Connecting the Loops

A Systems Thinking Analysis and Identification of Process Shifts and its Consequential Costs in Swedish Circular Construction

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Chalmers University of Technology
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SUMMARY
The construction sector is currently responsible for a significant portion of global resource extraction and greenhouse gas emissions. While the Circular Economy offers a pathway to decouple economic activity from environmental degradation, the transition from linear to circular models introduces significant operational complexities. Existing research has largely focused on technical feasibility and material flows, leaving a knowledge gap regarding how circular interventions reshape construction processes and influence economic dynamics in practice.

This thesis investigates these processual shifts and cost implications within the context of Swedish new development projects. Using a Systems Thinking approach, the study analyzes three ongoing projects in Gothenburg. The Botanical Garden, Sonyas Culture House, and Gothenburg Grand Central, where White Arkitekter serves as a key design stakeholder. Data was collected through semi-structured interviews and analyzed using Causal Loop Diagrams to visualize the non-linear feedback loops between circular strategies, process changes, and costs.

The findings reveal that circularity disrupts the traditional linear efficiency of construction, shifting the operational focus from production to early-stage planning, logistics, and verification. This shift generates significant "transaction costs" related to information search, risk management, and administrative friction. The study identifies that successful implementation relies on "organizational fit", large institutional actors benefit from standardized, supplier-led circularity to mitigate risk, while smaller, agile actors can leverage trust and experimental learning. Furthermore, the analysis demonstrates that while circularity often incurs higher upfront costs, these can be neutralized through financial leverage points, such as green bonds, or minimized through relational contracts that reduce uncertainty. The thesis concludes that for circular construction to scale, the industry must move beyond pilot projects to develop standardized market infrastructure and adopt relational governance models that account for the friction of circular flows.

Keywords: Circular Construction, Systems Thinking, Transaction Costs, Process Analysis, Causal Loop Diagrams, Project Management

Att sluta looparna:
En Analys Utifrån Systemtänkande och Identifiering av Processkiften och dess Följdkostnader inom Svenskt Cirkulärt Byggande.

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SAMMANFATTNING

Byggsektorn står idag för en betydande del av det globala resursanvändandet och utsläppen av växthusgaser. Även om den cirkulära ekonomin erbjuder en möjlighet att frikoppla ekonomisk aktivitet från miljöpåverkan, medför övergången från linjära till cirkulära modeller betydande operativa utmaningar. Befintlig forskning har i stor utsträckning fokuserat på teknisk genomförbarhet och materialflöden, vilket lämnar en kunskapslucka kring hur cirkulära åtgärder omformar byggprocesser och påverkar ekonomisk dynamik i praktiken.

Detta examensarbete undersöker dessa processuella förändringar och kostnadskonsekvenser inom ramen för svenska nybyggnadsprojekt. Genom ett systemteoretiskt angreppssätt (Systems Thinking) analyserar studien tre pågående projekt i Göteborg: Botaniska trädgården, Kulturhuset Sonyas och Göteborg Grand Central, där White Arkitekter är en central aktör i den cirkulära processen. Data samlades in genom semistrukturerade intervjuer och analyserades med hjälp av Causal Loop Diagrams för att visualisera de icke-linjära looparna mellan cirkulära strategier, processförändringar och kostnader.

Resultaten visar att cirkularitet bryter den traditionella linjära effektiviteten i byggandet och förskjuter det operativa fokuset från produktion till tidig planering, logistik och verifiering. Denna förskjutning genererar betydande "transaktionskostnader" relaterade till informationssökning, riskhantering och administrativ friktion. Studien identifierar att framgångsrik implementering bygger på "organisatorisk passform": stora institutionella aktörer gynnas av standardiserad, leverantörsledd cirkularitet för att minimera risk, medan mindre, agila aktörer kan dra nytta av tillit och experimentellt lärande. Vidare visar analysen att även om cirkularitet ofta medför högre initiala kostnader, kan dessa neutraliseras genom finansiella hävstänger, såsom gröna obligationer, eller minimeras genom relationsbaserade avtalsmodeller som minskar osäkerheten. Slutsatsen är att för att cirkulärt byggande ska kunna skalas upp måste branschen gå bortom pilotprojekt för att utveckla en standardiserad marknadsinfrastruktur och anta relationsbaserade styrningsmodeller som hanterar friktionen i cirkulära flöden.

Nyckelord: Cirkulärt byggande, Systemtänkande, Transaktionskostnader, Processanalys, Kausala loop-diagram, Projektledning

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I would also like to extend my thanks to all who participated in the study for giving your time and sharing your thoughts and experiences.

January, 2026
Olle Bergström

List of Acronyms

AI = Artificial Intelligence

BIM = Building Information Modelling

BREEAM = Building Research Establishment Environmental Assessment Method (Cert.)

CE = Circular economy

CEBM = Circular economy business models

CC = Circular construction

CLD = Causal Loop Diagram

ECI = Early Contractor Involvement

GFA = Gross floor area

HC slab = Hollow Core Slab

IPD = Integrated Project Delivery

LBM = Linear business models

LCA = Life Cycle Assessment

LCC = Life Cycle Cost

MCDA = Multi Criteria Decision Analysis

PM = Project Memorandum

ROI = Return on investment

SME = Small and Medium-sized Enterprises

TCO = Total Cost of Ownership

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1 Introduction

This part depicts the present state of the climate, circular construction in a Swedish context with highlighted focus on the role of architects, but also on systems thinking. It also presents the aim of the thesis, along with the fundamental thesis questions, and furthermore describing the scope and delimitations of the study, including a presentation of the cases studied.

1.1 Background

The world and living systems are currently challenged by alarming climate threats, threatening the status quo of how our world functions. Most parts of our society need to shift into more sustainable practice, for example, adopting circular economic principles, aiming at creating circular patterns that break unsustainable extraction of valuable planet resources. The construction sector accounts heavily for the impact on climate changes, suggesting that a transformation of this sector is vital for sustainable success.

The construction sector is shaped and defined by a tightly interweaved set of systems which all influence the decisions and trade-offs explored later in the thesis. The section begins by examining the global climate crisis, then zooms into the Swedish construction sector, before exploring the architect's position and role in this complex environment. Thereafter, the section will introduce the systems thinking principle and its application in the transition to a circular economy. Lastly, the section summarizes the knowledge gap this thesis aims at addressing.

1.1.1 Climate challenges and circular responses

Global warming continues to escalate, with 2024 marking new record temperatures and greenhouse gas levels (World Meteorological Organization, 2025), a crisis driven significantly by raw material extraction which accounts for roughly 50 percent of emissions (European Environment Agency, 2024). This reliance on a linear economic model places increasingly unsustainable pressure on planetary boundaries (Rockström et al., 2009), as global material consumption is expected to double within 40 years (OECD, 2019), driving a projected 70% increase in waste generation by 2050 (Kaza et al., 2018). The built environment is a critical contributor to this strain, responsible for a third of all waste (European Commission, 2025b) and significant shares of global energy and CO2 emissions (United Nations Environment

Programme & Global Alliance for Buildings and Construction, 2025). As energy grids decarbonize and operational emissions decrease, the sector must pivot to address embodied carbon by avoiding unnecessary extraction and prioritizing regenerative materials (United Nations Environment Programme, 2023), ultimately moving away from the industry's traditional "take-make-waste" linear model (Ellen MacArthur Foundation, n.d.).

The circular economy (CE) has emerged as a vital solution to decouple resource extraction from growth by eliminating waste, circulating products, and regenerating nature (Ellen MacArthur Foundation, n.d.). Defined as a model that extends product life cycles through sharing, leasing, and recycling (European Parliment, 2023, para. 3), CE is central to the EU's targets of reducing emissions by 55% by 2030 and reaching climate neutrality by 2050 (European Commission, 2025a). To achieve this, the European Commission launched the CE Action Plan in 2020 as a key pillar of the European Green Deal (*Circular Economy Action Plan - European Commission*, n.d.). Through legal frameworks that mandate life cycle assessments and material recovery, the EU aims to relieve pressure on natural resources and establish circular strategies as the norm within the European construction market.

1.1.2 Circularity in Swedish Construction

In Sweden, the construction sector remains a major polluter, accounting for 22.1% of total greenhouse gas emissions (10.8 million tons CO2-equivalents) in 2022, despite a 12.2% decrease since 2008. While production continues to rise (Miljöindikatorer – aktuell status, 2025), waste generation surged by 55% between 2014 and 2022 to 13.6 million tons, representing 39% of all Swedish waste (Naturvårdsverket, 2024a). To combat this, the government supports a transition to a CE (Regeringskansliet, 2020) driven by innovation and reuse strategies (Naturvårdsverket, 2024c). Although the national goal of recycling 70% of construction waste by 2025 (Naturvårdsverket, 2025). is unlikely to be met, the potential to reduce climate impact remains high (Naturvårdsverket, 2024b). Progress is supported by key initiatives such as IVL’s (Swedish environmental institute) CCBuild marketplace (IVL, n.d.). regional transformation goals in Gothenburg (Cirkulära Göteborg, n.d.), and collaborative efforts to develop circular planning tools (Lindborg et al., 2024).

To achieve a CE, businesses must adapt by finding value in alternative sources (Naturvårdsverket, 2024c). and moving beyond the linear model to identify new revenue streams and cost reductions (Hedenus et al., 2018). With the European circular market projected to be worth 1.5 trillion euros by 2040 (Circular Business Models, 2025) companies must develop models that embrace ecological, economic, and social sustainability (Naturvårdsverket, 2024c). By engaging in practices such as rentals, reuse sales, and refurbishment, firms can generate direct economic value while strengthening brand relationships and contributing to long-term sustainability (Tillväxtverket, n.d.).

1.1.3 The role of architects in a CE

The transition towards a CE is fundamentally reshaping the construction sector, placing significant responsibility on the architect to influence both costs and environmental impact through early design decisions (Aldersgate Group, 2012; Kanters, 2020; Webster, 2017). While many firms (Kaminsky Arkitektur, n.d.; Sweco Group, n.d.; White Arkitekter, n.d.) have already begun incorporating circular activities, ranging from detailed reuse inventories to material passports (Gerhardsson et al., 2020; Lisco, 2025), recent research suggests that a singular focus on material reuse is insufficient. True sustainability and the full exploitation of the CE's potential require a multilevel perspective that encompasses changes in technology, organizations, and ways of thinking (Fromberg et al., 2025; Geels, 2002).

To navigate this shift, architects must expand their roles beyond traditional design to include project leadership, stakeholder facilitation, and sustainability consultancy (Dokter et al., 2021; Kanters, 2020). This expansion is necessary because circular efforts introduce novel processes and unpredictable costs that are difficult to manage without extensive collaboration (Dokter et al., 2021). Kanters (2020) argues that architects must act as connectors between suppliers and clients, opinion makers, and even entrepreneurs. However, this drastically increases the complexity of the work. As more parameters are introduced, the system becomes non-linear (Meadows, 2008), requiring a systems-thinking approach to handle the multiple perspectives involved in decision-making (Josefsson & Thuvander, 2020).

A critical barrier to managing this complexity is the lack of adequate methods for decision-making. Architects currently struggle to make informed decisions at early stages and require simpler tools to assess both economic and ecological impacts (Dokter et al., 2024; Kanters, 2020). This challenge is exemplified by White Architects, a major Swedish firm combining design with circular consultancy. According to representatives, a primary difficulty lies in tracking costs and efforts to evaluate design decisions (personal communication, 28 August 2025). This practical hurdle confirms the gaps identified by Dokter et al. (2024) and Kanters

(2020) regarding the lack of effective tools for managing the cost and process implications of circular construction.

1.1.4 Systems thinking

While extensive research has addressed the physical implementation and management of circular design (Björklund & Lindborg, 2021; Josefsson & Thuvander, 2020; Wetterqvist, 2025) the tracking of procedural shifts and costs remains largely unstudied despite growing industry demand (personal communication, 28 August 2025). Although reuse strategies can theoretically reduce costs (Engstedt, 2025), systematic evidence at the project level is lacking. Furthermore, attempts to combine life-cycle assessment (LCA) with life-cycle cost (LCC) analysis (Johansson, 2021) often fail to capture the wide-ranging, interconnected impacts of the CE (Bassi et al., 2021). Because current models remain partial rather than holistic, they struggle to account for the non-linear complexity inherent in circular systems.

To navigate these complexities, a systems-thinking approach is required (Aggesund, 2018; Meadows, 2008; Webster, 2021). Rooted in general systems theory (Bertalanffy, 1950) and system dynamics (Forrester, 1961), this method maps actions into feedback loops to visualize behavior, often using Causal Loop Diagrams (CLDs) (Sterman, 2000).

