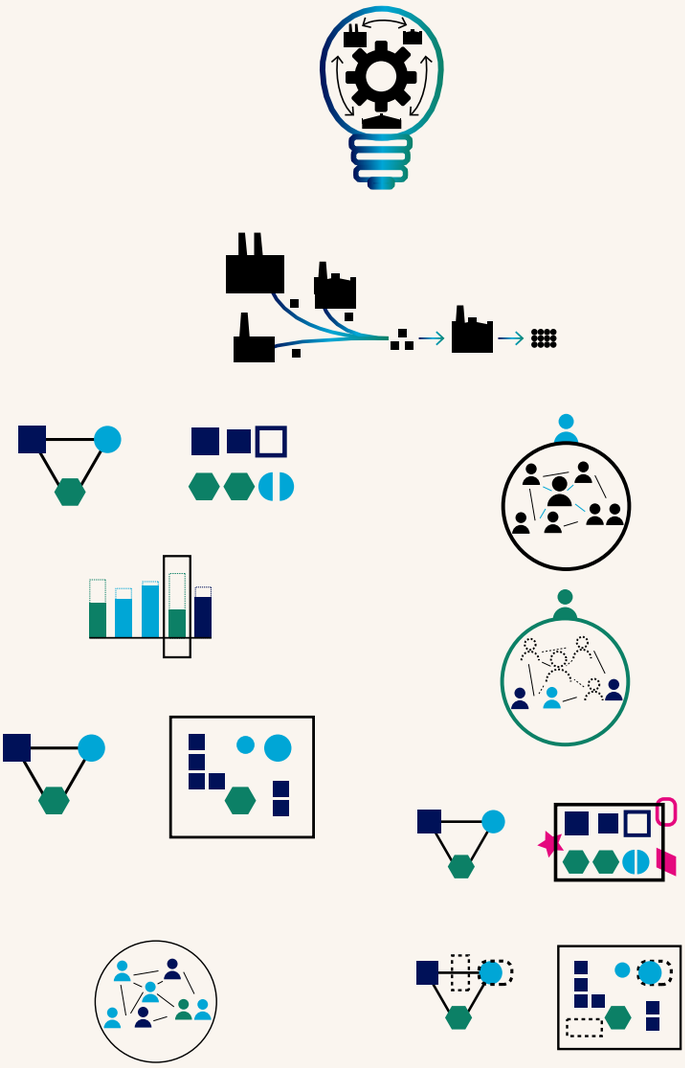
Groeneveld, 2016
Dell'anna, 2022
Tennekes et al., 2022
Hill et al., 2020

## Recommendations

Create flexibility
Create built-in flexibility: flexible layout, larger units of 1000m2, modular workspaces for multiple companies and room for growth and reconfiguration to facilitate scaling up-down High demand for companies in between first steps and larger scale-ups Avoid focus on only efficiency to maintain flexibility Move along with the changing requirements of users cooperation & flexibility of public parties Allowing flexible land-use & zoning: based on actual nuisance levels Maintaining a close relation during development & use phase Maintain Flexibility Make sure to maintain space for reconfiguration of tenants Offer flexible contracts Maintain & develop concept Make sure to have room for reconfiguration of tenants / buffer Offer flexible contracts for future changes in (space) requirements.

## Methods

Literature review
Interviews
Expert review



# S3 CLUSTERING (WITHIN A CERTAIN CONCEPT)

CLUSTERING COMPLEMENTARY COMPANIES FOR INNOVATION / CLUSTERING SIMILAR COMPANIES OR URBAN FUNCTIONS FOR CIRCULAR FLOWS

CONNECTED TO
S1, S2, S8, K1, G4, K2, M3

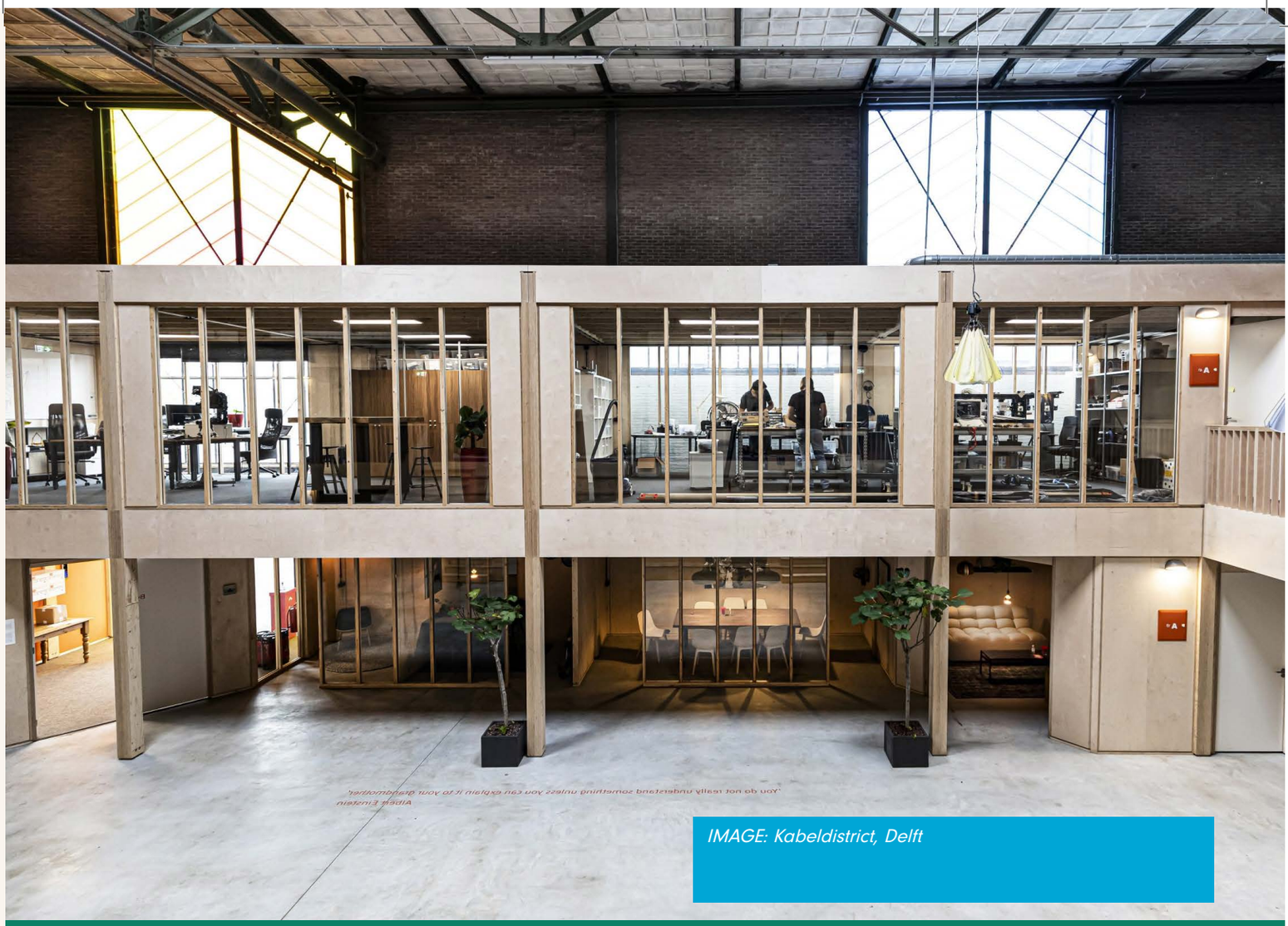


*IMAGE: Kabeldistrict, Delft*

## Theoretical Background

Clustering can help achieve knowledge exchange, facilitate trust and communication between companies which can result in innovation and facilitate them in their growth or development. (Grodach & Gibson, 2019; Grodach & Martin, 2021; Spalanzani et al., 2016). In addition, by clustering, a critical mass can be created which allows companies to (re)use material wasteflows locally by adding a function for processing these materials.

By selecting certain companies withing a certain concept in an area development, the right conditions can be created to stimulate circular practices and to realise successful urban areas. These don't have to be exactly the same, but can be complementary ( see pattern C2) and understand and respect each others production process to allow for coexistence at the same area.

Locations for such clusters are most likely found in the edges of cities, as here relevant economic, material and human (resource) flows come together (Girard, 2013; Girard & Nocca, 2019; Hill, 2020; Spalanzani et al., 2016). It is therefore also important to maintain these areas and reserve space for the circular functioning of the city (Jager, 2022; Ministerie van Economische Zaken en Klimaat, 2022; Hausleitner et al., 2022).

## References


Grodach & Gibson, 2019
Grodach & Martin, 2021
Spalanzani et al., 2016
Girard, 2013
Girard & Nocca, 2019
Hill et al., 2020
Jager, 2022
Ministerie van Economische Zaken en Klimaat, 2022
Hausleitner et al., 2022


## Recommendations

**Clustering complementary companies for innovation**
Complementary companies + support network.
Exchange of ideas, sharing processes to change > towards circularity

**Clustering similar companies for circular flows**
Gather & process waste locally / create a critical mass (resource)
Add complementary company to reuse waste (complete circle)

**Select & safeguard companies within concept**
Based on being complementary / like-minded / valueing heritage and concept / commitment to maintain heritage and concept and participation in community / (stable) source of income & market potential for a long-term contribution / similar steps in production process / similar financial means or types to avoid competition for space: commercial gentrification

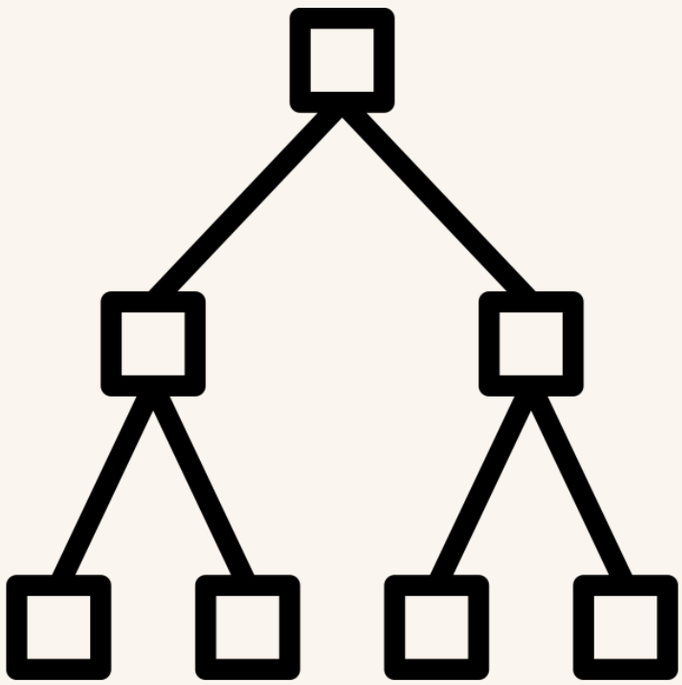
**Embed development and concept in (future) economic context**
Analyse economic gaps, future developments, proactive development

**Create concept & facilitate this**
Embedded in (economic) context,it should be 'real'
Basic placemaking
Based on a theme/ campus concept
Based on complementary economic functions, accessibility and present infrastructure
Maintain this concept
Provide the basics (accomodation, infrastructure & space) so it can be tailored to, and bycompanies.