This visualization helps identify "leverage points", places where small interventions generate significant sustainable effects (Abson et al., 2017; Meadows, 1999; Moreno et al., 2016). While traditionally applied to macro-level economic systems, there is a distinct gap in applying these approaches to micro- or meso-level design projects. Utilizing systems thinking at this scale could predict intervention outcomes and support better-informed early design decisions (Probst & Bassi, 2017).

1.1.5 Knowledge gap

Despite ambitious EU and Swedish targets and a rapidly growing body of research on circular construction, particularly on reuse of materials, there is still limited knowledge of how these strategies change day-to-day construction processes and decision-making in practice. Most existing studies focus on technical feasibility, environmental impacts, or high-level business models, while far fewer examine the micro/meso level where architects, contractors and clients plan, procure and execute projects with respect to social and economic parameters as well as environmental. Systematic methods for tracking the costs and value creation of circular interventions are still underdeveloped, making it difficult for project teams to compare alternatives or build the business case for circularity. This thesis addresses that gap by identifying and mapping how circular strategies influence construction processes and by exploring their effects on costs in ongoing Swedish projects.

“Furthermore, one direction could be to investigate how designers can be supported in assessing the effects (e.g., through qualitative assessment) of material and design choices on the circularity potential of different proposals during the earlystage design process to support informed decision-making when there is limited technical data or time for more advanced environmental impact assessments (i.e., LCA).”

(Dokter, 2023)

1.2 Aim and thesis questions

This thesis investigates how circular interventions influence project processes in Swedish construction, with a particular focus on the costs that emerge from these interventions and how they interact with each other. Circular strategies are increasingly promoted as responses to environmental and resource challenges, yet their implementation often emphasizes material efficiency and environmental metrics while neglecting broader social, cultural, and economic dimensions. By examining how circular approaches alter the design and construction process, this study seeks to clarify both the tangible and intangible impacts these strategies generate. The goal is to understand procedural shifts and concurrent financial costs, to understand the challenges and find ways to combat them.

To support this investigation, systems thinking is used as an analytical framework for understanding and mapping the interrelationships between processes, costs, and values in selected case studies from White Architects. Through systems mapping and causal loop diagrams, the research explores how circular interventions affect decision-making, collaboration, and project outcomes. The thesis aims to contribute to a more comprehensive understanding of the processual and cost effects of circular strategies and to demonstrate how a system's perspective can reveal synergies and trade-offs within circular construction practice.

To approach the problem, a couple of thesis questions were formulated to guide the research.

Main research questions

> How do circular interventions reshape project processes and impact costs in Swedish new development construction projects, and in what ways can systems thinking support a holistic understanding of these effects?

Sub-questions:

1. How do construction processes in new development change when circular strategies are implemented, and how are these changes linked to project costs?
2. How can systems thinking be applied to analyze and understand the interrelationships between project processes, costs, and values in circular interventions?
3. What additional insights can be identified regarding deeper reasons and factors that improve or hinder circular success?

1.3 Scope and delimitations

This study is situated within the Swedish construction sector, focusing on new-development projects in the Gothenburg region where White Arkitekter serves as a central design stakeholder. Three ongoing projects were selected through purposive sampling. *Botaniska* (new greenhouses), *Göteborg Grand Central* (train station), and *Sonyas* (culture house). These cases were chosen based on three strategic criteria to maximize data diversity. First, they represent different stages of completion, ranging from pre-construction to expected completion in 2026. Second, they vary significantly in scale (2,400–15,000 m^2) and timeline. Third, all contain explicit circularity targets. This multi-case approach allows for the examination of how circular interventions manifest across distinct organizational and temporal contexts.

The primary objective is to analyze how circular interventions influence project processes and how associated costs and values emerge throughout the lifecycle. The core analytical tool is systems thinking, used to map interrelations and feedback loops to support decision-making. The unit of analysis is strictly defined as the project-level design and construction process, rather than broader organizational strategies. Data was collected through nine semi-structured interviews with key actors, including clients, architects, constructors, and sustainability consultants, and an aim of complementary analysis of project documentation and quantitative cost data.

The thesis is deliberately limited to new-development projects with explicit circular goals, excluding renovation or demolition-only projects to focus on the significant processual shifts required in new construction. The analysis prioritizes economic and processual aspects; while social and environmental impacts are noted for holistic synthesis, they are not the primary focus. Furthermore, the scope is restricted to the design and construction phases, excluding operation and end-of-life stages due to the ongoing nature of the cases. Sampling is restricted to a small number of stakeholders to allow for analytical depth. Quantitative data were not available or possible to get, and consequently, the findings claim analytical generalizability, offering insights applicable to theory and similar contexts, rather than statistical generalizability. This prioritizes depth over breadth to test the viability of systems thinking as a visualization tool.

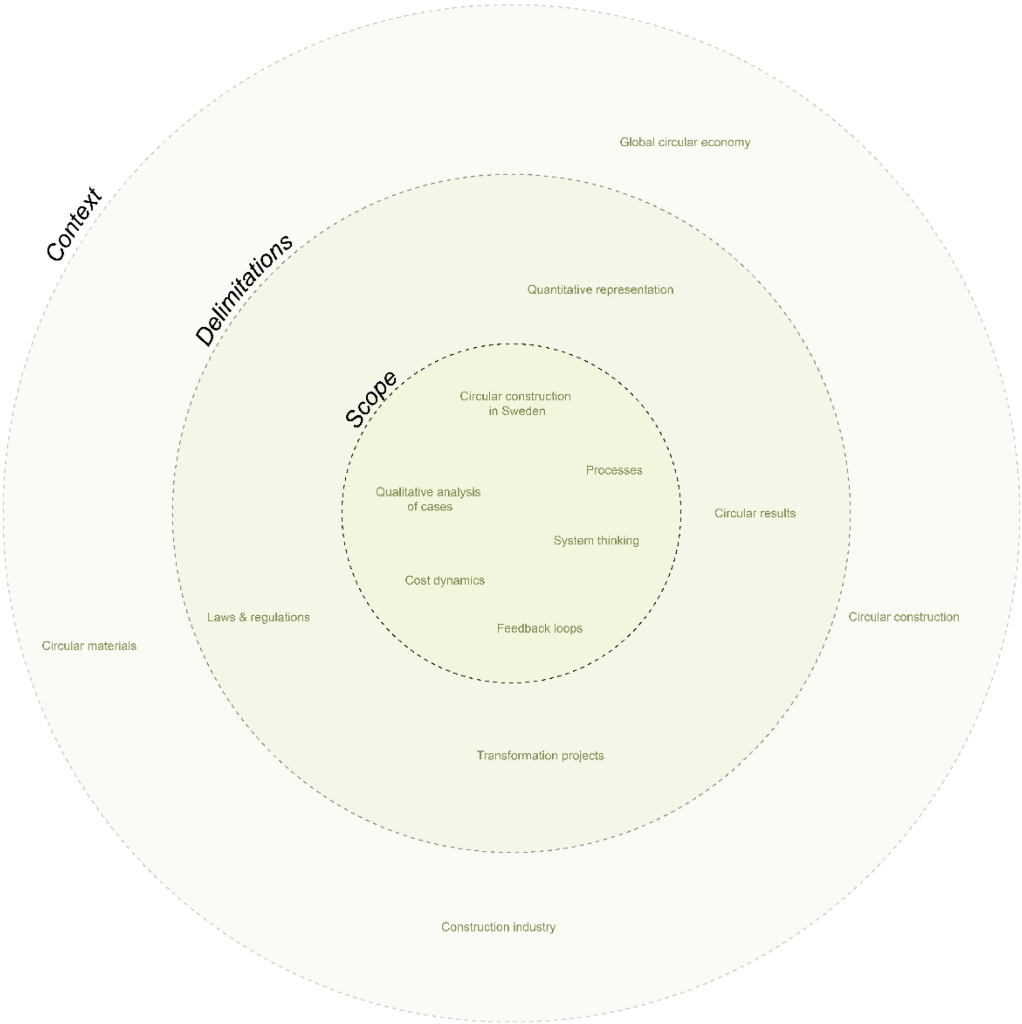

Figure 1: Scope and limitations

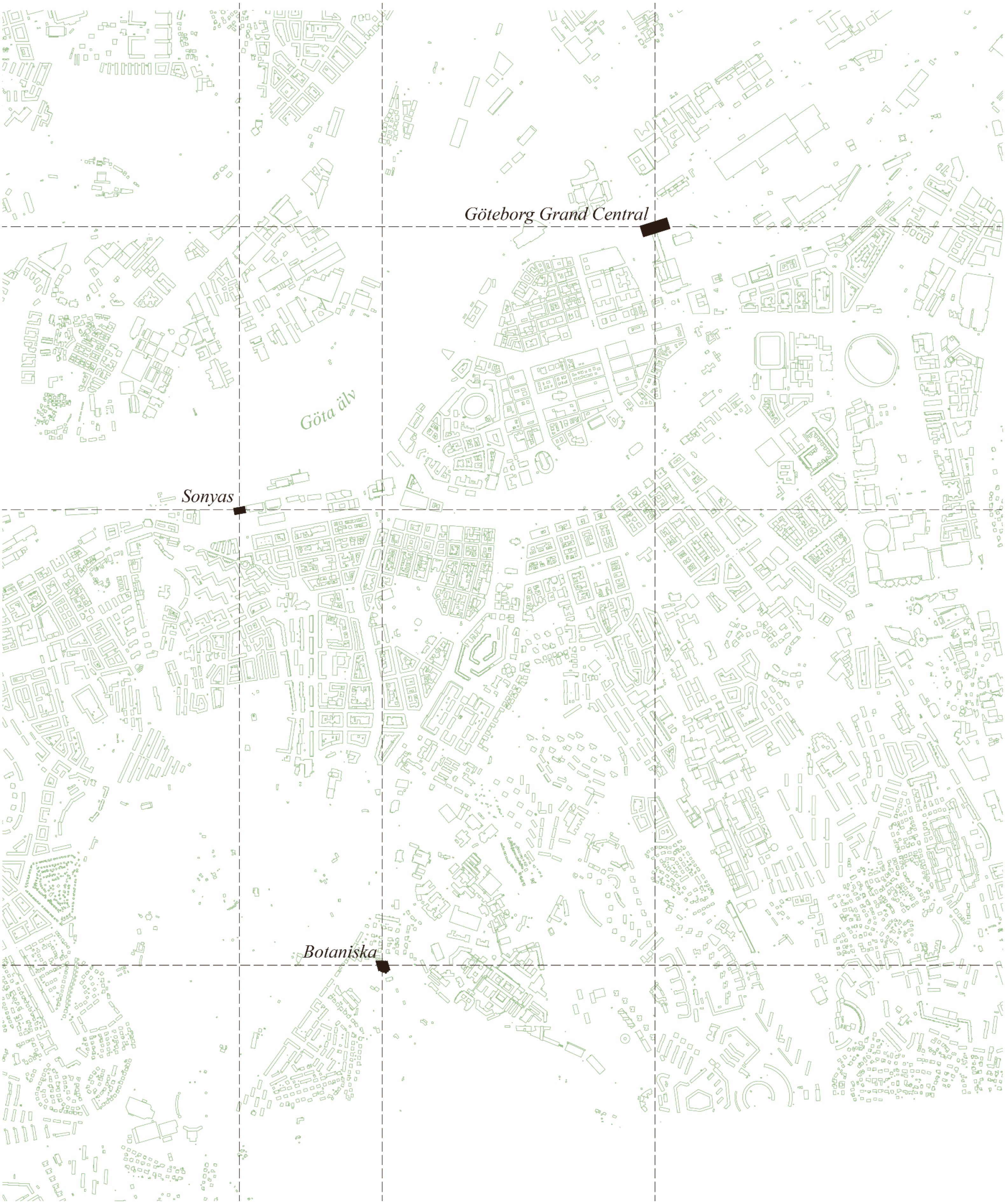

Figure 2: Map of case projects in Gothenburg - Scale 1:20.000

2 Cases

This study examines three distinct project typologies to capture the spectrum of circular friction, a public-sector project constrained by heritage and fixed budgets (Botanical Garden), a private, agile pilot project (Sonyas), and a large-scale infrastructure project driven by institutional finance (Gothenburg Grand Central).

2.1 The Botanical Garden

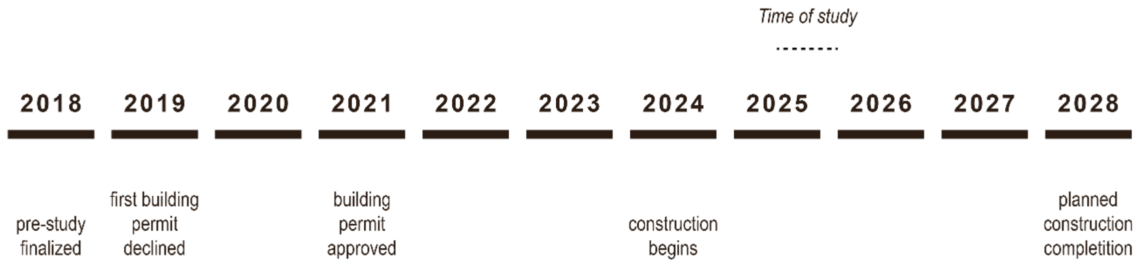

Figure 3: Timeline of Botanical Garden

The Botanical Garden project represents a compliance-oriented approach driven by political mandate rather than profit. Commissioned by Västra Götalands Fastighetsförvaltning, the project involves the construction of a new greenhouse complex situated within a sensitive heritage environment. The project's operational context is heavily defined by its status as a public procurement utilizing a turnkey contract (Table 1). This rigid model, typically designed for fixed-price certainty, set specific boundary conditions for how the project could handle scope changes and financial risk.

Furthermore, the project faced a prolonged development timeline, having started planning as early as 2018 (Figure 3). During this period, the project encountered significant external disruptions, including budget cuts driven by the Covid-19 pandemic. These financial constraints created a tension between the project's high initial ambitions and the economic reality of the final budget, forcing the organization to navigate strict public spending limits while attempting to manage the complexities of a heritage site development.

Project name and site	Botanical Garden, Gothenburg
Product	New greenhouse
Contract type	Turnkey contract
Size	6,600 m^2
Client	Västra Götalands Fastighetsförvaltning
Architect	Cobe Architects
Sustainability consultant	White Architects
Entrepreneur	PEAB Sverige AB
Status/timeline	Started construction
Circular goals	Build with as small environmental impact as possible, large focus on reuse of brick from another site. Reuse of site materials such as wood and granite/limestone. Furniture, doors, ventilation ducts and cable ladders sourced from other sites.

Table 1: Summary of key characteristics and operational parameters of the Botanical Garden project

2.2 Sonyas

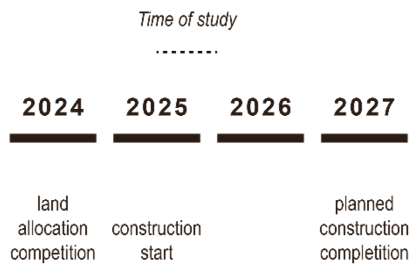

Figure 4: Timeline of Sonyas

In contrast to the heavy institutional oversight of the Botanical Garden, Sonyas is a smaller, private development driven by rapid decision-making. Developed by Broods Group AB, this culture house operates on a compressed timeline (Figure 4) with strict environmental requirements imposed by the municipality during the land allocation phase. The project is characterized by its organizational agility and lack of prior experience with circular processes, operating in a mode of "learning by doing".

Crucially, the project utilizes a partnering contract (Table 2) established early in the process. This contractual framework allowed the client and contractor to collaborate closely from the onset, creating an organizational structure capable of managing high levels of uncertainty. The project operates without the safety net of a large institutional bureaucracy, meaning the client and contractor must navigate regulatory hurdles and technical risks directly, relying on a "fighting spirit" rather than established corporate protocols.

Project name and site	Sonyas culture house, Gothenburg
Product	New culture house with focus on mixed use
Contract type	Partnering
Size	2,400 m^2
Client	Broods Group AB
Architect	White Architects
Sustainability consultant	White Architects
Entrepreneur	BRA Bygg
Status/timeline	In planning phase
Sustainability goals	Large reuse efforts, co-use of built spaces, optimized material use and novel material use.

Table 2: Summary of key characteristics and operational parameters of the Sonyas project

2.3 Gothenburg Grand Central

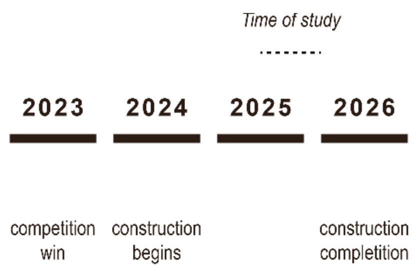

Figure 5: Timeline of Gothenburg Grand Central

Gothenburg Grand Central illustrates the operational conditions of major infrastructure. Developed by the state-owned Jernhusen AB, the project is situated above the West Link tunnel, a location that imposes strict engineering constraints regarding weight and structural integrity. Unlike the other cases, this project operates within a robust institutional financial framework, governed by Green Bonds and EU Taxonomy alignment. This creates a context where sustainability is not just an ambition, but a binding financial requisite linked to loan terms.

The project operates under a turnkey contract with Early Contractor Involvement (ECI)(Table 3), a model designed to bridge the gap between design and production in complex builds. Due to the scale of the project (15,000 m²) and the commercial nature of the asset, the operational environment is defined by high requirements for asset specificity, standardized warranties, and risk mitigation. This creates a context where the project must balance the innovation of sustainability with the rigorous demands of commercial real estate valuation and long-term asset management.

Project name and site	Göteborg Grand Central, Gothenburg
Product	New central station for the West Link project
Contract type	Turnkey contract with ECI
Size	15,000 m^2
Client	Jernhusen AB
Architect	Reiulf Ramstad Arkitekter
Sustainability consultant	White Architects
Entrepreneur	Peab Sverige AB
Status/timeline	Started construction (completion expected Q4 2026)
Sustainability goals	Achieving the sustainability certification Breeam Outstanding (offices) + Excellent (entrance). 100% reused brick. 50-60% reused glass. At least 50% reused structural steel. Climate improved concrete. Wood structure. Reused installations. Solar panels and electric vehicles are used during construction.

Table 3: Summary of key characteristics and operational parameters of the Gothenburg Grand Central project

3 Theoretical frameworks

To comprehensively analyze the effects of circular strategies on construction projects, this chapter constructs a synthesized theoretical framework that integrates three distinct domains. Rather than treating these theories in isolation, they are structured here as a logical sequence of investigation:

Section 3.1 defines the current context, the CE and the construction sector, how they interact, functions and how the linear logic of the construction sector is being challenged by circular interventions,

Section 3.2 introduces Systems Thinking which provides the necessary analytical lens to map the complex, non-linear process shifts that this disruption triggers.

Section 3.3 explains Cost Theory, with a critical focus on Transaction Costs, which serves as the economic language to measure the 'friction', such as increased information search and coordination, generated by these systemic shifts.

This integrated model moves beyond simple cost estimation to explain *why* circularity alters the fundamental mechanics of project delivery.

3.1 Circular design and construction

The CE has emerged as a key strategy in transitioning towards a sustainable industry. It offers an alternative to the traditional take-make-waste approach that dominates the industry today. Within the built environment, the concept has particular urgency, as construction accounts for a significant share of global resource extraction, greenhouse gas emissions, and waste generation. By rethinking how materials are designed, sourced, used, and re-used, the CE promises to reduce environmental impacts while also unlocking new forms of economic and social value. This section outlines the theoretical foundations of circularity, its strategies and applications in construction, and the challenges and knowledge gaps that motivate the present study.

3.1.1 Circular economy

The CE offers a systemic alternative to the linear "take-make-waste" model that currently dominates the construction industry. While the linear economy generates value by extracting finite resources at the lowest cost and discarding them after consumption (Knight, 2023), the CE decouples economic activity from the consumption of finite resources (Ellen MacArthur Foundation, n.d.). The European Parliament (2023) defines this as a model of production involving sharing, leasing, reusing, and refurbishing to extend product life cycles. Webster (2017) emphasizes that this must be viewed through a systems lens: much like a tree is nothing without its forest, every element in a circular system is interconnected through feedback loops of stocks and flows.

To operationalize these principles, Potting et al. (2017) introduced the 10R framework (Table 4), which prioritizes strategies based on their environmental impact. This hierarchy indicates that the highest value is achieved not by recycling, but by rethinking design itself. At the top (R0–R2) lie strategies for "smarter product use," such as Refuse and Rethink, which in construction implies maximizing the utility of existing assets to build less. The middle tier (R3–R7) focuses on "extending lifespan" through Reuse and Refurbishment, the primary focus of this thesis, while the outer loops (R8–R9), such as Recycle, represent the least circular options as they destroy a product's embodied energy to recover raw materials.

Description	Label	Strategy
Smarter product use and manufacture	R0	Refuse
	R1	Rethink
	R2	Reduce
Extend lifespan of product and its parts	R3	Reuse
	R4	Repair
	R5	Refurbish
	R6	Remanufacture
	R7	Repurpose
Useful application of materials	R8	Recycle
	R9	Recover

Table 4: The 10R framework, developed by Potting et al. (2017), ordering circular strategies after level of circularity. From *Circular Economy: Measuring Innovation in the Product Chain* (p. 5) by Potting et al., 2017, PBL Publishers.

The application of these strategies is best understood through the Ellen MacArthur Foundation's (2021) "Butterfly Diagram" (Figure 6). Since the built environment relies on finite, non-biodegradable stocks like metals and concrete, materials that are "used" rather than "consumed", construction belongs to the technical cycle. Consequently, buildings should be viewed as "material banks" (BUILD UP, 2024). The sector must mimic the diagram's "inner loops" (maintenance and reuse) to retain value, utilizing recycling only as a last resort. Supporting this requires design for disassembly, material passports, and digital tools like BIM to track resource flows (ECESP, 2021).

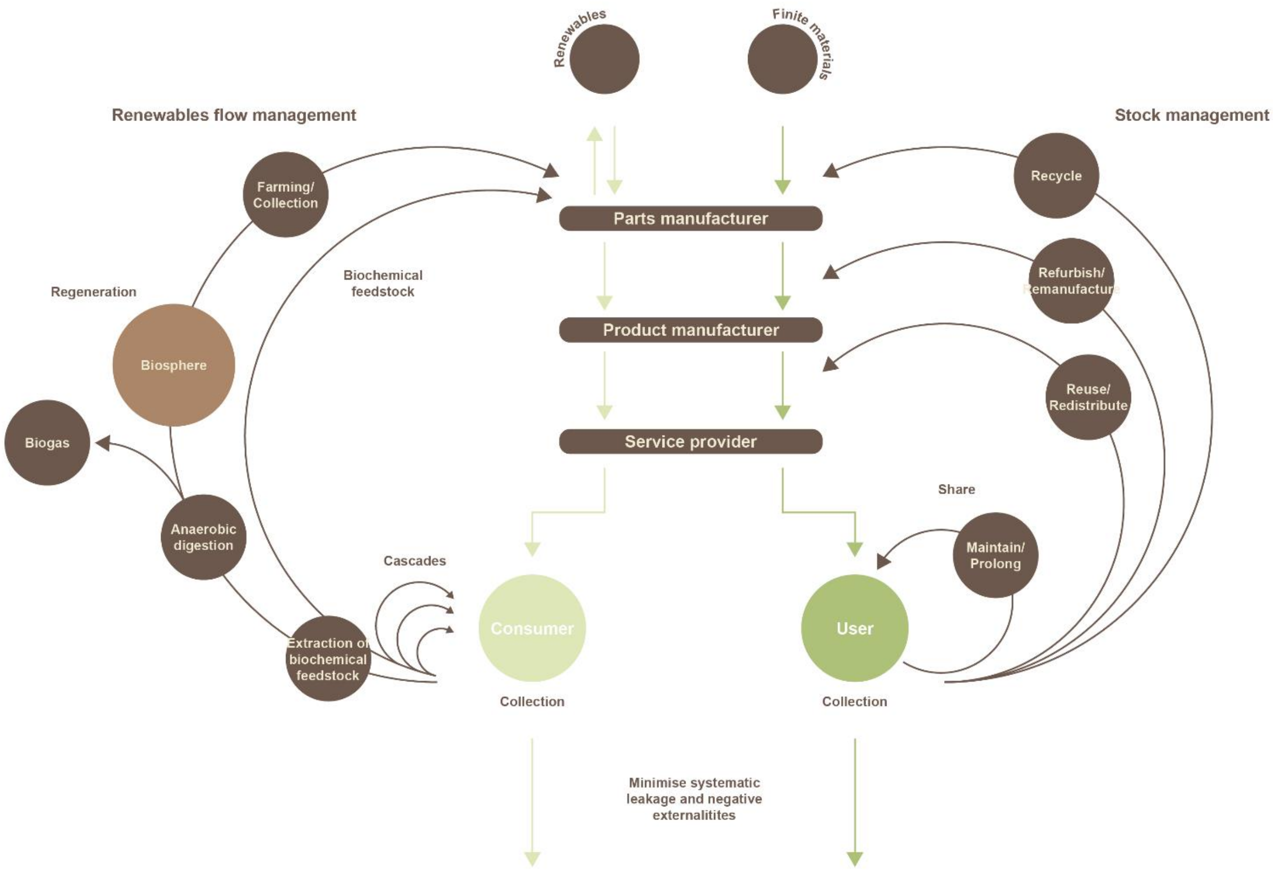

Figure 6: The Butterfly diagram, illustrating the continuous flows of materials in a circular economy. From *The butterfly diagram: visualizing the circular economy,* by Ellen MacArthur Foundation, 2021 (https://www.ellenmacarthurfoundation.org/circular-economy-diagram).