**Facilitate & manager a network & community**
Appoint a permanent & accessible location/network manager to create a community, select companies and establish a network on different scales
Maintain involved for changes in requirements, thinking along & maintaining network
External relations: surrounding urban areas
Organised community events by companies (informal), offer support
Unorganised: facilitate & allow independent events (informal, no intermediate person)

## Methods

Literature review
Interviews
Expert reviews



# S4 SUPPORT FROM THE ORGANISATION

THE CIRCULAR POLICIES MAY NOT BE ADEQUATELY TRANSLATED INTO ACTION, WHICH MEANS THAT EMPLOYEES LACK THE RESOURCES AND FREEDOM TO IMPLEMENT CIRCULAR PRACTICES EFFECTIVELY

CONNECTED TO
S8, G1, G3, G4

## Theoretical Background

Top managers need to be more culturally open to make decisions about circular innovation (Kuhlmann et al.,2022).. Sometimes, an individual may want to make a project circular, but their organization behind this person must have the space to accommodate this. However, it is often the case that individuals are impeded by their organizations in this regard. This often stems from standard rules applied within companies, such as the NEN or minimum profit requirements that need to be met. However, the implementation of the circular economy often involves significant innovation that is not yet incorporated into standard policies and regulations. Strict adherence to these policies and regulations hinders the application of innovation in the circular context.

## References

Kuhlmann et al.,2022

## Recommendations

It is essential for organizations to support individuals as much as possible. Often, individuals are hindered in implementing the circular economy by their own companies. This is frequently due to top-down decision-making within the organization, where only standard rules are considered.
For this reason, it is important for organizations not to solely adhere to regulations and focus solely on profit, but to provide greater freedom to individuals to implement circularity in their projects.

## Methods

Interviews, literature

# S5 EXISTENCE OF THE PILOT-PARADOX

THE CURRENT PURPOSES OF CIRCULAR BUILDING PILOT PROJECTS ARE LIMITED TO PROOF OF CONCEPT, MARKETING AND INSPIRATION WHICH HINDERS THE OPPORTUNITIES OF

UPSCALING AND CONFIRMS THE PILOTPARADOX

CONNECTED TO
K1, G1, D2

*Image: The intricate thinking process and interconnectedness within pilot projects (Sintef,n.d.)*

## Theoretical Background

The scalability of circular building solutions is restricted by the lack of systemic thinking, structural change, and replicability of current projects. This ties to the pilotparadox: "Pilots never fail, they also never scale". Several studies have displayed the lack of expansion from pilot studies to large-scale projects since the pilots merely act as a means of demonstration (Billé, 2010; Cooley & Howard, 2019; Monitor Deloitte, 2015; van Winden & van den Buuse, 2017; Woltering et al., 2019). This pilot-paradox posits a clear limitation to the adoption of circular building on a wide-scale. Consequently, an assessment of the pilotparadox within the scope of the circular building field can overcome the challenge and increase the propensity for scaling. The first step of developing successful replication methods is to determine the current state of the change context and to assess the purposes of circular building pilot projects.

## Recommendations

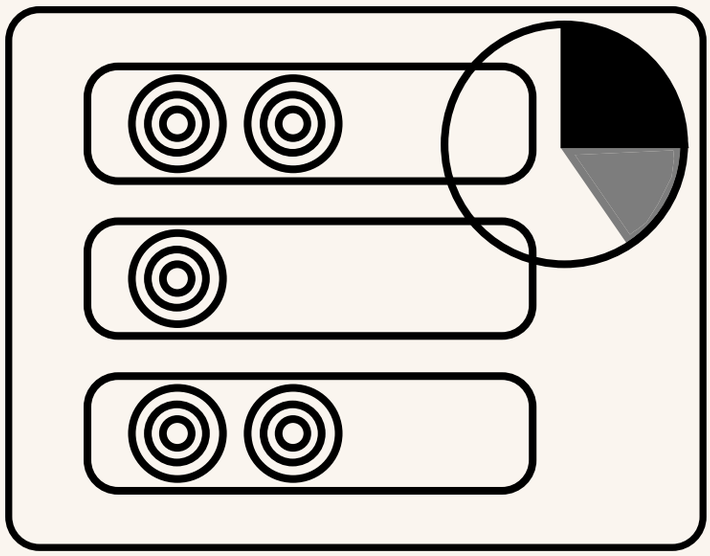
During the interviews, the participants unanimously agreed about the existence of the pilot-paradox in practice. Participants emphasized that pilots are indeed successful, yet they do not result in the required systemic change to upscale the transition to circular building. The unfortunate aspect about pilot projects is that while they illicit enthusiasm at the start of the project, this enthusiasm and dedication tends to die out as the pilots progress or are finished – heightened by the lack of futuristic aims or goal setting within the pilots. Three main functions were established on the basis of circular building pilots: used as a proof of concept, used for marketing purposes, and used for inspiration. Participants iterated that the pilots were mostly used to "put the flag on and cut the rope and say, okay, look how nice it is", albeit having a much higher potential for impact. Moreover, pilots are viewed as a great marketing tool with which organizations can enhance their public image. Consequently, organizations in the industry need to acknowledge this occurrence and instead plan for upscaling. They should ensure knowledge capture from both successful and failed pilots.

## References


Billé, 2010
Cooley & Howard, 2019
Monitor Deloitte, 2015
van Winden & van den Buuse, 2017
Woltering et al., 2019


## Methods

Literature review and data analysis (13 semi-structured interviews)



# S6 DIVERGENT VIEWS

DIVERGENT VIEWS ON CHANGING ROLES AND ASSOCIATED COMPETENCIES OF INDIVIDUAL ACTORS IN CIRCULAR  USINESS MODEL.

CONNECTED TO
G5, F1, M3, T6

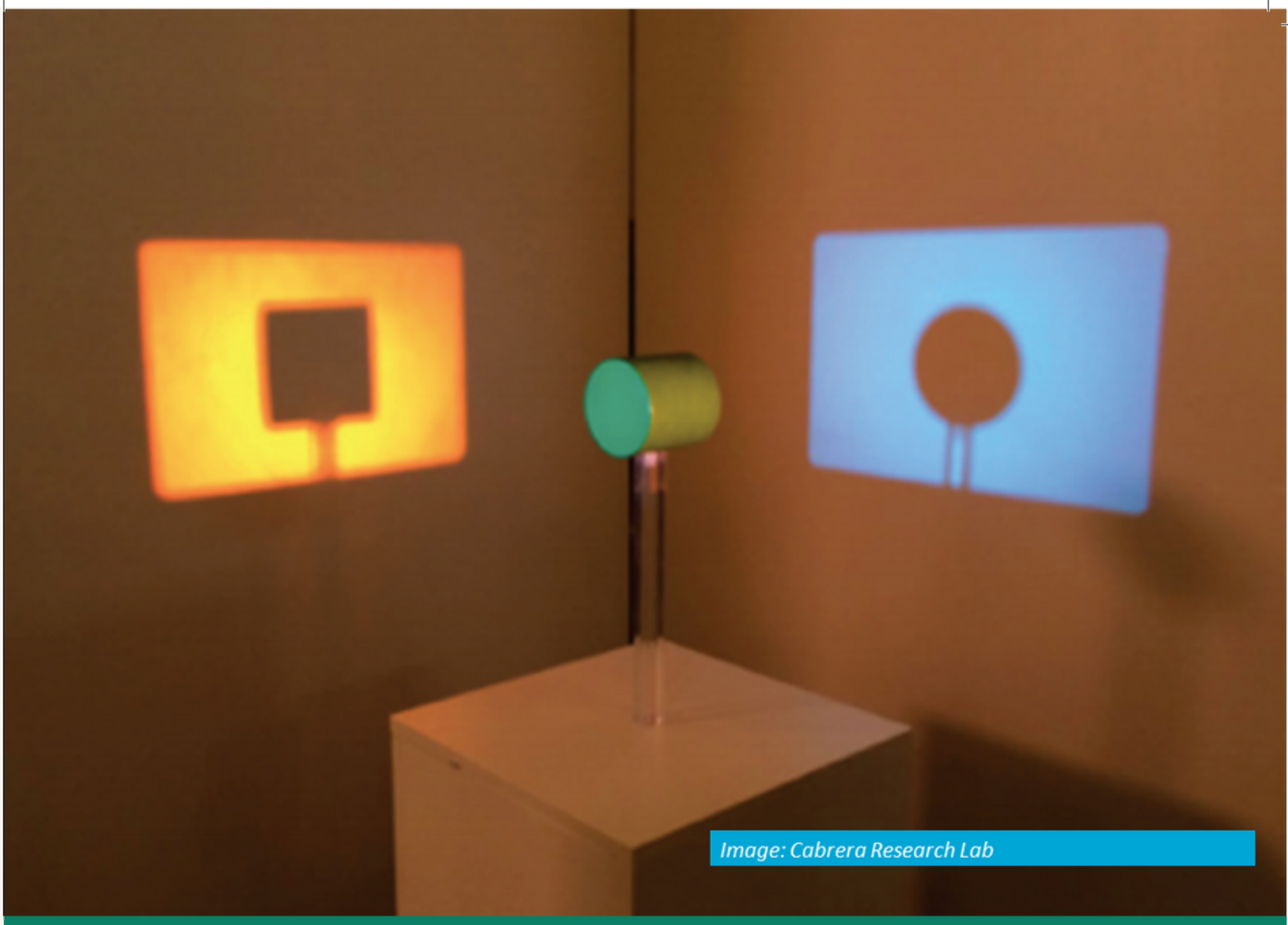


*Image: Cabrera Research Lab*

## Theoretical Background

The circular viaduct was found to be characterized by multiple stakeholders striving for common goals (Ratna et al., 2018), and was considered key to the success of reuse (Acciarri et al., 2017; Charef et al., 2021; Hart et al., 2019c). It was validated that CBM is different from Linear BM on various parameters including, the innovativeness of BM (Planing, 2015), new project organization (Pinto & Winch, 2016), new competencies (PlatformCB23, 2021) need for intensive cooperation (Venselaar et al., 2019), complex project scope (van Elburg, 2008) varied perspectives of stakeholders (Reichel, 2008). New structure and new governance of responsibilities (Ludeke-Freund et al., 2019) required.

## References

## Recommendations

- Circular Business Model (CBM) proved to be vital for the success of circular infrastructure projects.

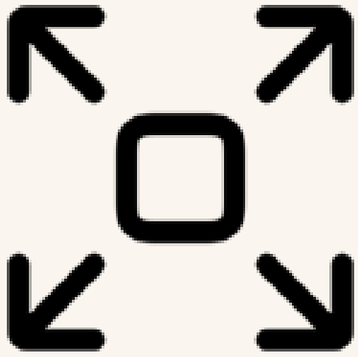
- New business opportunities emerged for construction firms, material providers, and demolition contractor.

- Incentivizing and Building new competencies for demolition contractors.

- Need of redefining roles and responsibilities related to component search.