Despite this theoretical framework, implementation is hindered by a conservative industry mindset, perceived economic risks, and inflexible building codes that prioritize operational over embodied energy (Kanters, 2020). These barriers create high consultant costs, as locating and validating circular solutions takes significantly longer than standard processes. Overcoming this friction requires systemic change. Charef and Lu (2021) argue that early stakeholder involvement and tools like Integrated Project Delivery (IPD) are vital to align the value chain. Furthermore, planning for circularity must occur at the earliest possible stage (Gerding et al., 2021), supported by an infrastructure of organized resource markets that allow contractors to treat reuse as a reliable industrial process rather than an isolated pilot effort.

3.1.2 The Swedish construction process

According to Eringstam and Sandahl (2022), the Swedish construction process follows a linear sequence of four phases: pre-study, planning, production, and management (Figure 7). This begins with a pre-study to determine economic feasibility, evolving into a planning phase where requirements are consolidated into a program. Design progresses iteratively from proposal drawings to system documents, defining load-bearing structures and installations, and finally to detailed construction documents. This final stage is the most time-intensive, as it ideally requires the complete dimensioning of all components, from structural elements to lighting fixtures, before production begins.

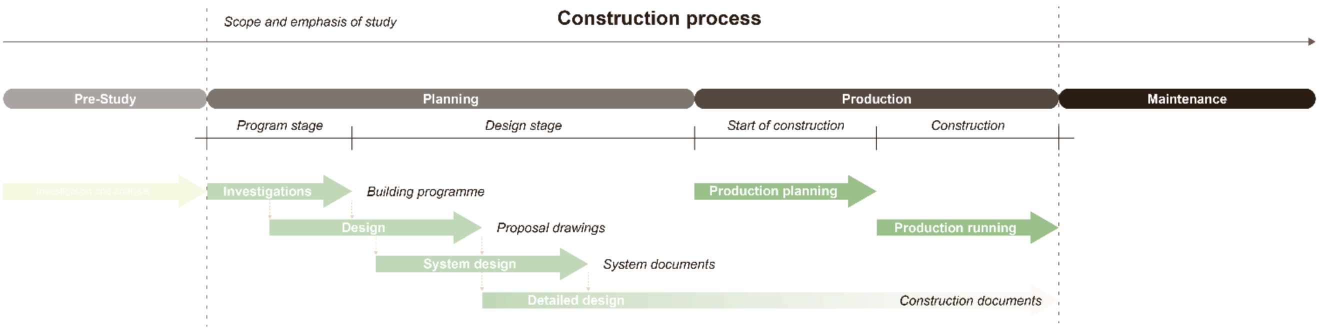

Figure 7: Swedish construction process, derived from Eringstam & Sandahl, describing phases and its main activities.
From *Arkitekt 3.0: Guide för projekterande arkitekter,* by Eringstam & Sandahl, 2022, Svensk Byggtjänst.

Procurement traditionally relies on assignments of trust or competitive tendering, where the lowest cost is often the deciding factor. However, incentivizing circularity during this phase is increasingly recognized as a critical leverage point (Gerhardsson et al., 2020; Hart et al., 2019; Wetterqvist, 2025). Yet, circular strategies introduce significant uncertainty into this linear model. As current markets cannot guarantee material availability or quantities, estimating costs for tenders becomes difficult without clear legal frameworks or incentives (Eringstam & Sandahl, 2022). Collaborative contracts, where contractors are involved during the planning phase, mitigate some of these uncertainties by allowing for earlier decision-making.

In the production phase, the contractor translates these plans into work schedules, logistics, and budgets. If circular strategies are not defined early, they disrupt this precise planning. Uncertainties regarding reuse targets require flexibility that standard production budgets often lack. Consequently, successful implementation requires shifting circular decisions earlier in the process, such as conducting reuse inventories and urban mining, to ensure they are integrated before construction begins (Björklund & Lindborg, 2021).

3.2 Systems thinking

Since circularity introduces complex feedback loops that linear project management tools cannot capture, Systems Thinking is used here as the primary diagnostic tool.

3.2.1 Theoretical foundations

Systems thinking stems from General Systems Theory (Bertalanffy, 1950), which argues that entities must be understood not as isolated parts, but as open systems interacting with their environment . In the context of this thesis, a construction project functions as such a system,

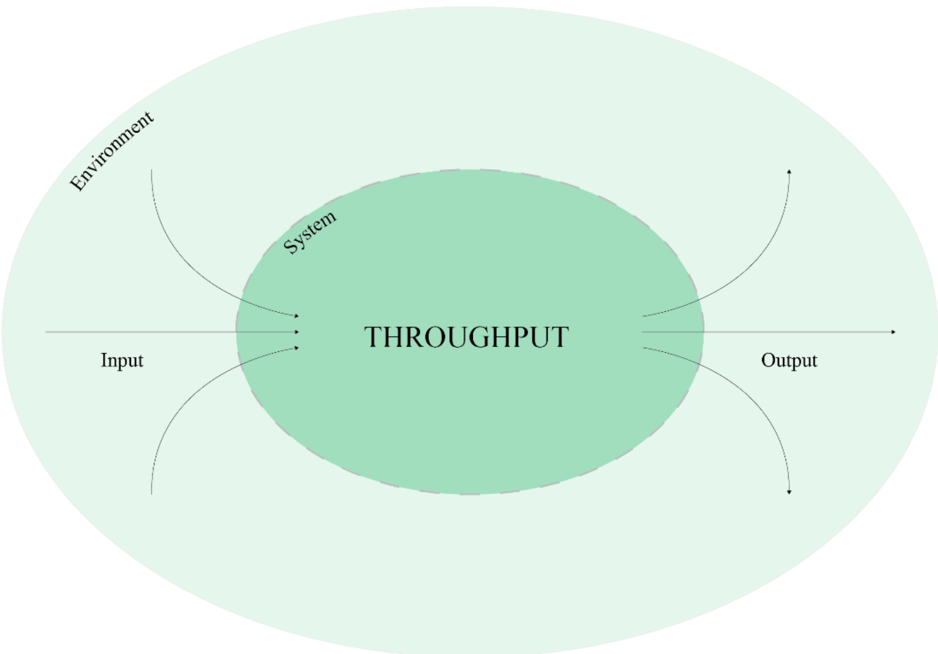

Figure 8: The general system defined by Bertalanffy, describing how a system is something that is affected by an environment and in turn affects it, called the throughput. From *"An outline of general systems theory",* by L.V. Bertalanffy, 1950, The British Journal for the Philosophy of Science, 1(2).

influenced by external factors like regulations and budgets (input) while generating physical and economic outcomes (output).

To analyze the internal dynamics of these systems, Forrester (1961) developed System Dynamics. This methodology utilizes Causal Loop Diagrams (CLDs) (Figure 9) to map how actions create non-linear feedback loops. These loops can be reinforcing (amplifying change) or balancing (stabilizing the system). By mapping these connections, it becomes possible to predict the complex outcomes of specific circular strategies.

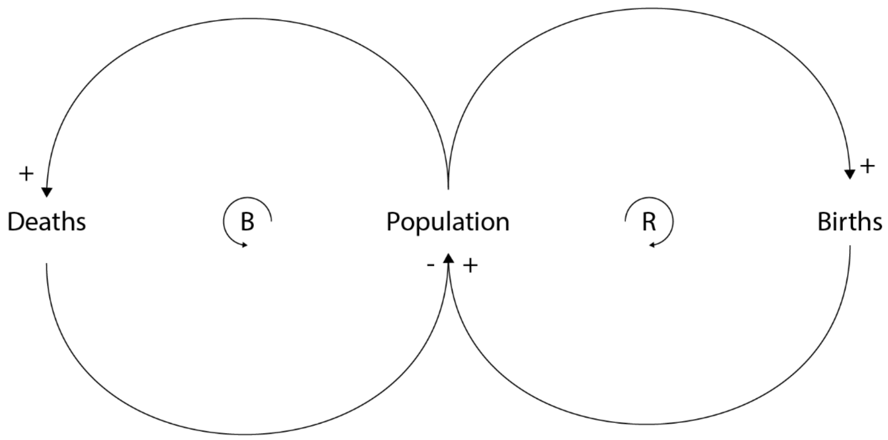

Figure 9: Example of a basic causal loop diagram, derived from the works by Forrester. From *Principles of systems,* by J.W. Forrester, 1968, System Dynamics Society.

3.2.2 Leverage points

To identify where to intervene within these loops, Meadows (1999) developed the framework of Leverage Points. She argues that complex systems are often resistant to change because managers target "shallow" parameters (like subsidies or numbers), which have little long-term effect. In contrast, targeting "deep" leverage points, such as the goals, rules, or mindsets of a system, can produce transformative results (Meadows, 2008). This thesis uses this hierarchy (Table 5) to evaluate the potential impact of identified circular interventions.

12	*Constants, parameters, numbers (such as subsidies, taxes and standards).*
11	*The sizes of buffers and other stabilizing stocks, relative to their flows.*
10	*The structure of material stocks and flows (such as transport networks, population age structures).*
9	*The length of delays, relative to the rate of system change.*

8	*The strength of negative feedback loops, relative to the impacts they are trying to correct against.*
7	*The gain around driving positive feedback loops.*
6	*The structure of information flows (who does and does not have access to what kinds of information).*
5	*The rules of the system (such as incentives, punishments, constraints).*
4	*The power to add, change, evolve, or self-organize system structure.*
3	*The goals of the system.*
2	*The mindset or paradigm out of which the system – its goals, structure, rules, delays, parameters – arises.*
1	*The power to transcend paradigms.*

Table 5: Meadows leverage points, describing where to intervene in a system, where the lower number indicates more impactful interventions. From *Leverage Points: Places to intervene in a system (p. 3),* by D. Meadows, 1999, The Sustainable Institute.

Meadows (2008) explain complex systems and how natural systems often show non-linear behavior that is near impossible to control or predict, and require us to move away from linear mindsets that "A causes B" as it neglects the interconnectedness and complexity of systems.

3.2.3 Strategic application

The application of systems thinking moves beyond theoretical mapping to practical management. As Weiss (1995) argues in her work "Theory of Change," complex initiatives often fail not because the end goal is wrong, but because the intermediate steps required to reach it are poorly understood. Without articulating these specific causal links, collaborative projects struggle to navigate complexity, reducing the likelihood of success. Systems thinking provides the framework to map these "mini-steps," making the invisible friction of the process visible and manageable.

Recent research applies this specifically to the CE. Bassi et al. (2021) demonstrate that CE strategies cannot be copy-pasted, but they rely on territorial dynamics where local feedback loops dictate success or failure. By applying Causal Loop Diagrams (CLDs) to case studies across Europe, they show that identical interventions can produce vastly different outcomes depending on the local context. This validates the need for this thesis to analyze circularity at the specific project level rather than relying on generic industry assumptions.

For decision-makers, Probst and Bassi (2017) outline a structured approach to handling this uncertainty, moving from problem identification to system characterization and finally to strategy assessment. Crucially, they emphasize that system characterization must be collaborative, incorporating multiple stakeholder perspectives to capture the full picture. This thesis aims at characterizing the system out of a problem formulation, which later can be used for strategy assessment. However, Seager and Snell (2015) warn that incorporating several perspectives often reveals contradictory opinions on how the system works. To navigate these conflicting realities, managers can utilize tools like "influence tables" and "impact/uncertainty matrices" alongside CLDs. Ultimately, as Abson et al. (2017) argue, the goal of these tools is to shift focus away from weak, tangible interventions (like tweaking parameters) toward "deep leverage points", interventions that fundamentally restructure the intent and design of the system itself.

3.3 Costs

While the environmental benefits of circular construction are well-documented, economic implications remain the primary barrier to adoption. Standard construction cost management typically focuses on direct tangible costs, such as materials and labor. However, this traditional view fails to capture the 'hidden' costs inherent in circular workflows, such as the time spent verifying reuse materials or negotiating novel contracts. Therefore, this section outlines construction costing fundamentals to establish a baseline before introducing Transaction Cost Theory to describe the administrative and logistical 'friction' that distinguishes circular projects.

3.3.1 Construction cost fundamentals

Construction is a complex industry that involves many, and large transactions, meaning big costs for the project. These are vital to keep track of and have good estimations of in order to manage the complex business (Ottosson, 2013). Ottosson (2013) and Holm (2019) describe that costs can be subdivided into direct costs, including labor costs (internal or contracted), material and equipment costs, travel costs and fees. Indirect costs, also called overhead costs, include administrative costs (headquarters expenses, benefits, telephones and electricity, heating, fringe benefits), marketing and sales, but also research and development costs. Potts (2013) adds that costs can entail land acquisition and fees, organizational costs, site investigations, early site preparation, insurances, consultant fees, construction costs, taxes, contingency and risk. The biggest project costs usually consist of the construction costs, in which the largest financial post usually is the cost of materials (Figure 10) (Byggföretagen, 2024).

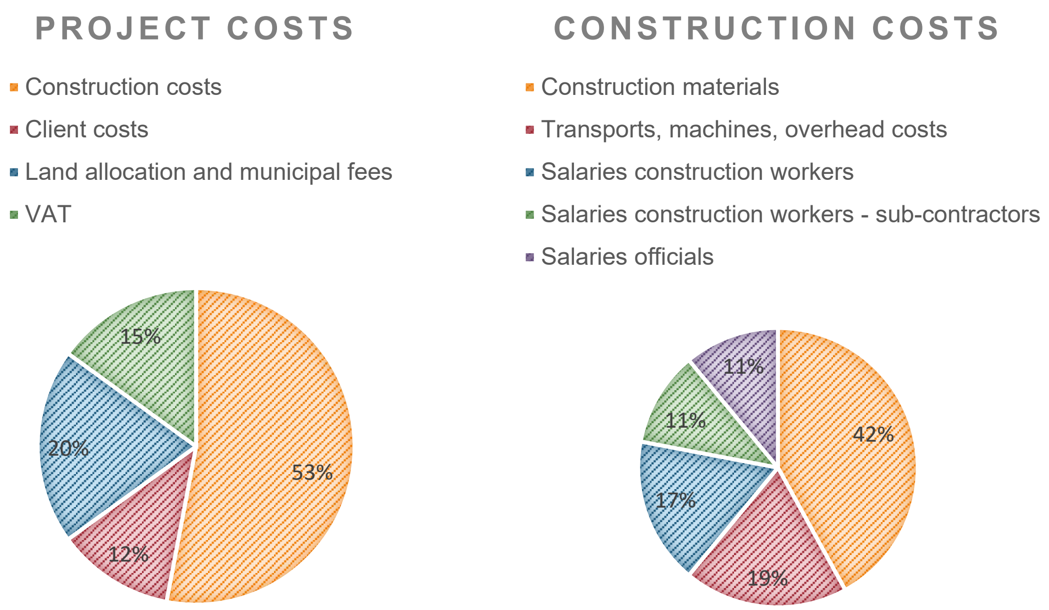

Figure 10: Division of project costs of new development residential buildings, based on data from SCB (statistiska centralbyrån). From *Byggkostnader*, by Byggföretagen, 2024 (https://byggforetagen.se/statistik/byggkostnader/).

Many construction projects fail to meet their initial cost estimates, resulting in either higher or lower final expenses according to Ottosson (2013). This is often due to unclear scope and performance requirements, overlooked items in the cost calculations, needs and wishes that fall outside project control, delays, market fluctuations, design changes, and additional work arising from poorly executed planning, design, and procurement. Other contributing factors include neglected uncertainties, cost index developments, and currency fluctuations (Ottosson, 2013).

3.3.2 Economic implications of circular construction

The CE rewires the construction value chain, introducing new variables that alter project preconditions. While some expenses decrease, such as waste management costs due to reduced generation (Ghisellini et al., 2016), others increase, particularly during the early planning and design phases which require more holistic and technological solutions (Finamore & Oltean-Dumbrava, 2024). To combat the early costs of circular adoption, Gerhardsson et al. (2020) emphasize the importance of financial incentives to drive the transition.

Transitioning to Circular Economy Business Models (CEBM) introduces specific complexities. Hina et al. (2022) note that remanufacturing and refurbishment often incur higher costs than producing new products due to return transportation and the need for new technology and employee education. However, the Linear Business Model (LBM) of discarding materials is becoming increasingly difficult to sustain. CEBMs offer drivers such as lower raw material costs and reduced exposure to price volatility (Hina et al., 2022). By decoupling projects from volatile global resource markets, circularity enhances long-term economic resilience (Chiarella et al., 2025; Ghisellini et al., 2016; Hina et al., 2022). Furthermore, integrating SMEs through industrial networks has been proven to lower business costs and enhance market impact (Hina et al., 2022).

While the economic system often struggles to measure holistic sustainability, the benefits are clear, circular construction reduces pollution and social externalities while increasing welfare through job creation in labor-intensive reuse processes (Ghisellini et al., 2016). Conversely, neglecting the social perspectives can lead to long-term costs related to inequality and lack of integration (Aguilar-Hernandez et al., 2021). Despite these long-term values, Webster (2021) warns that without optimizing flows and developing new business models, circular efforts may not be economically viable, especially if value chains remain global and optimized for linear transport. Therefore, effective transition requires the full participation of the entire value chain, from clients to manufacturers, to align incentives and share the economic burden (Chiarella et al., 2025).

3.3.3 Transaction costs

To measure the "friction" introduced by this collaboration and complexity, this thesis employs Transaction Cost Theory. Defined by Dahlman (1979), transaction costs are not the price of the goods, but the costs of market interaction. Coase (1937) identifies these as the costs of searching for information, gathering data, and bargaining terms. Once terms are settled, Dahlman (1979) adds that costs arise from monitoring and enforcing compliance.

Williamson (1979) expands on this by identifying five key concepts that drive transaction costs: uncertainty, transaction consistency, bounded rationality (incomplete knowledge), opportunism (self-interest), and asset specificity (unique goods). In a circular context, uncertainty, transaction consistency, opportunism and asset specificity are particularly critical. Unlike standardized new materials, reused components are unique and require significant search time. They are also often bought at singular occasions and not repetitively, and additionally stakeholders may act upon opportunistic reasons considering the novel materials or methods. Coase (1937) argues that firms exist to internalize these operations when market transactions become too costly.

Governance structures play a vital role in mitigating these costs. Williamson (1979) argues that increasing complexity requires relational contracts rather than simple market transactions. Turner and Simister (2001) suggest that design-build or partnering contracts can combat high uncertainty. This is supported by research in construction procurement, where Rajeh et al. (2015) found that relational contracts significantly reduce the time spent on information gathering and administration. These transaction costs occur throughout the project lifecycle, from pre-contract negotiations and feasibility studies to post-contract monitoring and dispute resolution (Jin et al., 2017). By applying this lens, the increased effort required to manage, learn about, and treat circular materials can be understood not just as inefficiency, but as a structural transaction cost inherent to the transition.

3.4 Synthesis

To comprehend the complex effects of circularity on Swedish new development, this thesis integrates CE, Systems Thinking, and Cost Theory into a single framework. Rather than viewing construction as a linear sequence, this synthesis conceptualizes the project as an open system influenced by its environment (Bertalanffy, 1950).

Within this framework, circular strategies are not viewed merely as material substitutions, but as systemic interventions. Drawing on the 10R framework (Potting et al., 2017), strategies such as reuse (R3) challenge the "take-make-waste" paradigm (Ellen MacArthur Foundation, n.d.), forcing the system to manage the technical cycle of finite stocks (Webster, 2017). This shift immediately impacts project processes. Early planning and design stages are extended (Finamore & Oltean-Dumbrava, 2024), and significant effort is diverted to finding circular solutions (Kanters, 2020). This increases transaction costs (Coase, 1937; Dahlman, 1979), necessitates value chain collaboration (Chiarella et al., 2025; Webster, 2021), and complicates tendering due to material uncertainty (Eringstam & Sandahl, 2022; Hina et al., 2022).

Systems Thinking serves as the diagnostic tool. Utilizing System Dynamics (Forrester, 1961), the analysis moves beyond linear reasoning to identify the reinforcing and balancing feedback loops that define project behavior. Causal Loop Diagrams (CLDs) are employed to visualize how early circular decisions trigger non-linear trade-offs across the project (Sterman, 2000). Furthermore, Meadows' (1999) leverage points are used to categorize these interventions based on their potential to effect system-wide change, ranging from simple parameter adjustments to deep shifts in goals.

Economically, circular efforts remain challenged by global supply chains optimized for linear flows (Webster, 2021). While aiming to reduce raw material dependency (Chiarella et al., 2025; Ghisellini et al., 2016), circularity increases early-stage costs and labor intensity (Finamore & Oltean-Dumbrava, 2024; Ghisellini et al., 2016). Additionally, costs frequently deviate from estimates due to the "neglected uncertainties" inherent in circular flows (Ottosson, 2013).

Critically, standard cost management fails to account for this "friction" (Dahlman, 1979). Therefore, Transaction Cost Theory (Coase, 1937) is incorporated to explain the economic impact. The amplified need for information gathering and risk management regarding uncertain materials is analyzed using Williamson's (1981) concepts of uncertainty and asset specificity. These costs can further be categorized as pre- and post-contract transaction costs (Jin et al., 2017). By viewing expenses as transaction costs rather than simple losses, the model explains why circular projects often face high initial economic barriers despite potential long-term value and may pose hidden costs related to the transition.

In summary, circular strategies act as inputs that destabilize the standard project system. Systems thinking maps the resulting process dynamics, and traditional/transaction cost theory explains the subsequent economic friction. This framework is visualized in (Figure 11) and structures the analysis in Chapter 7, enabling a holistic understanding of how circular interventions reshape the Swedish construction sector.

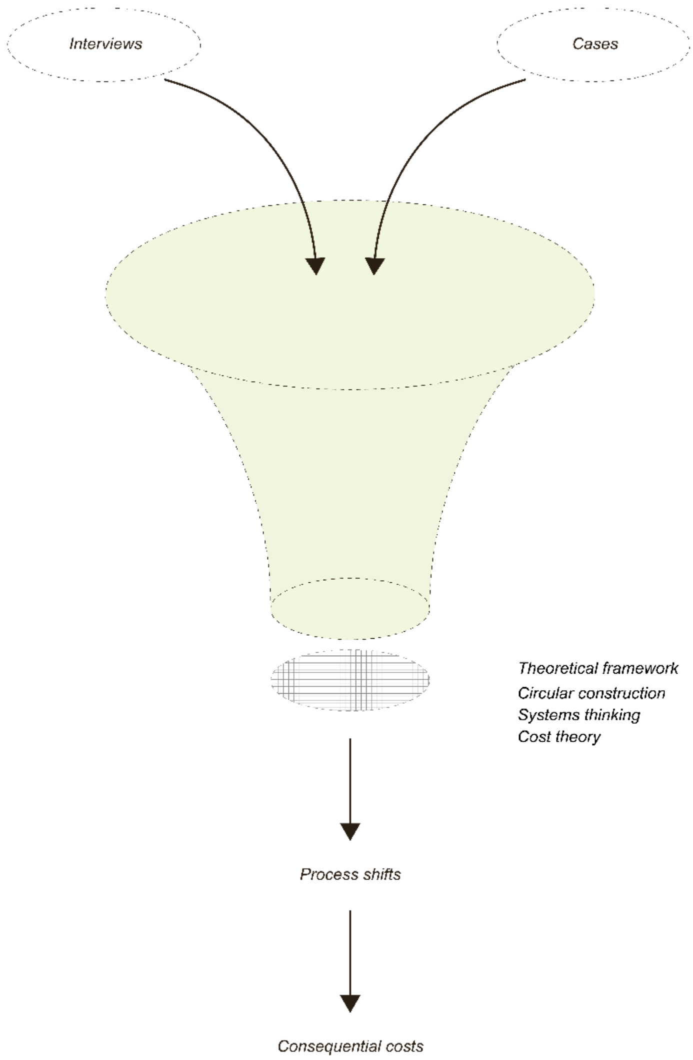

Figure 11: Analytical framework

4 Method

This part will present the design of the study, its philosophy and approach. This is meant to make it possible to recreate the study in the future and provide transparency on the chosen method and its implications. In section 4.3 the methods of collecting data and the reasoning for choosing interviewees are presented. Section 4.4 explains how the data were processed and analyzed. The final sections establish the ethical considerations, trustworthiness and limitations of the study and finalizes in explaining the use of AI.