## Methods

Interview
Secondary Data
Qualitative Analysis



# S7 UPSCALING BEYOND PILOT PROJECTS

THE SUCCES OF CIRCULAR BUILDING PILOTS CAN BE UPSCALED TO ELICIT SYSTEM CHANGE BY REFRAMING THE

PURPOSE OF THE PILOTS IN THE LARGER SCHEME OF THINGS

CONNECTED TO
M3, G1, K1

*Image: An image embodying upscaling within several distinct points in the respective cities and countries (City Innovators Forum, 2019)*

## Theoretical Background

Despite successful pilot projects and the involvement of local municipalities and partnerships within such pilots, smart city endeavors appear to 'fade out' – limiting scalability opportunities (van Winden & van den Buuse, 2017). Urban development pilots are used for demonstration purposes and implemented within highly controlled environments which do not mimic the requirements for an enabling external environment, and this restricts the feasibility of transitioning to real-world projects (Woltering et al., 2019). A contributor to the lack of scalability is the respective fuzziness around (up)scaling's definition – contributing to a superficial use of the concept (van Winden & van den Buuse, 2017). Since there exists low methodological and conceptual crystallization on the boundaries of upscaling, participants in the pilot tend to subsequently aim for lower expectations of expansion (Woltering et al., 2019). The research will explore how structural change can be implemented within the field of circular building – utilizing a multisectoral approach to ensure that successful projects exceed the pilot threshold. Successful replication methods must be developed to reach the maximum capacity of benefits given the proven technological knowhow developed within such pilots.

## References

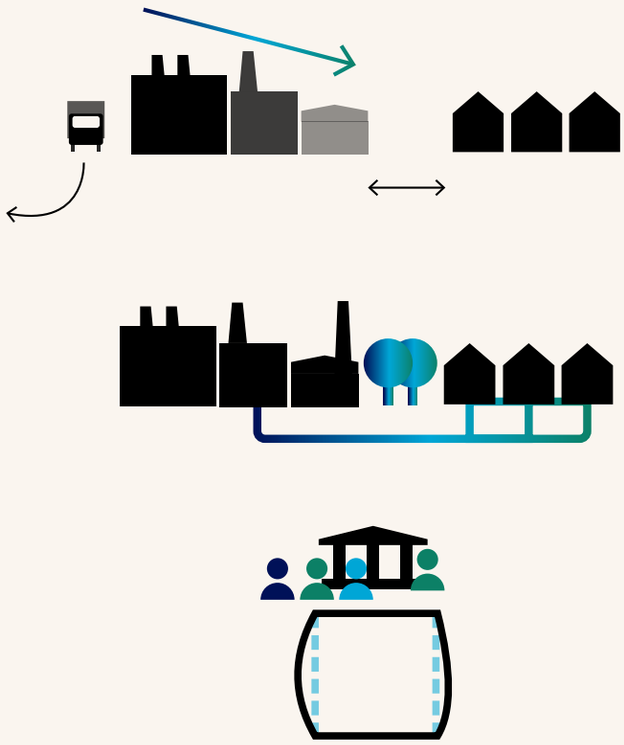
van Winden & van den Buuse, 2017
Woltering et al., 2019

## Recommendations

The data displayed that successful pilots will never be upscaled unless adequate time is assigned for upscaling at the initiation and post-pilot evaluation. The pilots need to be framed within the larger sphere of the system to capitalize on the presented technological benefits and successful endeavors. Similarly, the boundaries of upscaling and of circular building should be well-established: the organizations need to forecast a trajectory for upscaling and establish a definition for the constituents of circularity. The strategies towards pilots should be grounded in backcasting: first envisioning the desired industry and developing a steppingstone plan to reach the end goal. Since the pilots were displayed to be proof of concept, marketing, or inspiration, there needs to be a heightened sense of chaos and urgency established to encourage the quick mobilization of firms. The current line of thinking views circular building projects as a niche market. The built environment needs to realize the material scarcity and rising prices which will force the adoption of circular building – one way or another. Furthermore, there needs to be a digitization of knowledge sharing among the industry. Rather than working on diverged paths, firms' collaboration on a knowledge platform will accelerate the time to market specific innovations.

## Methods

Literature review and data analysis (13 semi-structured interviews)



# S8 INVOLVING THE SURROUNDINGS

SELECT, DESIGN & MAINTAIN THE RIGHT LOCATIONS / INVEST IN RELATIONS WITH SURROUNDINGS / COOPERATION &

FLEXIBILITY OF PUBLIC PARTIES

CONNECTED TO
S2, S3, S4, G1, K1, G4, K3, D4

*IMAGE: Manner factory, Vienna*

## Theoretical Background

Productive functions like manufacturing and revitalisation of urban areas can give a lot to the urban surroundings, but it is also important that this is accepted (Arfa et al., 2022; Dell'anna, 2022; Foster, 2020). Besides a selection on the most suitable urban companies and transition zoning to reduce nuisance, acceptance can be created by giving back to the surroundings to improve this relationship, such as waste heat or additional services, to also create the conditions for further (circular) relationships.

Finally, having a mix of uses at the same site requires flexibility from developers and public parties. New forms of manufacturing can be better combined with other functions due to innovative production processes, but land-use and development plans should facilitate this by being flexible and open for experiment as the industry and urban development principles are changing faster than regulation sometimes.

## References


Arfa et al., 2022
Dell'anna, 2022
Foster, 2020


## Recommendations

**Select & design locations for production**
Select locations for producing higher levels of nuisance for companies who need this
Avoid logistic infrastructure crossing residential neighbourhoods
Apply environmental zoning for nuisance / fading towards the (noise-sensitive/residential)
city:
A transition in building types to facilitate a transition in functions

**Invest in relations with surroundings**
Giving something back to the surroundings for acceptance of urban manufacturing. This can
foster collaboration and better relationships, which is required for potential circular networks
In this way, mixed use developments cán be successful and become circular

**Cooperation & flexibility of public parties**
Allowing flexible land-use & zoning: based on actual nuisance levels
Maintaining a close relation during development & use phase

**Safeguard space for manufacturing: public parties & developers**
Be critical on urban developments near logistic network
Take the context of new urban developments into account when redeveloping near manufacturing site

## Methods

Literature review
Interviews
Expert reviews

# MINDSET CHANGES

# M1 LIFESTYLE TRADE-OFFS

TO CHANGE THE BUILT ENVIRONMENT, THE WAY PEOPLE LIVE IN THE BUILDINGS COULD BE CHANGED. GROWING POPULATION IMPLIES GROWTH OF CO-LIVING AND SMART USE OF LIVING SPACE.

CONNECTED TO

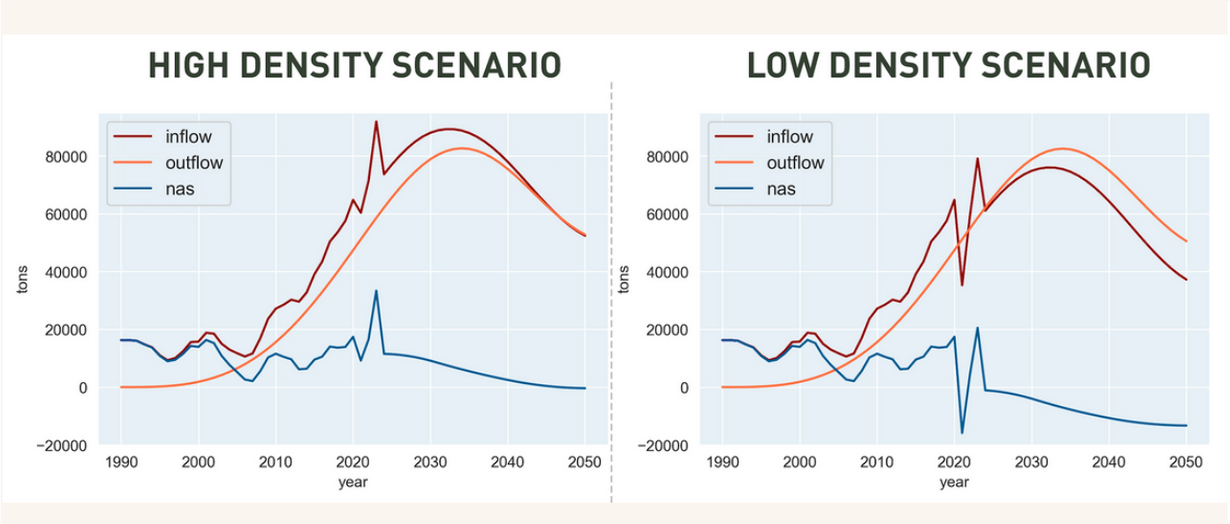



*Image: Density of householdss scenarios , by author*

## Theoretical Background

Larger amounts of demolition and higher recycling rates support the production of secondary materials. Yet following the population growth projections, housing the Dutch population with the same density of persons per household as in 2021 will not create a surplus of demolished buildings until 2047. Therefore, the alternative scenario was researched, when the households' density decreased from an average of 2,2 persons per household by 10% (an average of 2,4 persons per household). In the research of possible future wood flows in the construction of residential buildings, the scenario of decreased household density (les persons per household) and increased use of wood has shown that the outflow of wood material from the construction is higher than the demand for the new buildings. Such circumstances open an opportunity for widening the secondary material market and cutting the primary wood consumption by the built environment.

## References

## Recommendations

Along with the previously described methods regarding inflows of wood, the demand also could be manipulated. To provide the growing population with enough households, the density of the persons per household could be increased, meaning the living space for each person will go down or more co-living is promoted. For example, increasing the number of persons per household from 2,19 (2020 value) by 10% till 2050 lowers the inflow of wooden material significantly. Such change requires a shift in the lifestyle of the Dutch population that could be promoted by the government. Promotion of co-living practices or bigger family households, as well as smaller private spaces and bigger common areas, are some of the possible recommendations, for minimizing the effects of the increased demand for wood.

## Methods

Dynamic Material Flow analysis model

# M2 GAMIFYING CIRCULAR BUILDING GOALS

GAMIFICATION POSITS AN INTERESTING AND FUN POTENTIAL METHOD TO ENCOURAGE THE PRIVATE SECTOR TO ADOPT CIRCULAR BUILDING DESPITE SLOW-MOVING GOVERNMENTAL REGULATIONS

CONNECTED TO
D2, S3

*Image: Quantifying and gamifying circular building goals can connect actors within the network and motivate them (Edublogs, 2019)*

## Theoretical Background

When it comes to tackling prevalent sustainability challenges like that of circularity, the mainstream approach adopted is the creation of a business case, which has proven to be unsuccessful as it takes the economic gain as the core prerequisite – indirectly decreasing the importance of the environmental and social aspects (Hahn et al., 2014). Entities within the circular building field must simultaneously tackle legislation requirements, consider consumer demands, while ensuring sufficient profits. The circular building ecosystem can therefore be classified as a complex adaptive system which is enriched by the self-organization of the respective stakeholders in shaping the building environment, the feedback loops across distinct levels of the supply chain, and the communicative hierarchies present along the vertical chain of command (including governments, businesses, suppliers, and consumers) (Holling, 2001; Grewatsch et al., 2021). Moreover, studies like those by Kanters (2020) have displayed that the pilot-paradox is exacerbated by the lack of political priority regarding circular building – governmental regulations in this area appear to be slow-moving. Thus, a method to encourage the private sector to willingly adopt circular building should be established until the legislative requirement to have completely circular buildings is set.