4.1 Research philosophy and approach

This thesis adopts an interpretivist research philosophy, seeking to find synergy and understanding from qualitative data. It is the researcher's belief that truth can be found in the stories and experiences from stakeholders in the industry and can only partially be described by theoretical framework. Furthermore, the subject on circularity is still immature and complex and needs further research. Therefore, it is hard to state hard facts about the phenomenon, but understanding is sought out of experiences and beliefs from the early adopters of circularity. The approach seeks to understand changes in processes and causal links to costs, that will build knowledge about the effects of circular efforts and in extension give opportunity to put into an evaluative decision-making process.

While the thesis primarily follows inductive logic, seeking to form insights and theories based on qualitative investigations from different subjective settings and experiences, it also draws on existing theory to interpret findings, interweaving an abductive perspective. It aims to investigate and theorize how costs and processes are affected by circular interventions in construction and thus create an understanding of these effects. Existing theory and models, such as systems thinking models, was used as a tool to understand and create understandings from the complex reality.

4.2 Research design

The research is designed as a study of three projects, all interlinked with White as a key actor. This is done because the thesis aims at comparing different projects with similar strategies to investigate whether you can create general conclusions out of the phenomenon. The research also believes that subjectivity matters, and that truth may differ depending on the actors involved or the circumstantial setting.

To get a full picture of the complex reality, a quality-dominant mixed-methods approach was used. Primarily, qualitative interviews were conducted to get an in-depth understanding of the effects of circular interventions. Complementary information, to support subjective understandings, was gathered through seminars and discussions arranged at White Architects and at Chalmers. Additionally, key project documents were targeted for investigation.

4.3 Data collection and sampling

Semi-structured interviews served as the primary data collection method. Developed in collaboration with a Chalmers supervisor, the interview guide (Appendix 1) was designed to identify costs emerging from circular process shifts. The dialogue structure progressed from participant backgrounds and specific interventions to economic implications, specifically comparing emerging costs to standard practices, before concluding with future-oriented reflections.

Participants were selected via purposive sampling (Saunders et al., 2023) across three cases. To facilitate comparison, the sampling remained homogeneous, targeting equivalent actors in each project: clients, architects, constructors, and sustainability consultants. This resulted in a total of nine interviews (Table 6). Selection prioritized actors in connected roles with broad process oversight, while specialized roles (e.g., cost engineers) were excluded due to their assumed limited scope and overview. This sample size is supported by Bell et al. (2019) regarding data saturation and Brinkmann and Kvale (2018), who advocate for 5–25 subjects to generate deep, rich knowledge.

Interviews were recorded, transcribed, and thematically coded into categories of “circularity,” “processes,” “costs,” and “values,” with deeper coding applied where patterns emerged (Table 7). While attempts were made to corroborate findings with quantitative data (e.g., budget sheets), this information was either non-existent, or the interviewees were reluctant to provide such information. Literature was sourced through the Chalmers Library using keywords including “Circularity,” “Systems thinking,” “Costs,” and “Values,” followed by a snowball approach based on primary sources such as Dokter et al. (2023), Bassi et al. (2021), and Björklund and Lindborg (2021).

Label	Type of firm	Role	CE Experience	Interview date
The botanical garden				
A1	Real estate	Project manager	11 years	2025-10-06
A2	Real estate	Environmental strategist	15 years	2025-10-06
A3	Construction	Contracting Engineer	14 years	2025-10-22
A4	Architecture	Sustainability consultant	3 years	2025-10-29
Sonyas				
B1	Real estate	Project development manager	10 years	2025-10-23
B2	Construction	Environmental specialist	8 years	2025-10-13
Gothenburg Grand Central				
C1	Real estate	Project manager	4 years	2025-11-13
C2	Construction	Project director	2 years	2025-11-13
C3	Architecture	Sustainability consultant	14 years	2025-10-31

Table 6: Table of interviewees

4.4 Data analysis

Answers to open interview questions was coded thematically based on the framework created by Braun and Clarke (2006) which describes how data gathered is first familiarized by the researcher and later systematically coded according to themes. Sub-themes were then constructed to gather data in smaller and more manageable groupings. The themes were then reviewed in the full dataset, refining them to find common themes and understandings.

Qualitative data from the interviews were meant to identify process shifts and emerging costs and were concluded into causal links between circular interventions, transformed processes and emerging costs, aiming at capturing the full dynamics of the complex system of a construction project. The development of the causal loop diagrams were constructed through the tool Kumu.

Primary themes	Circularity	Processes	Costs	Values
Secondary themes	Refuse	Planning	Administration	Aesthetics
	Rethink	Budget & Purchase	Structure	Learning
	Reduce	Design	Logistics	Local connection
	Reuse	Logistics	Market	Financial
	Repair	Production	Upcycling	Cultural enrichment
	Refurbish	Upcycling	Labor	Environmental
	Remanufacture	Governance	Development	Social/collaborative
	Repurpose			Influence
	Recycle			
	Recovery			

Table 7: Table of emerging themes

4.5 Ethical considerations and trustworthiness

Ethical compliance was established prior to the interviews by distributing a consent form detailing voluntary participation and the right to withdraw at any time. Throughout the thesis, both participants and their companies are presented anonymously. Data security is maintained by storing transcripts and recordings on the researcher's personal computer, with deletion scheduled upon thesis completion no later than June 1, 2026.

The researcher is a Chalmers master's student with a background in architecture. While operating as a "neutral outsider" with no prior connection to White Architects, the researcher is dependent on the firm for access to project information. These dynamic warrants consideration: as White Architects is a major stakeholder, other actors may have felt an obligation to participate to maintain good relations. To mitigate the risk of "social desirability bias", where respondents hesitate to criticize the project, strict confidentiality was guaranteed. Consequently, while the response rate may have been positively influenced by the connection to White, the truthfulness of the views expressed is considered preserved.

Regarding personal bias, the researcher acknowledges an expectation to understand architectural processes and views circularity as a vital sustainability strategy. However, personal experience suggests circularity is often met with resistance in the industry, where it is frequently perceived as a costly and tedious practice lacking sufficient reward.

To ensure robust results, the framework by Lincoln and Guba (1985) was applied. Credibility was established through data triangulation, combining interviews with literature due to limited documentation, alongside peer debriefing with the supervisor and allowing participants to check the text for factual errors. Transferability is supported by a "thick description" of the cases to allow readers to judge relevance in their own settings. Dependability was ensured through transparent processes, two peer reviews during the writing process, and final seminar presentations at both White Architects and a Chalmers research group. Finally, confirmability was achieved through the use of direct quotes and comparative analysis across data sources.

4.6 Limitations

The thesis has its limitations, as it only investigates projects which White Architects are a part of. Even though the projects themselves are varied, a more nuanced picture would have been achieved if projects with another sustainability consultant than White would have been involved.

A deeper understanding would also have been achieved if the investigation had larger data samples, including more projects (than three) with varied settings and preconditions and more interviews with interviewees of different contexts and experience. The aim of the thesis is to develop understanding and explore causes of circular interventions, regarding costs and values and therefore fewer but deeper data was preferred. Thus, the results are analytically generalizable rather than statistically generalizable.

A limitation of the study is the exclusion of specialized roles, such as cost engineers, from the interview sample. The research design was based on the premise that project management possesses a holistic overview of project costs and availability. However, the data collection revealed that cost information for circular interventions is often not aggregated at the management level but may remain dispersed among specialists. Future studies could therefore benefit from targeting these specific financial roles to capture quantitative economic data.

Another limitation of this study was the unavailability of measurable quantitative data regarding the costs of circular interventions. The participants either did not know the exact figures, did not want to share them or did not have the time to investigate. Consequently, the intended triangulation of interview findings with project budgets was not possible. As a result, the analysis relies primarily on qualitative data to describe economic impacts, focusing on the perceived drivers of cost rather than verified accounting figures.

4.7 Artificial intelligence

Artificial intelligence (AI) tools (Grammarly, Copilot and Gemini) were utilized in this thesis in two distinct methods. Primarily, AI served as an instrument for literature discovery and bibliographic analysis. Tools such as ResearchRabbit were employed to identify initial sources and scope their relevance through automated summaries. This process was supplemented by a 'snowballing' method, where AI-generated recommendations were cross-referenced against the reference lists of key studies to locate further relevant literature. All sources identified by AI tools were manually verified by the author to ensure accuracy and relevance. AI summaries served only as a preliminary filter, not a substitute for in-depth reading.

Secondly, AI tools functioned as editorial assistants throughout the writing process. These tools were used strictly to improve grammatical accuracy, identify stylistic inconsistencies, and enhance overall comprehensibility, ensuring that the original arguments and analysis remained solely that of the author. While AI assisted in refining the text and giving suggestions on improvements, the text formulation, conceptualization, analysis and final phrasing of arguments were performed solely by the author.

No sensitive data, provided by the interviewees, was shared with the AI tools.

5 Results and analysis

This chapter synthesizes the empirical findings from the three cases, The Botanical Garden, Sonyas, and Gothenburg Grand Central, with a diagnostic systems analysis. By integrating the descriptive results (Strategies, Processes, and Costs) with the explanatory power of Causal Loop Diagrams (CLDs), this section illustrates not only *how* circular interventions disrupted standard project workflows, but *why* specific economic and processual frictions emerged.

The analysis demonstrates that circularity acts as a destabilizing input in traditional construction systems, transforming linear efficiencies into complex feedback loops defined by transaction costs, uncertainty, and administrative friction.

5.1 The Botanical Garden

The Botanical Garden project represents a compliance-oriented approach situated within a sensitive heritage environment. Governed by a public procurement framework and a fixed-price turnkey contract, the project faced the specific challenge of implementing circularity within a rigid administrative structure. The project, which began planning as early as 2018, was also heavily influenced by external disruptions, including budget cuts driven by the Covid-19 pandemic, which forced a tension between high initial ambitions and strict spending limits. The results reveal a system heavily burdened by "transaction costs" resulting from a strategy that placed the logistical and risk-management burden on the project team rather than the market.

5.1.1 Strategy overview

The project's primary strategic intervention was the conceptualization of the construction site not merely as a plot for development, but as a "quarry" or material depot. This strategy focused on closing the loop within the site boundary, prioritizing the R3 (Reuse) level of circularity. The inventory process identified significant volumes of hardscape elements, specifically curb stones, granite bollards, and limestone stairs, that could be directly appropriate for the new design.

To supplement these on-site resources, the project expanded its procurement boundary to utilize an "internal market" strategy. This involved sourcing off-site targets from other properties owned by the client, such as small cobblestones and additional sanitaryware like toilets and utility sinks. By relying on the client's internal asset management system, the project effectively bypassed the uncertainty and volatility of the external open market.

A particularly innovative strategy involved "on-site remanufacturing", linking to the R6 (Remanufacturing) level of circularity. During site clearance, several large trees required felling. Rather than treating this as organic waste or chipping it for low-grade biomass, the project established a manufacturing loop. The harvested timber was transported to a local wood manufacturer, Derome, where it was dried, sawed, and processed. These trees are subsequently planned to be returned to the site as finished interior wall panels. This strategy was highlighted by respondents as a tangible and symbolic example of circularity, connecting the new building's interior directly to the site's cultural heritage (A1, A4).

However, the ambition to reuse was not without physical limitations. While labor-intensive restoration strategies were successfully applied to brick masonry, where façade and floor bricks were dismantled from a hospital demolition at Sahlgrenska, cleaned, and stored at *Bruksspecialisten*, other attempts failed due to the condition of the stock. A notable failure was the attempt to reuse cable ladders. The project team intended to salvage these technical components, but upon assessment, the old units were found to be skewed and damaged. The labor required to straighten them was deemed ineffective, and crucially, many available ladders did not meet the dimensional requirements for the new technical installations (A1, A3, A2).

5.1.2 Process shifts

The implementation of circular strategies necessitated a comprehensive transformation of standard project processes, creating a workflow that was significantly more iterative and administratively heavy than traditional linear construction.