## References

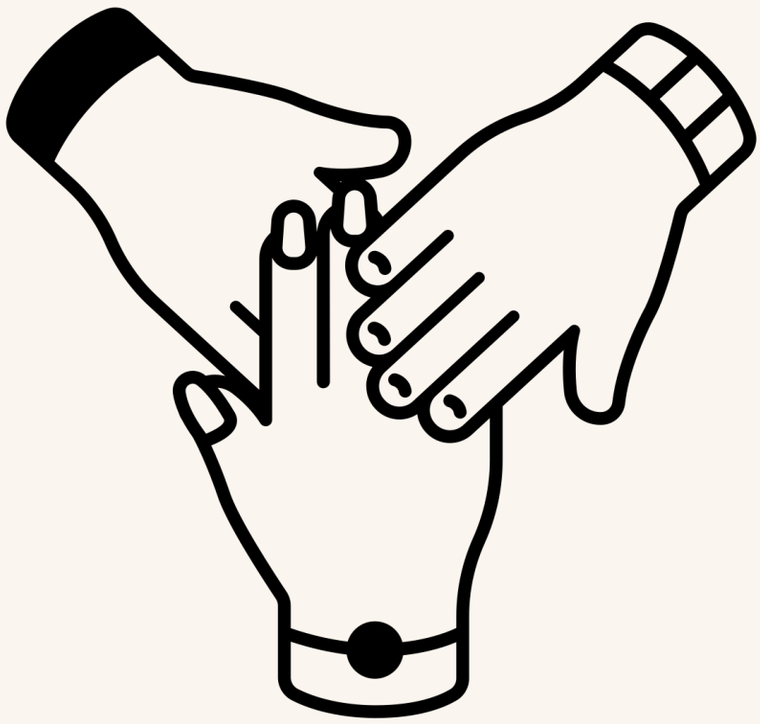

Hahn et al., 2014
Holling, 2001
Grewatsch et al., 2021
Kanters, 2020


## Recommendations

The government should clarify the implications of the overarching circularity goal of 2050 by quantifying the goals which should be reached and catering them to local settings (e.g., 10,000 circular houses in Rotterdam in one year and 5,000 in the Hague). The concept of gamification can be applied to governmental goals – making it more fun for the involved companies and giving awards (which serve as a subsequent form of marketing). This suggestion is applicable to both general goals and pilot-specific goals. The idea of gamification stemmed from discussions over the unclarity around the 2050 goal, and it was expressed as a potential method to enrich accountability as needed. It can be achieved by setting some sort of competition around it – giving awards to companies who have the best progress. Subsequently, there will be a higher incentive to work towards circular building and upscaling pilots than there would be from legislation alone. Correspondingly, organizations will feel like they are acting out of their own accord to be more circular which will decrease the accompanying resistance. Simultaneously, the awards and the progress can be used as marketing for the respective organization's actions towards circularity and sustainability – improving the surrounding business case.

## Methods

Literature review and data analysis (13 semi-structured interviews)



# M3 COLLABORATIONS IN THE EARLY STAGES

IN THE EARLY STAGES OF A PROJECT, IT IS IMPORTANT TO SEEK COLLABORATIONS WITH SPECIALISTS AND INDIVIDUALS WHO HAVE IDEALISTIC GOALS

CONNECTED TO
G4, S7

## Theoretical Background

All parties must be involved early in the project to ensure that personal ambitions can become a shared goal. Alignment of interests and behaviour between organisations are two key factors on which collaborative relationships depend (Berardi & Brito, 2021). To successfully complete complex projects like circular construction, it is important to establish everyone's goals from the beginning of the project. This way, everyone has the same expectations and can work towards a common objective.

## Recommendations

It is beneficial to align with all parties involved in circular projects from the beginning to determine everyone's expectations and the project's end goals. This way, everyone is aware of the desired outcomes and can work towards a unified objective, avoiding conflicting goals among different stakeholders. It is also important that the involved parties include specialists and individuals with idealistic goals.

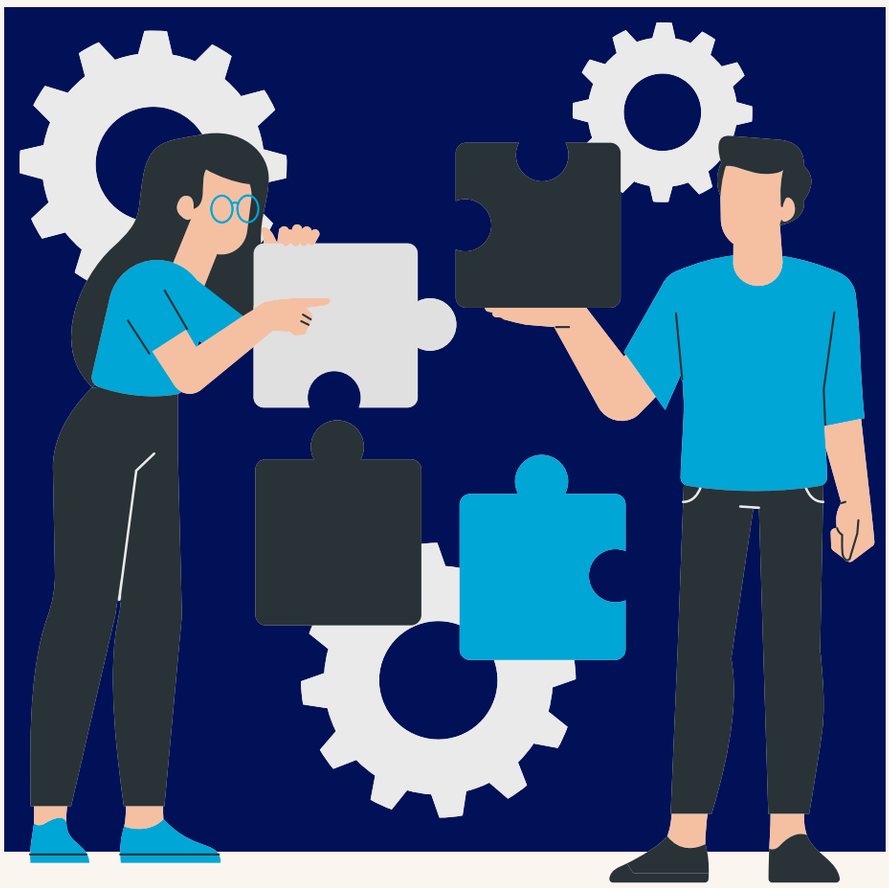
## References

Berardi & Brito, 2021

## Methods

Literature, interviews

# MATERIALS/
# DESIGN



# D1 COMPLEX SOLUTION

SUSTAINABLE CONSTRUCTION REQUIRES A COMPLEX MULTIDISCIPLINARY SOLUTION. FOCUSING ON ONE SOLUTION FOR THE DECARBONIZATION OF THE CONSTRUCTION SECTOR

COMES WITH RISKS.

CONNECTED TO
K1

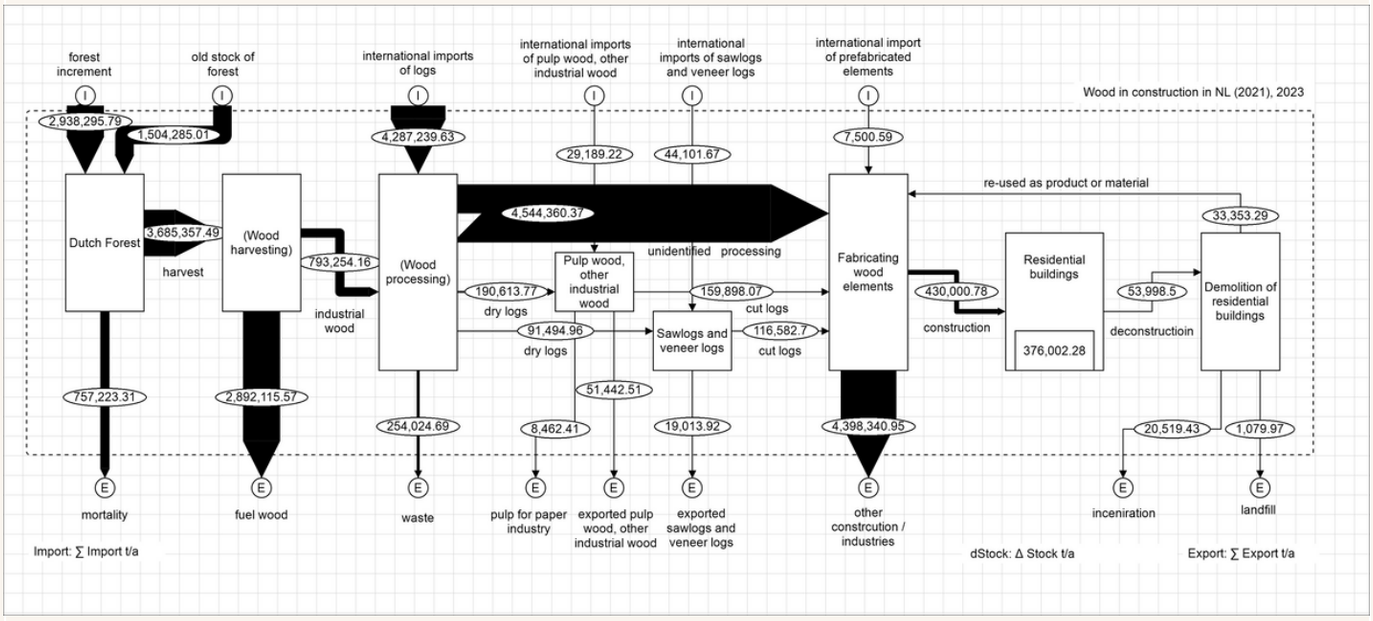



*Image: Static material flow model , by author*

## Theoretical Background

Wider use of wood in future construction was found to be an effective strategy for countries with high wood supply, could it be also the case for the Netherlands? The research has shown, increasing wood material intensity of rural and urban households by 100% creates heavy dependency on international imports in the short term. The model for the prospective use of timber in construction of the residential buildings has shown that both the local supply of wood and the supply of recycled wood could not compensate for the growing demand for material. Without proper land management and subsidies for certain land use, increasing the local supply threatens biodiversity in the Netherlands as well as puts pressure on the agriculture sector which also requires vast amounts of land. According to the model, the pursuit of wider use of recycled wood is only possible in the case of recycling rate of wood waste is exceptionally effective: by 2047, 100% of the wood coming out of the stock of residential buildings after demolition should return to the new residential stock.

## Recommendations

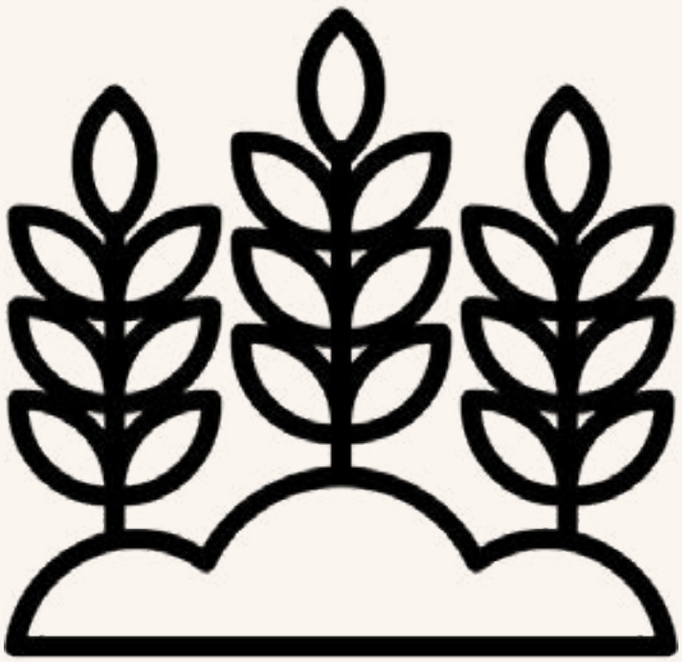
For the sustainable growth of wood-use in the Dutch constriction sector, all options to satisfy the growing demand for timber should be considered. If the average density of the household is kept the same as in 2020, no single-inflow solution is enough to meet the needs for sustainable construction. Therefore, the combined changes in the policy of the local timber management, recycling efficiencies and imports-flow should be considered. For Dutch forestry, the research has shown that about ¾ of the locally produced wood ends up in the energy sector as fuel wood. Shift towards alternative sources of energy opens an opportunity to increase the flow of wood to the construction sector. The thorough land-use change and subsidies towards forest-covered land is another strategy for the increase of the local supply. The downside of such a strategy is its timeline: the forest could be harvested 60-70 years after the planting (Schelhaas M.-J., et al., 2022). The recycling rate of wood material is a time-consuming process, though the development of recycling technologies and promotion of use of the secondary wooden elements will help to increase the recycled material inflow to the construction.

## References

Mart-Jan Schelhaas, Sandra Clerkx & Bas Lerink. (2022). 7th Dutch National Forest Inventory. In wur.nl/wotnatuurenmilieu. Wageningen University & Research. https://doi.org/10.18174/576640

## Methods

Material flow analysis, dynamic material flow analysis, literature research



# D2 BIO-BASED CONSTRUCTION MATERIAL AS INNOVATION IN CONSTRUCTION INDUSTRY

THE ACCREDITATION OF BIO-BASED MATERIALS IN CONSTRUCTION INDUSTRY IS ESSENTIAL TO ACHIEVE THE 2030 CLIMATE TARGET. HOWEVER, THE TRANSITION IN THE SECTOR IS ALWAYS SLUGGISH. THE ACCEPTANCE FROM BOTH SUPPLY AND DEMAND SIDES ARE REQUIRED TO ACCELERATE THE ADOPTION.

CONNECTED TO
D1, K1, S5, G3

## Theoretical Background

Bio-based materials had been around in traditional construction and now coming back as a promising alternative to reduce the emission in the industry. Studies show energy use intensity, net CO2, and life cycle energy cost can be reduced significantly by using more bio-based material. The ability to carbon capture, renewability, and biodegradability at end of service life have been highlighted the most as the key factors to achieve the sustainability and circularity goals in the sector.

Excellent acoustic performances and thermal insulation properties of bio-based materials are suitable for the building environment. The chemical, mechanical, fire, health, and esthetical qualities are also qualified for foundation, wall, roof, and floor building system applications. When compared to conventional construction materials, bio-based materials have the advantage of being lightweight, having the lowest amount of waste during the life cycle, the lowest transport impact, and the lowest water and energy consumption on site. In theory, using bio-based materials is not only cheaper to maintain but cheaper to construct as well.

## References


Krasny et al., 2017
Bourbia et al., 2023
Jones and Brischke, 2017
Winch, 1998


## Recommendations

The eminence of start-ups

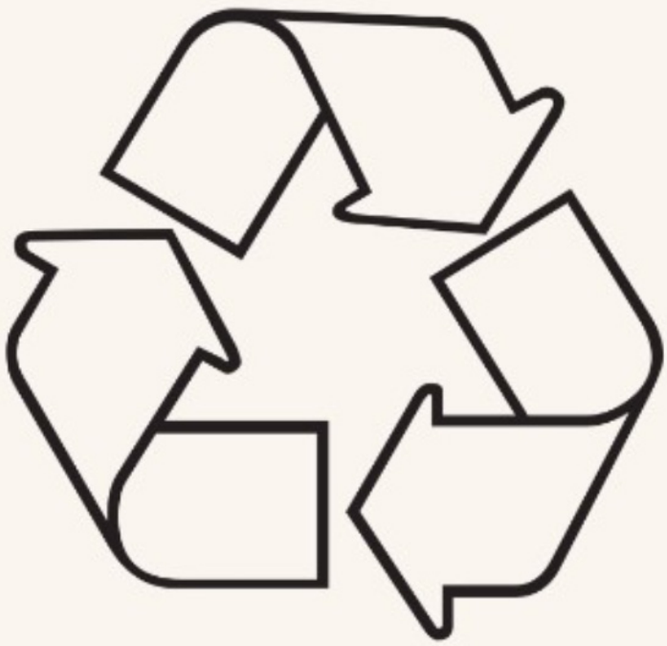
The emergence of bio-based construction firms is solely based on the goodwill of the initiators to make positive impacts and the awareness that they cannot achieve it alone. These firms are willing to set examples and play crucial roles in demonstrating the implementation maturity and delivering the knowledge for the market to adopt and replicate. The function of independent brokers as the catalysts in the innovation process is critical, especially in the construction industry. As vital as they are to the other actors, it is also important to expedite the recognition of wider audiences and reshape the perception of the public. The succession to incubate and survival of these start-ups might determine the bio-based adoption rate

The significance of the big firms

The low-hanging fruit in the adoption of bio-based material is through the recently established construction firms that implement bio-based material since the beginning of their operations. Long-established firms require a lot more effort to convince their rigid networks to start working with bio-based materials. However, it is essential to push the transition within the big firms to make substantial impacts. Incentive schemes which can accommodate iterative cycles instead of abrupt change can be effective for the big firm to learn in a project-based and collaborative manner.

## Methods

Literature Review, interview



# D3 USE RECYCLED MATERIALS

THE USE OF RECYCLED MATERIALS IN BUILDING APPLICATIONS.

CONNECTED TO
T4, T5, S2, T7

## Theoretical Background

Rahla et al. (2021b) described the term "recycle" as an operation that involves the recovery and reprocessing of waste materials into substances, materials, or products for the same or different purposes. In circular building design, the use of recycled materials involves combining materials that were previously used in other products after they reach their end of life (Rahla et al., 2021a). In this context, the use of recyclable material can be integrated with material reuse during the design and construction phase (Eberhardt et al., 2022).

## Recommendations

The land-use plan of the area will have to be updated to ensure a mix of functions. New rules on the design of the plinth can be incorporated to create a lively neighbourhood. Furthermore current regulations regarding available parking spaces have to be reduced to ensure a better position for other types of transport.

## References

Eberhardt et al., 2022
Rahla et al., 2021a
Rahla et al. (2021b

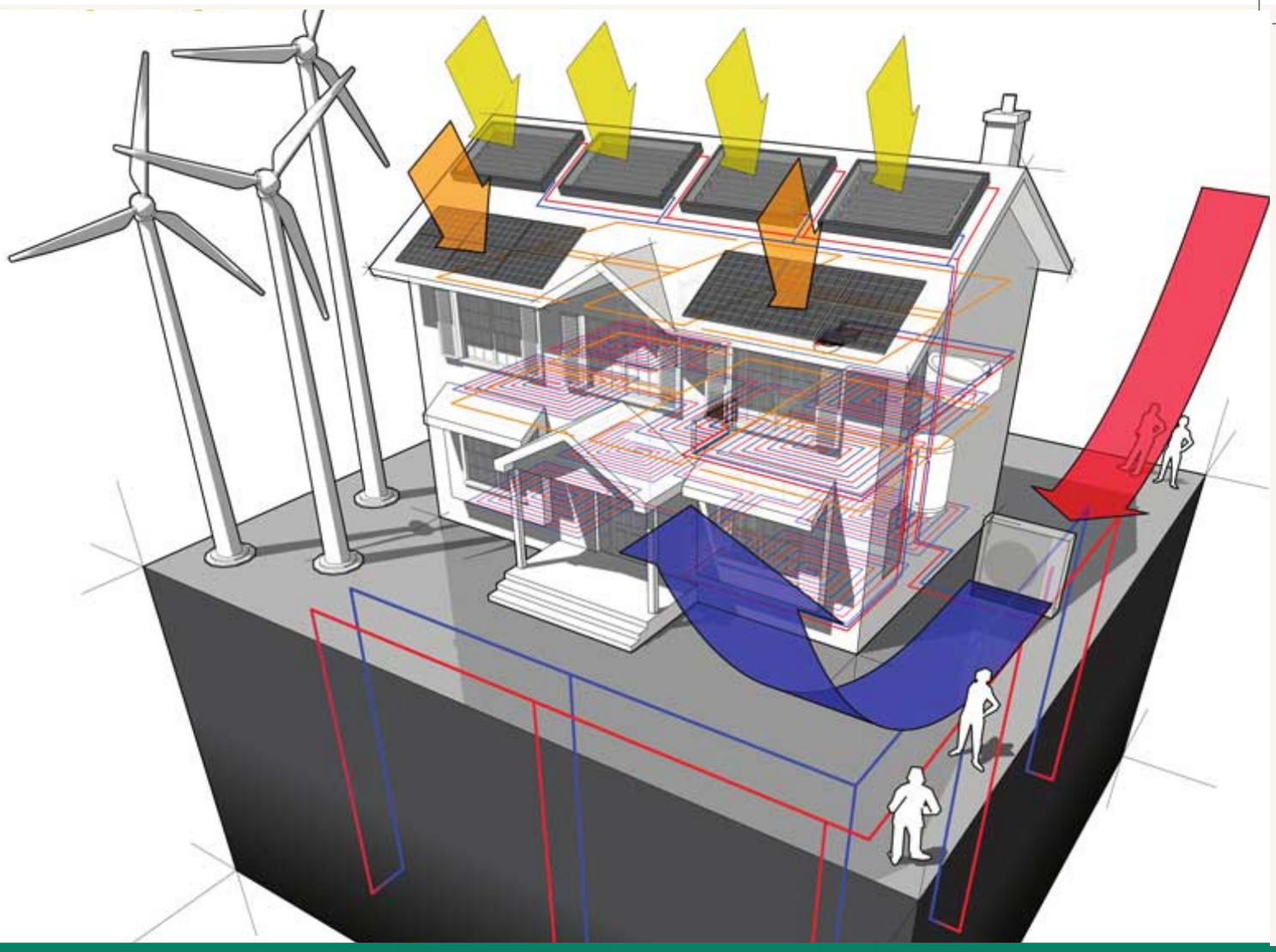
## Methods

Literature Review

# D4 USE REGENERATIVE DESIGN PRINCIPLES

## REGENERATING AND RESTORING NATURAL CAPITAL

CONNECTED TO
T7, S8



## Theoretical Background

In circular building design, the term using regenerative design principles involves the establishment of the renewability of resources while eliminating the generating of any sort of leftovers or resource depletion (Iyer-Raniga, 2019 ; Rahla et al., 2021a).

## Recommendations

Exemplary solutions for the use of regenerative design principles are those pertain to the technique that promote energy neutrality, such as: net zero and renewable energy strategies, low-impact design and efficient water recycling (Iyer-Raniga, 2019).

## References

Iyer-Raniga, 2019
Rahla et al., 2021a

## Methods

Literature Review

# D5 USE MODULAR DESIGN

USE MODULAR DESIGN

CONNECTED TO
T1, S2

## Theoretical Background

Modularity, often known as regularity, refers to the capacity to improve the consistency of a construction pattern in the building configuration. It can be promoted by including modularity in both spatial and physical dimensions of the building, which entails modularizing the organization of spaces and utilities as well as using standardized building products (Hamida et al., 2022). Employing modular design in circular building design entails purposefully creating building parts that are manufactured offsite before being assembled together at the project site (Kitagorsky, 2022).