A central challenge was the "turnkey paradox" inherent in the contract model. While a turnkey contract was necessary to secure early contractor involvement, its fixed-price nature made tendering extremely difficult due to a lack of data regarding reuse targets (A1). Because the contractor could not calculate risks for undefined reused materials, the project treated these targets as "contract options." This meant the baseline budget was calculated using new materials, with reuse implemented only if the budget allowed. Additionally, the demanding nature of circular construction may have required more collaboration and contractor involvement even earlier.

While this strategy secured the budget, it created a process defined by low incentives for reuse and constant scope revisions. The administration was forced to continuously exchange priced project management documents (PMs) to track costs as options were exercised, a workflow that respondents described as administratively heavy and inefficient (A1, A2, A3). As Respondent A1 noted, the uncertainty meant that calculations often had to be simplified, but the subsequent workload of re-initiating circular targets was immense.

Logistically, the project moved away from standard "order-and-arrive" flows to a complex system of tracking multiple sources. This proved difficult as working with several reuse sources and multiple warehouses increased access and transport hassles (A1, A2, A4).

In the specific case of the reused bricks from Sahlgrenska, the client was forced to assume direct responsibility for purchasing and management simply because the contractor had not yet been procured. This meant the client had to coordinate the salvation of bricks from demolition, washing, and storage, effectively externalizing the logistical risk from the contractor to themselves (A1). The bricks were sent to *Bruksspecialisten*, which simplified the treatment and storage of the bricks. The logistical friction was exacerbated by the physical locations of storaga. Materials had to be stored at external locations, including a forensic psychiatric institution (*Rågården*). Respondent A1 described the severe administrative burden of this arrangement:

"Rågården is a forensic psychiatric institution, so it is a hell of a process to get in there. You have to get approval and book escorts in advance... so it was very troublesome to have it there." (A1)

The design dynamics were forced to shift from a linear progression to a reactive, overlapping process. Architects and engineers struggled to produce accurate early drawings without knowing future material availability or specific dimensions. Moreover, constant scope revisions required the drawings to constantly be updated, leading to a scenario where detailed design overlapped with production (A1, A3, A4). The team identified that an optimal process would utilize "interval designs", adapting the design to the materials available rather than the reverse (A4).

Through this iterative learning process, the project realized that "easier" targets should be prioritized. While technical requirements for fire, sound, and automation made the reuse of complex doors difficult, forcing a focus on "dumb" doors, the inability to find correct dimensions for cable ladders forced the abandonment of using ladders entirely (A1, A2, A3).

5.1.3 Economic consequences

The economic consequences of these process shifts manifested primarily as transaction costs and labor inefficiencies.

The project faced high transaction costs related to information search and risk management. Unlike standardized new materials, reused components required extensive manual inventory, measurement, and verification of upcycling potential (A1, A2). The lack of standardized industry practices meant that significant capital was spent on administration and human resources, and respondents noted that efforts to collaborate, supervise, and investigate material properties were sometimes disproportionate to the end value of the item (A2, A3, A4).

Direct costs also increased due to the loss of economies of scale. The sensitive dismantling and labor-intensive upcycling required for reuse, such as cleaning, painting, and treating doors with fire protection, proved far costlier than streamlined new production (A1, A2). For example, even seemingly simple items like toilet furniture required the procurement of new mixers, adding unexpected layers of cost and process (A3).

Furthermore, the project incurred costs for testing and certification. Reused products, even those from suppliers, required rigorous testing (e.g., load-bearing checks) to verify technical properties (A3). Respondent A3 noted that some items, like the skewed cable ladders, were simply more expensive to restore than to buy new ones.

Logistics emerged as a major cost driver due to the fragmentation of the supply chain. Unlike the streamlined delivery of new materials, the project incurred costs from accessing distant warehouses and unnecessary transport between storage locations (A1, A3, A4). Specific logistical hurdles, such as recycling transports containing mineral wool or materials sent to Norway incurring export taxes, further inflated the budget (A3). The client concluded that taking responsibility for these logistics was not only administratively burdensome but financially costly, suggesting that a model where suppliers provide project-ready items would be far more economical (A1, A2, A3).

"At the current stage, reuse is much more troublesome than buying new." (A1)

5.1.4 Dynamics

To understand the underlying causes of these frictions, the project is analyzed through the lens of Systems Thinking.

The system is initially defined by the "*Early Optimization Loop*" (Figure 11). Ideally, early planning leads to clear reuse targets, which facilitates efficient design. However, in this case, the loop was destabilized by vague goal setting. Because goals were not "locked in" early, the incentives for reuse diminished as budget pressures mounted. The analysis identifies "*Lock-in Goals*" (Meadows Level 3) as a critical leverage point. By formalizing circular objectives in the early program documents, rather than leaving them as "ambitions", the project generates the rigidity needed to resist value engineering and sustain the cycle.

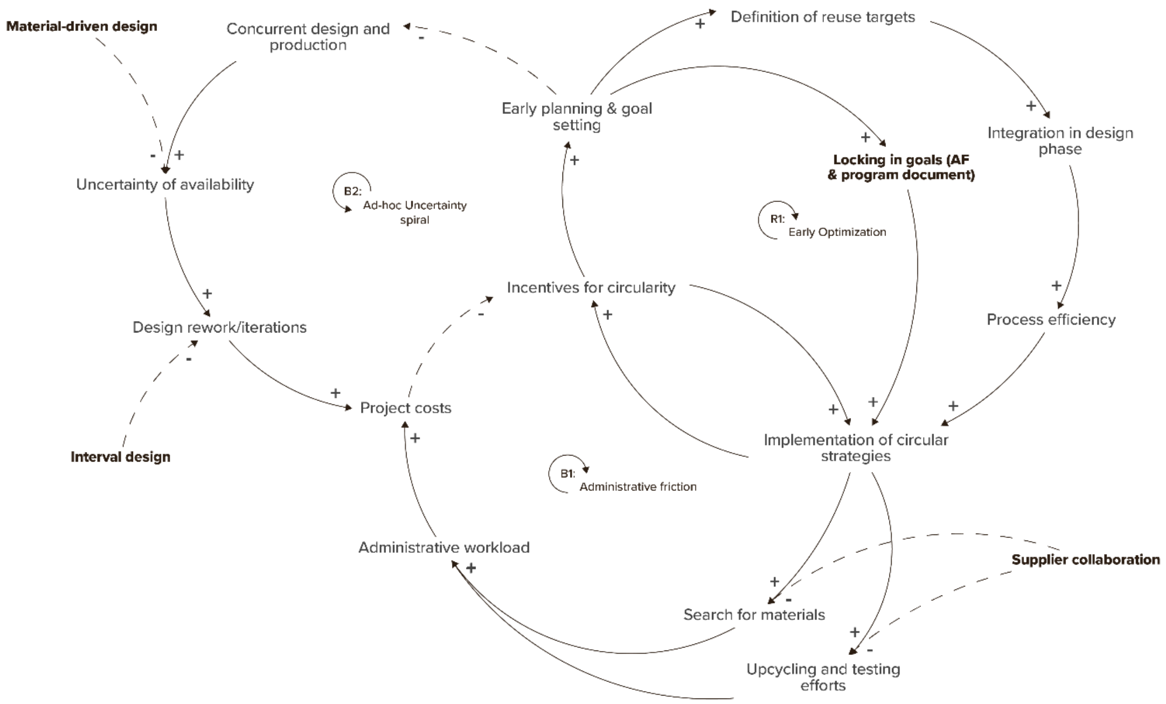

Figure 12: The early optimization loop

The friction regarding the bricks and off-site storage is explained by the "*Supplier Standardization Loop*" (Figure 12). Currently, the system is dominated by the "*Warranty Gap*" Loop (Balanced loop 2). Because the client assumed responsibility for sourcing and storing materials (project-managed logistics), they faced a high burden of risk . This necessitated a lot of administration and coordination of expensive, bespoke testing and certification to verify the quality of the bricks. The more the project managed itself, the higher the transaction costs became.

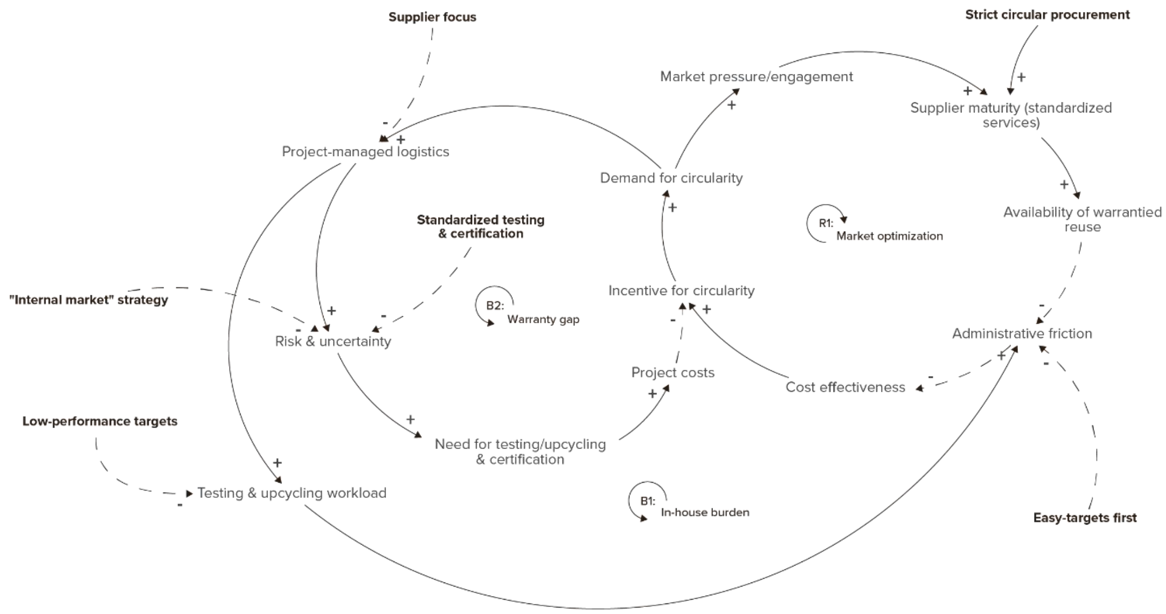

Figure 14: Supplier standardization loop

The analysis identifies "*Supplier Focus*" and "*Market Optimization*" (Reinforcing loop 1) as possible solutions. By shifting the burden of sourcing and testing to external suppliers (e.g., *Bruksspecialisten*), the project can bypass the warranty gap. When suppliers provide warrantied, tested products, the administrative friction of the project team drops effectively to zero, mirroring the efficiency of linear procurement.

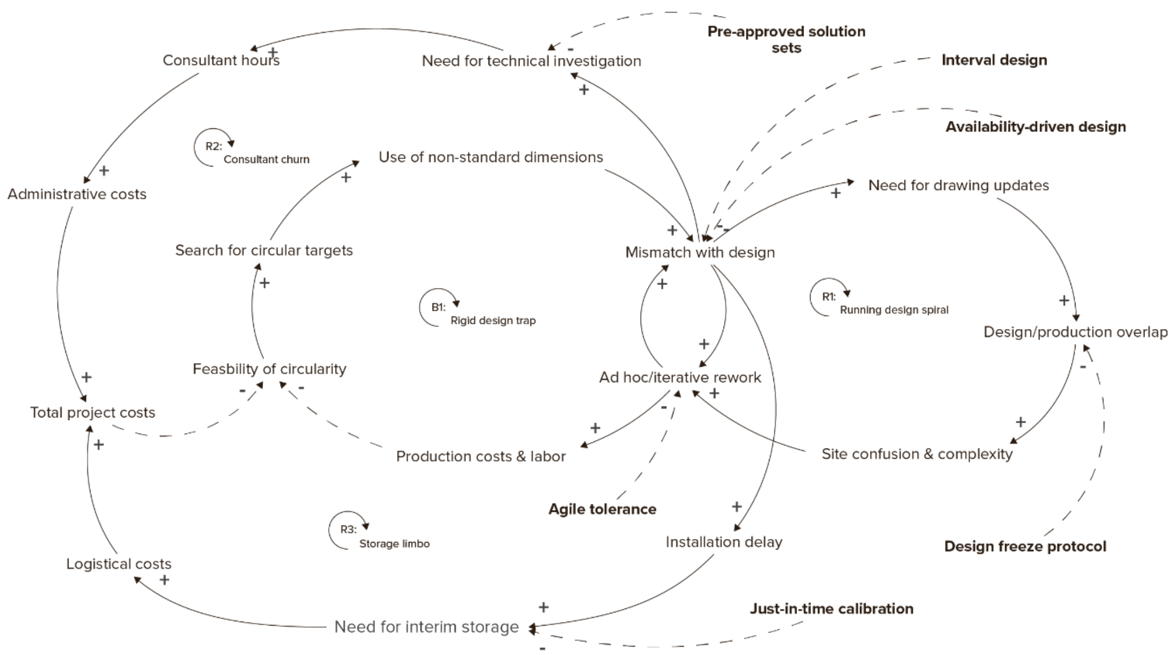

Figure 13: Design rigidity loop

Finally, the "*Design Rigidity Loop*" (Figure 13) illustrates the cost of the "Turnkey Paradox." The mismatch between variable reuse materials and rigid architectural plans triggered the "*Running Design*" Loop (Reinforcing loop 1), where the team was forced into a cycle of constant redesign and scope revision. To stabilize this, the system suggests "*Interval Design*" as a leverage point, designing with tolerance ranges rather than fixed dimensions to accommodate material variability without triggering rework.