## Recommendations

To achieve a modular building design, designers can use various strategies, including standardizing the module size and utilizing demountable and movable parts that allows for easy customization (Dams et al., 2021 ; Eliote and Leite, 2022). Designers can use this strategy by dividing a product into adjustable parts that can be easily adapted and customized, resulting in facilitated flexibility and simplified maintenance (Antwi-Afari et al., 2022 ; Iyer-Raniga, 2019).

## References

Antwi-Afari et al., 2022
Dams et al., 2021
Eliote and Leite, 2022
Hamida et al., 2022

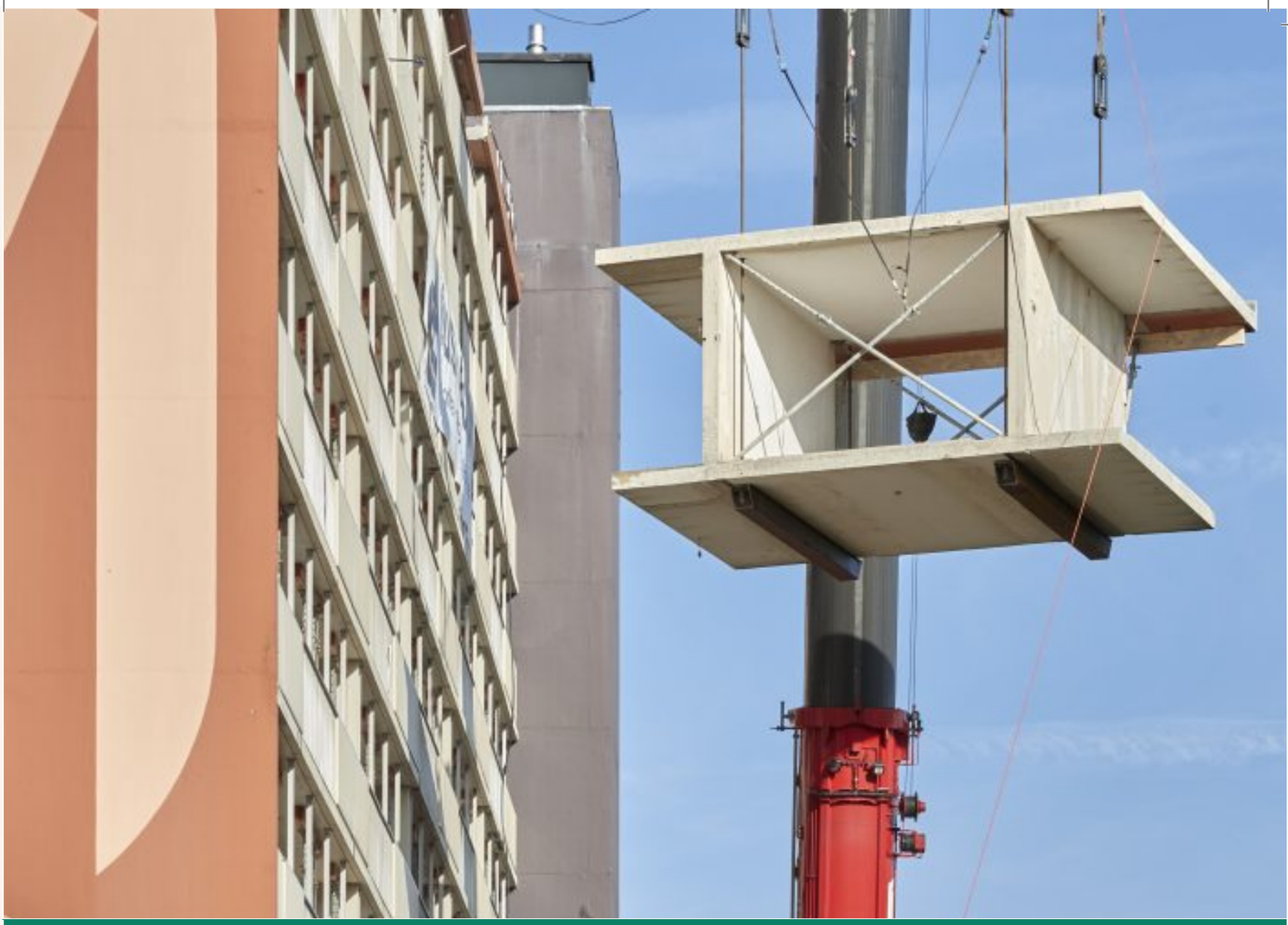
## Methods

Literature Review

# D6 USE DISMANTABLE DESIGN

DESIGNING FOR DISASSEMBLY AND REUSE IN BUILDING.

CONNECTED TO
D3, D5, T1



## Theoretical Background

In circular building design, the use dismantlable design refers to the intentional configuration of building components and systems with the goal of allowing their disassembly and reuse at the end of a structure's life cycle (Bertino et al., 2021).

## Recommendations

To facilitate disassembly in building design, designers can employ demountable building products and dry connections instead of wet connections (Geldermans, 2016).

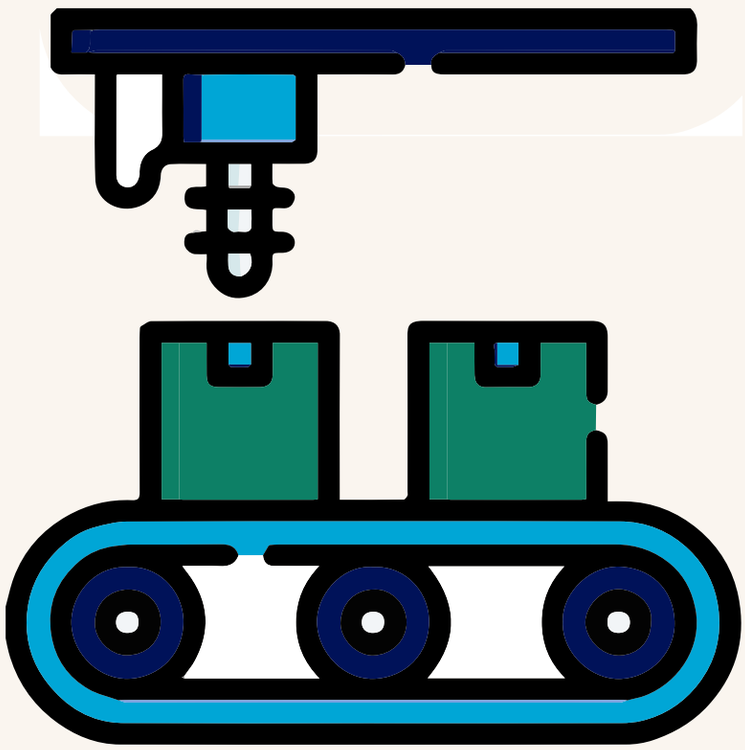
## References

Bertino et al., 2021
Geldermans, 2016

## Methods

Literature Review

# TECHNOLOGIES



# T1 INDUSTRIALIZED CONSTRUCTION AS TRANSITION CATALYST

TTHE ADOPTION OF BIO-BASED MATERIALS IN THE CONSTRUCTION INDUSTRY IS ESSENTIAL TO ACHIEVE THE 2030 CLIMATE TARGET. HOWEVER, THE TRANSITION IN THE SECTOR IS ALWAYS SLUGGISH. INDUSTRIALIZED CONSTRUCTION IS FOUND TO BE VITAL IN ESCALATING THE COMPETITIVENESS OF THESE MATERIALS.

CONNECTED TO
D2, F2, T7

## Theoretical Background

Construction industry had been there for centuries and has been running based on conventional practices that are inefficient and unsustainable. Industrialized construction (IC) is an approach to boost productivity and predictability by transforming the industry from project sites to safer and faster factory productions. The concept of IC consists of eight basic principles. Planning and control of process is having well-defined designs and roles as well as well-communicated and documented processes. Technical building system is delivering robust systems as products. Prefabrication of building part is taking as much work as possible off-sites.

Long-term relationship is enabling co-development across the actors and reducing transaction costs.

Logistic integrated into building process is incorporating overall phases into efficient material flows.

Used of ICT tools is utilizing suitable technologies for accurate and reliable information to support the production. Measurement and re-use of experience are capturing the knowledge and experience to be implemented for further improvements. Customer and market focus is choosing the right strategies for the right target.

## References

Kedir et al., 2018
Winch, 1998

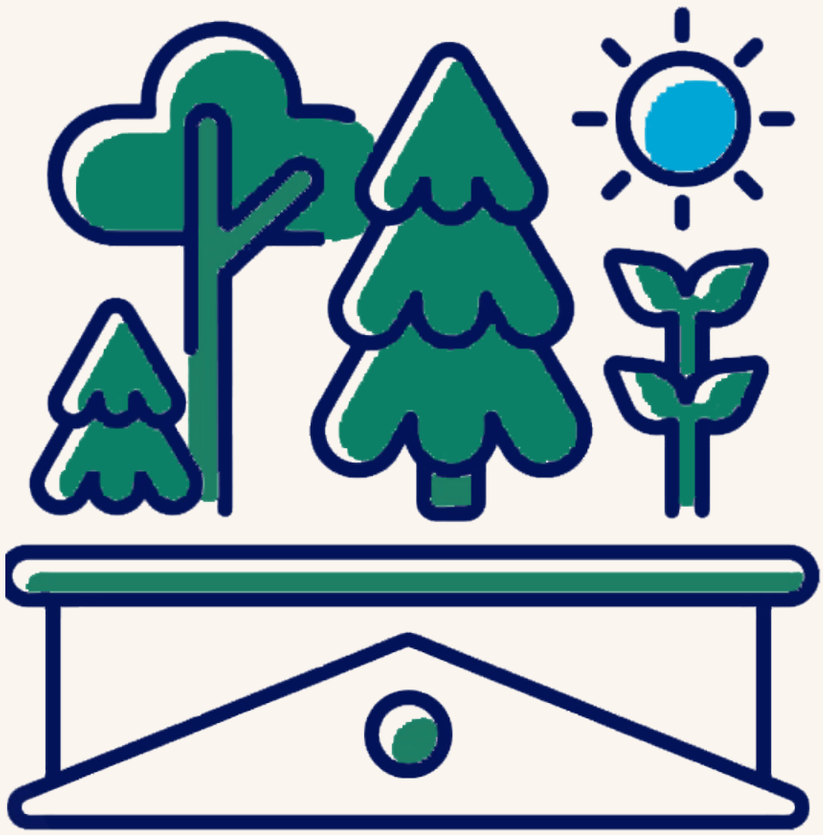
## Recommendations

The issue with bio-based materials is that they are perceived as eco-friendly alternatives that are nonetheless expensive 'options to choose'. Therefore, designers and developers are hesitant to incorporate these materials into their designs, or simply do not because they are not required to. In contrast, bio-based building systems on a higher level can be both environmentally friendly and economical when construction firms as system integrators implement a certain degree of IC principles. IC methods are able to compensate for higher material price by having more efficient processes, leading to even cheaper unit prices in the market. It is a trade-off between economies of scale and economies of scope. The higher degree and bigger scale of IC principles implemented, the higher standardization to make the construction cheaper and faster, and consequently the less customization and variation can be accommodated.

System integrators have strategic roles and competencies to integrate interdependent components that meet all of the aspects from available resources, workable designs, legal conditions, up to desired specifications by the client in the area. It is only doable when the principal contractor and the principal designer are a single entity or, at the least, when the principal contractor and the principal designer are closely working together. In addition, location and transportation also take significant parts in both construction costs and impacts. Thus, having system integrators dispersed across the country can tailor the aspects to fulfill the local demand.

## Methods

Literature Review, interview



# T2 A “MORE SUSTAINABLE” GREEN ROOF LIFECYCLE

EXTENSIVE AND INTENSIVE GREEN ROOFS PERFORM BETTER THAN CONVENTIONAL ROOFS IN THE POTENTIAL BUILDING OF THE GREENPORT HORTI IN WESTLAND, BUT THE ENVIRONMENTAL HOTSPOTS THAT EXIST IN THE USE PHASE OF GREEN ROOFS STILL NEED TO BE FURTHER REDUCED BY CORRESPONDING INTERVENTIONS.

CONNECTED TO
D2, D3, M3, M4, T2, F2, T7

## Theoretical Background

Green roofs are a popular building product that can be used to address environmental issues in urban environments, helping to improve building energy efficiency and reduce urban heat island effect and surface runoff, among other environmental benefits (Thornbush et al., 2013). However, there are still some challenges to the widespread implementation of green roofs, like the lack of awareness among policy makers, developers, and homeowners of the specific benefits of green roofs in various aspects such as environmental hotspots, environmental benefits etc. (Koroxenidiset al., 2021). In Westland project, a comprehensive environmental impact assessment needs to be carried out throughout the life cycle of the project, as the current green roof program spans 50 years. Identifying environmental hotspots at different stages of a green roof's lifecycle is essential.

## References

Thornbush et al., 2013
Koroxenidis et al., 2021
Cubi et al., 2016

## Recommendations

Because a green roof is a building product with a long lifespan, a full life-cycle sustainability assessment as well as a cost assessment are only more valuable in this study. This is why life cycle assessment and life cycle cost analysis can be used to identify environmental and cost hotspots. After the results have been obtained, policy decision makers should make certain interventions in response to the environmental and cost hotspots of the different green roofs obtained, e.g., energy saving, material transformation of the recycling layer, etc. Thus, green roofs can continue to function for the next 50 years without certain negative effects.

## Methods

Literature review; Life Cycle Assessment

# T4 USE MATERIAL PASSPORTS

THE PROVISION OF A DOCUMENTATION OF INFORMATION ON THE CHARACTERISTICS OF BUILDING MATERIALS

CONNECTED TO
D3, S1

## Theoretical Background

The use of material passports (MP's) is a record of detailed data such as dimensions, material type and shape to enable efficient supply chain collaboration and data flow, and to assess the recoverability of materials in different design options (Çetin et al., 2021).

## Recommendations

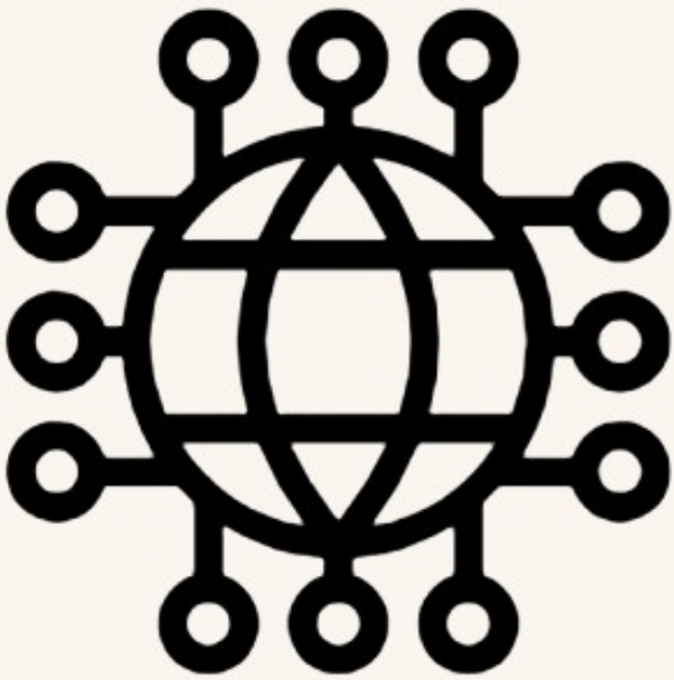
MP's are seen as a powerful technique for realizing the closed-reversible material loop in all structures; including new, existing, or to be demolished (Ping Tserng et al., 2021). The use of MP's also allows for the easy tracking and monitoring of a building's environmental performance throughout its life cycle, which can lead to the development of new economic models that support circularity in the building sector (Bertino et al., 2021). MP's can also provide designers with input on material selections during the design phase (Kanters, 2020). Furthermore, MP's are considered as an essential tool for achieving a circular built environment and prolong the lifespan of building materials (Rahla et al., 2021a).

## References


Bertino et al., 2021
Çetin et al., 2021
Kanters, 2020
Ping Tserng et al., 2021
Rahla et al., 2021a


## Methods

Literature Review



# T5 USE DIGITAL TECHNOLOGIES

ADVANCED TECH USED TO OPTIMIZE BUILDING DESIGN AND OPERATION.

CONNECTED TO
T1, T4 AND ALL OF D

## Theoretical Background

Using digital technologies in circular building design refers to the use of sophisticated technologies such as Building Information Modelling (BIM), sensors, and 3D printing to optimize the design, construction, and operation of the structure (Çetin et al., 2022 ; Iyer-Raniga, 2019). Designers can utilize various strategies to implement digital technologies in building design, including creating digital models of building components using BIM software (Cavalliere et al., 2019), 3D printing customized building components (Oluleye et al., 2023), and incorporating sensors to monitor and optimize building performance (Windapo and Moghayedi, 2020).

## Recommendations

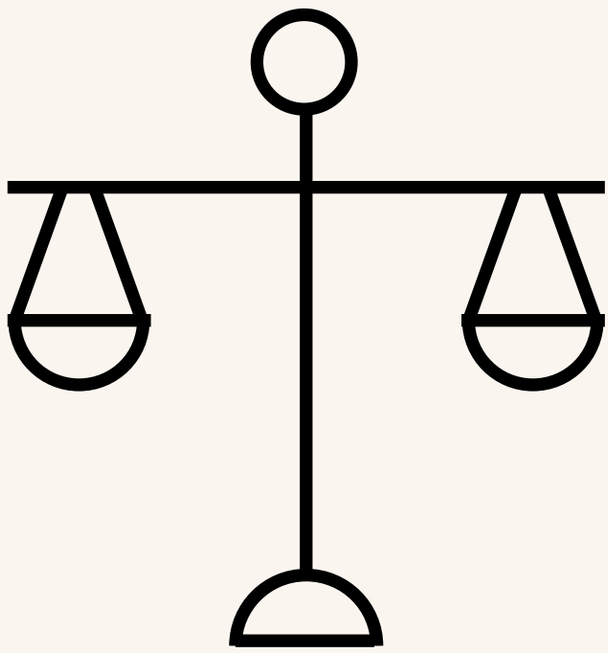
Digitizing the built environment is seen as a quick way to implement CE in the building sector by keeping track of materials through specialized databases, and thereby, facilitating the reuse of materials once they have reached their end-of-life, while keeping their value (Rahla et al., 2021a).

## References


Cavalliere et al., 2019
Çetin et al., 2022
Iyer-Raniga, 2019
Oluleye et al., 2023
Rahla et al., 2021a


## Methods

Literature Review



# T6

# SUCCESS OF HIGH-VALUE REUSE IN NFRASTRUCTURE PROJECTS AS A FUNCTION OF MULTI-CRITERIA DECISION-MAKING

HYPOTHESIS

CONNECTED TO
G2, G5, F1, M3, S6

*Image:. Insperity*

## Theoretical Background

Stakeholder circularity decisions are primarily multicriteria decision-making (Sanchez & Haas, 2018). Certain circular strategies including the deconstruction strategy (Coenen, et al., 2021b), were based on project context (PlatformCB23, 2021). The project involved a wide range of stakeholders (Lahti et al., 2018) and information flows were perceived of high value (Loomba & Nakashima, 2012b). Some departure from the literature was found as not all stakeholders experienced a new role or process (Pinto & Winch, 2016) and the extent of reuse (Cholifihani, 2018), was not based on predefined criteria, but to whatever extent components were feasible to reuse.

## References

## Recommendations

- The stakeholder circularity decisions in the ircular viaduct project were found to be complex and a collective result of several parameters, including a mix of strategic, technical, intrinsic value-based, and shared circularity ambition.

- For pilots projects, cost is not usually a barrier due to excess budget provisions.

- Shared circular ambition of actors is imperative for the success of circular infrastructure projects

## Methods

Interview
Secondary Data
Qualitative Analysis


# T7

## A COMPREHENSIVE APPROACH TO A CARBON-NEUTRAL BUILT ENVIRONMENT NEEDS TO CONSIDER THE WATER-ENERGY-MATERIALS NEXUS

WHILE CIRCULARITY IN THE BUILT ENVIRONMENT IS GAINING MOMENTUM, THE DIVERSE OPINIONS ON HOW THIS TOPIC IS APPROACHED POSE THE RISK OF ENERGY EFFICIENCY BEING LEFT BEHIND. MOREOVER, THE EMBODIED CARBON EMISSIONS IN THE WATER CONSUMPTION OF BUILDINGS REMAIN ABSENT

CONNECTED TO
D3, D4, F2, T2


*Earthship buildings are an example of how to mitigate Climate Change from the Built Environment looking at the Water-Energy-Materials nexus*

*Image: lorem ipsum*

## Theoretical Background

Gooroochurn (2022) proposes a concept of Circular Homes that integrates the energy-water-material nexus. Gooroochurn identifies carbon emissions as pollutants resulting from the built environment and suggests that the use of Passive Design strategies can aid in designing CO2 out of the cycle, in line with CE principles. In line with Gooroochurn, other authors also propose to widen the scope of circularity from materials to energy and water. For instance, Sala Benites et. al. (2021) propose that circular practices evolve to a regenerative circularity approach that integrates nature-based solutions to address human wellbeing and achieve biodiversity benefits, generating bioconnections. An example of this is the use of microalgae reactors to simultaneously capture CO2 in the biomass of the algae, while generating energy. These reactors also help to purify wastewater extracting its nutrients and produce biomass that can be used afterwards as a biofuel, fertiliser, animal feed, or to generate biogas for an extra energy generation.

## References

## Recommendations

Developing a shared vision that unifies the different existing ideas around Circularity in the Built Environment, including the various elements of its carbon footprint, will reduce the chances of Circularity of Materials displacing other essential aspects of the Sustainable Built Environment.

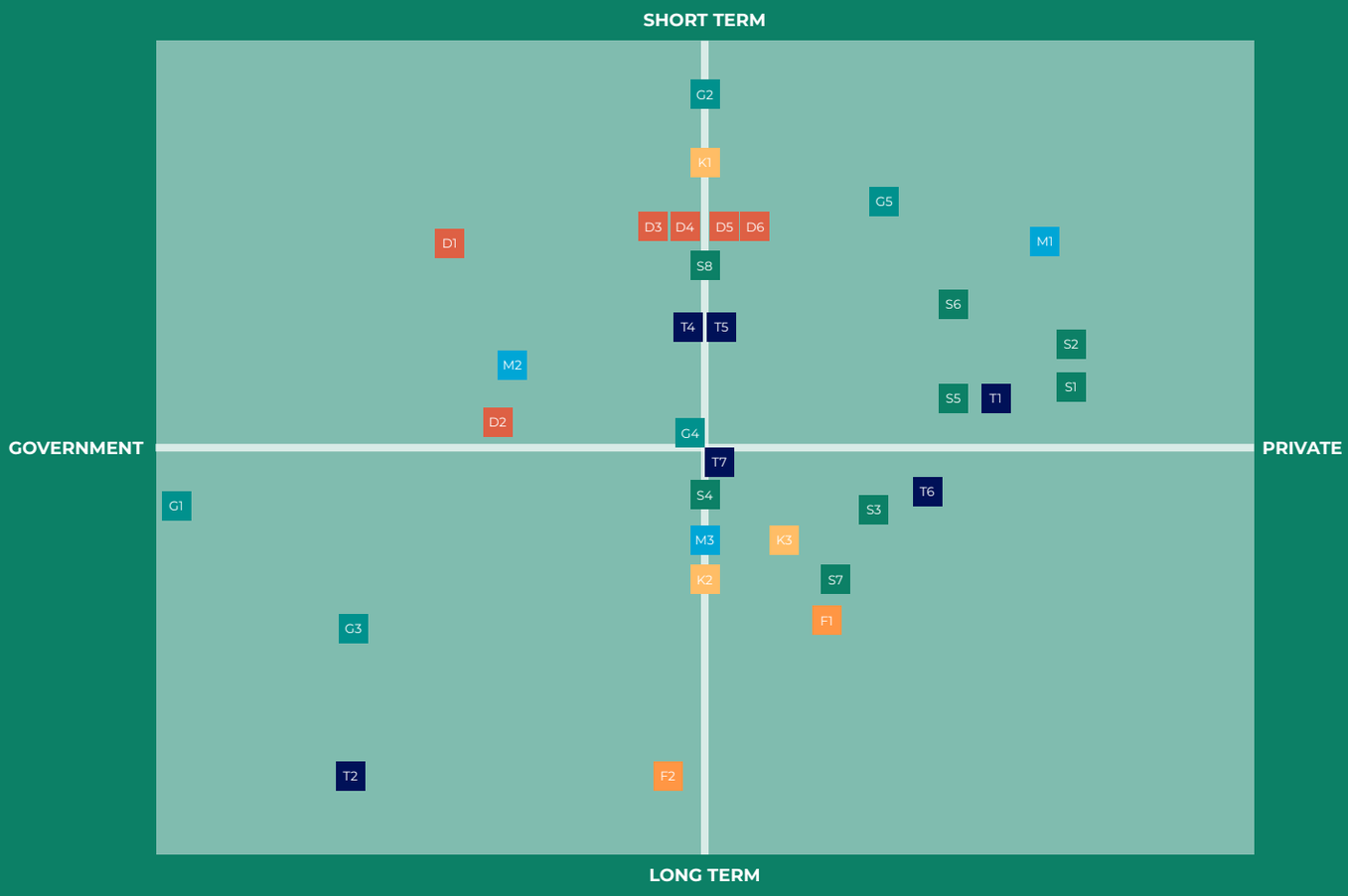
More research needs to be done to reflect the real value of biobased materials in life cycle assessments, as well as the potential of making a circular use of water and energy, to generate reliable data that supports the use of CO2 measurements as an indicator of success. The use of biobased materials and passive design strategies, and the design for demounting at the end-of-life, have been found among interviewees as potential strategies to drive down these emissions.

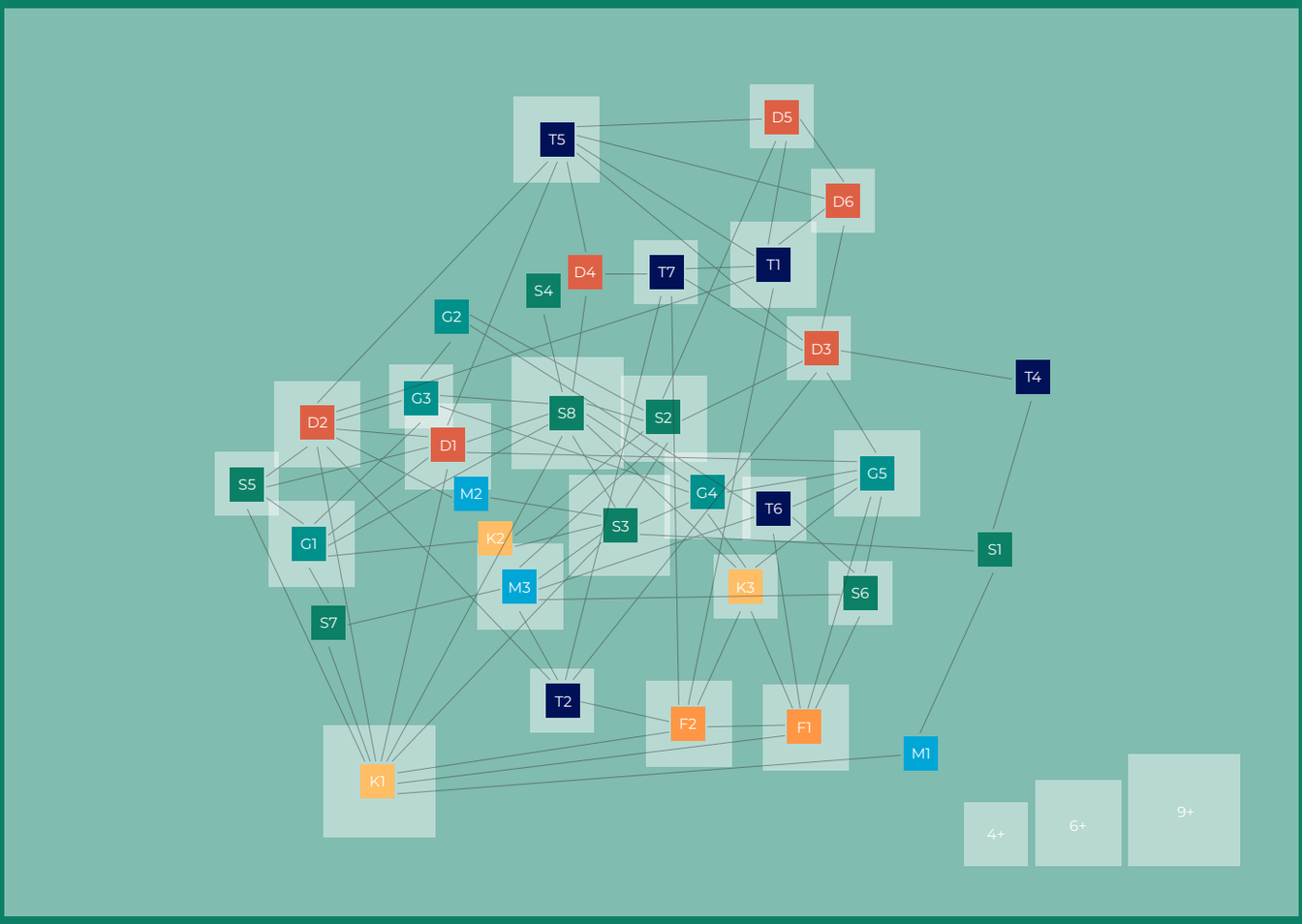
The formulation of policies for a Circular Built environment needs to have different characteristics than the ones for Circularity in other supply chains, as they need to create links and interactions with the other aspects of sustainability.

## Methods

Methods: Mixex Qualitative/ Quantitative: Survey + Interviews

# NETWORK DIAGRAM


SHORT TERM
G2
K1
G5
D3
D4
D5
D6
D1
M1
S8
S6
T4
T5
S2
M2
S1
S5
T1
D2
G4
GOVERNMENT
PRIVATE
T7
T6
G1
S4
S3
M3
K3
K2
S7
F1
G3
T2
F2
LONG TERM
(NUMBER OF) CONNECTIONS BETWEEN PATTERNS




**(NUMBER OF) CONNECTIONS BETWEEN PATTERNS**

# CONCLUSION

This pattern catalogue, the outcome of the Interdisciplinary Thesis Lab Circular Building and Area Development, has successfully captured the collective efforts of the participating students from Leiden University, Erasmus University Rotterdam (EUR), and Delft University of Technology (TU Delft). It represents a crucial link between their diverse theses, aiming to address the multifaceted challenges faced by cities in terms of social, ecological, and economic sustainability.

The patterns showcased in this booklet offer valuable insights into various aspects of the transition towards sustainability and circularity. From optimizing resource flows and reusing materials in building and area development projects to considering the spatial scale of building sector-related resource flows and policies, these patterns represent a comprehensive set of strategies.

From a socio-technical perspective, the transition to a Circular Built Environment can be seen as currently in the intermediary between Niche and Stabilization. To progress further, the transition must be managed holistically through elements like Governance, Knowledge Development, Finance, System Design, Mindset Changes, Materials, and Technologies. Collaboration with key stakeholders to implement regenerative design principles combined with biobased materials offer promising solutions to address the challenges ahead.

However, it is crucial to acknowledge that governing this transition is complex and requires interdisciplinary coordination to drive change effectively. Adapting legislation, improving the cost-benefit ratio of circular investments, supporting pilot projects to scale up, and promoting lifestyle changes are among the steps needed to foster a successful transition. Additionally, strengthening existing networks and communication channels among them will facilitate collective action among stakeholders, advancing the shift towards a more sustainable and circular built environment.

In conclusion, this catalogue of patterns marks an essential milestone in the journey towards sustainability and circularity in the built environment. It provides a roadmap for the transition, offering a diverse range of insights and strategies that can guide policymakers, practitioners, and researchers alike. As we look to the future, more research and concerted efforts are needed to implement these patterns and move towards a greener, more sustainable, and circular future for our cities. By building upon the foundation laid by this thesis lab, we can collectively work towards achieving the ambitious goals set for 2030 and beyond, and in doing so, create a lasting impact on the well-being of our urban environments and the planet as a whole.

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# PATTERN CATALOGUE
# CIRCULAR BUILDING AND AREA DEVELOPMENT

This pattern catalogue is developed by students who graduated in the Interdisciplinary Thesis Lab 2022-2023: Circular Building and Area Development organised by the Leiden Delft Erasmus Centre for Sustainability (LDE CfS). Those students have different disciplinary backgrounds but share their passion for innovation and impactful urban knowledge production for the sake of more sustainable cities and regions.

The Circular Building and Area Development thesis lab program ran from the beginning of February until the beginning of July 2023. Master thesis students from Leiden, Delft and Erasmus universities followed a biweekly program together with in-depth lectures and workshops related to their sustainability challenge about circular building and area development. During these sessions, the students discovered and discussed the interdisciplinary aspect of this challenge. At the end of the program they integrated their findings in several sessions and this resulted in this interdisciplinary pattern catalogue.

The LDE CfS facilitated this lab as one of its practice oriented research and education approaches, going beyond sectoral and disciplinary boundaries. It bring researchers, students and various stakeholders from practice together to work on innovative, inter- and transdisciplinary approaches.

**INTERDISCIPLINARY THESIS LAB 2022-2023**
LDE CENTRE FOR SUSTAINABILITY