5.2 Sonyas

In contrast to the heavy institutional oversight of the Botanical Garden, Sonyas is a smaller, private development driven by rapid decision-making. Developed by Broods Group AB, this culture house operates on a compressed timeline with strict environmental requirements imposed by the municipality. The project is characterized by organizational agility and a "learning by doing" approach, supported by a partnering contract that allowed for close collaboration from the onset.

5.2.1 Strategy overview

The circular strategy employed in Sonyas represents a distinct shift towards a philosophy of "Radical Low-Tech". Rather than focusing solely on the recirculation of existing components, the project prioritized material innovation to reduce the environmental footprint. This included the introduction of bio-based materials such as clay blocks, clay plaster, and clay paint (B1).

Simultaneously, the project challenged standard technical requirements. The design strategy actively questioned the necessity for advanced technical systems, aiming to significantly reduce the quantity of ventilation piping and control devices needed (B1). A core component of their "Strategic Pragmatism" was the decision to forego formal environmental certifications. The team deliberately skipped certifications to save costs, redirecting those resources toward the building's actual environmental performance and community value (B1).

The project also engaged in rigorous structural optimization. Engineering efforts focused on optimizing load-bearing structures to minimize resource consumption, utilizing shorter spans of 4.8 meters to allow for the use of thinner hollow-core decks (B1). This decision had a cascading positive effect, reducing overall concrete use and allowing for lighter piling foundations (B1).

However, the team remained flexible. Initial plans to reuse hollow-core (HC) slabs were abandoned not only due to logistical and warranty issues but because the reuse options would have required thicker slab dimensions. Paradoxically, this "thickening" would have resulted in an increased climate impact compared to the optimized new production (B1). Furthermore, the project successfully pivoted to plan for the reuse of slate tiles for the roof, even though it was first deemed impossible to find (B1).

5.2.2 Process shifts

The process shifts in Sonyas were heavily influenced by the organization's agility and a "learning by doing" culture.

The client leveraged its small size to make decisions significantly faster than larger companies, as key players sat close together and could bypass standard administrative hurdles (B1). Success was driven less by rigid planning and more by a "fighting spirit" and problem-solving mindset, often spurred by tough early environmental demands from the municipality (B1, B2). The partnering contract was essential to this agility, allowing the client and contractor to collaborate closely from the start (B2).

The sourcing process resembled a "hunter-gatherer" model. The team quickly realized that the construction sector relies heavily on informal tips between consultants, meaning the best reuse products often never reach the open market (B2). Consequently, they pivoted from searching high-uncertainty open marketplaces to building direct relationships with suppliers. For example, the team contacted *Ecophon* directly to secure reused suspended ceilings, finding it more effective to utilize supplier resale channels than to scavenge for materials (B2).

The project also had to navigate regulatory hurdles. The team negotiated with lawyers and municipalities to classify left-over materials as reuse, thereby avoiding the requirement to process the materials through a formal marketplace to officially qualify (B1, B2).

In production, the project faced friction due to material irregularities. Variable brick dimensions and the design required the mounting of reused bricks one by one, rather than using efficient pre-assembled blocks (B1, B2). Furthermore, the project encountered resistance from sub-contractors, such as locksmiths, who were reluctant to solve the technical hurdles of reuse (e.g., recoding locks) or found that it disrupted their optimized "just-in-time" workflows (B1).

5.2.3 Economic consequences

The costs associated with circular shifts in Sonyas were primarily driven by labor intensity, unfamiliarity, and systemic inefficiencies.

Labor emerged as the primary cost driver, with contractors billing significant premiums to cover the risks and learning curves associated with novel materials. Respondent B1 provided specific figures, as the application of clay plaster was billed at approximately 1700–1800 SEK/m², and clay paint at ~900 SEK/m², compared to just ~220 SEK/m² for standard paint. With labor rates hovering around 1000 SEK/hour, the extended time required to work with these materials significantly inflated the budget (B1, B2).

Capital was effectively "wasted" on administrative churn, specifically, investigating alternative solutions that were initially deemed impossible only to be pursued later, or searching for warehouse solutions that turned out to already exist (B1). High process costs also emerged during competitions for central land allocations, where strict CO2 budgets required significant resource investment to fulfill (B2).

Direct material costs also played a role. Reused materials, such as bricks, often cost 20–30% more than new ones due to the complexity of the supply chain (B1, B2). The lack of standard warranties increased financial risk, leading actors to bill premiums to cover potential liabilities. Additionally, costs were driven up by the physical necessity of adjusting materials, such as cutting interior glass, and the requirement for expensive third-party structural testing to verify the integrity of reused components (B1, B2).

5.2.4 Dynamics

The systems analysis highlights how agility can mitigate some costs while exposing the project to others.

The excessive cost of the clay paint is explained by the "*Uncertainty Premium Loop*" (Figure 15). When the project introduced a novel circular strategy, it triggered "*Contractor Unfamiliarity*". Lacking historical data, the contractor perceived high risk and applied "*Risk*

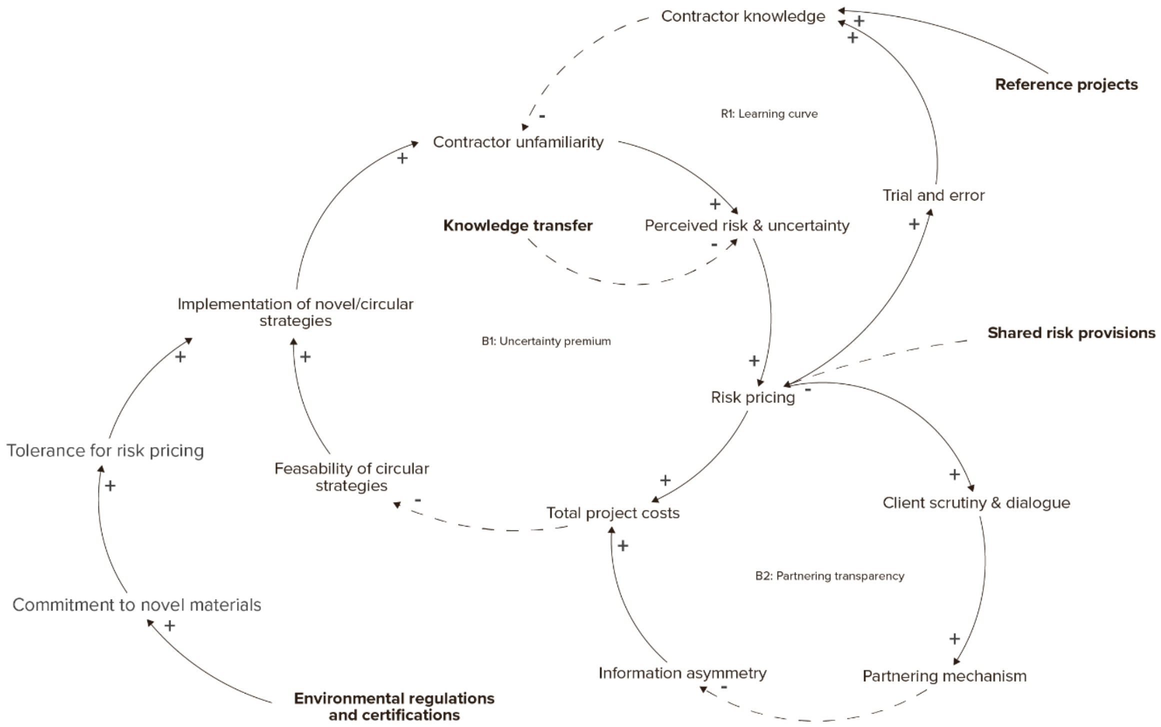

Figure 15: Uncertainty premium loop

Pricing" (the 900 SEK/m² rate). This loop threatens to kill innovation by making it financially unviable .

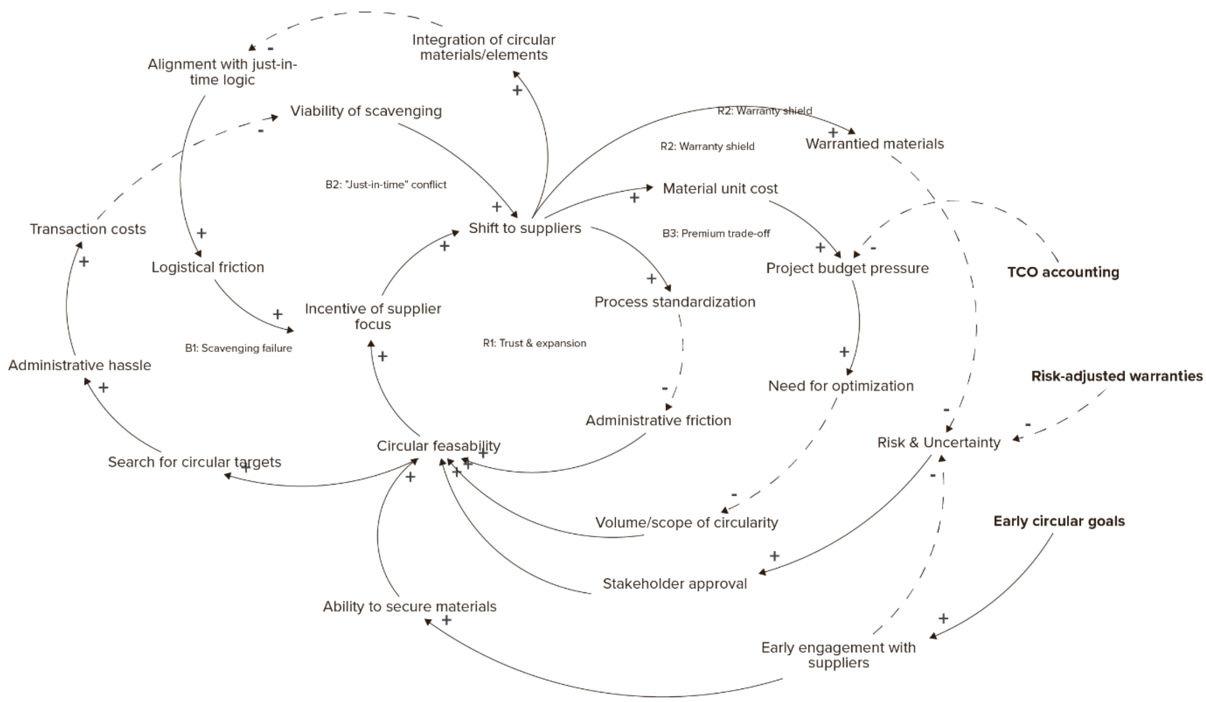

Figure 16: Supplier optimization loop

The analysis identifies "*Shared Risk Provisions*" as the critical leverage point. By shifting the liability for failure from the contractor to the client, the link between perceived risk and pricing is severed. Additionally, "*Partnering Transparency*" (Balancing loop 2) allows for open-book calculations, removing the "mystery" costs and stabilizing the budget .

The shift in sourcing strategy is visualized in the "*Supplier Optimization Loop*" (Figure 16). The project initially struggled in the "*Just-in-Time Conflict*" (Balancing loop 2), where "*scavenging*" for materials on the open market caused logistical chaos. By pivoting to "*Supplier Focus*" (Reinforcing loop 1), working with *Ecophon* instead of marketplaces, the project moved towards "*Standardized Servicing*". This intervention reduced administrative friction and reinforced the feasibility of the strategy .

The failure of the HC-slabs is captured in the "*Structural Deadlock Loop*" (Figure 17). The ambition to reuse triggered the "*Green Conflict*" (Balancing loop 2). The uncertainty of the old material required engineers to increase the slab dimensions (thickening). This structural

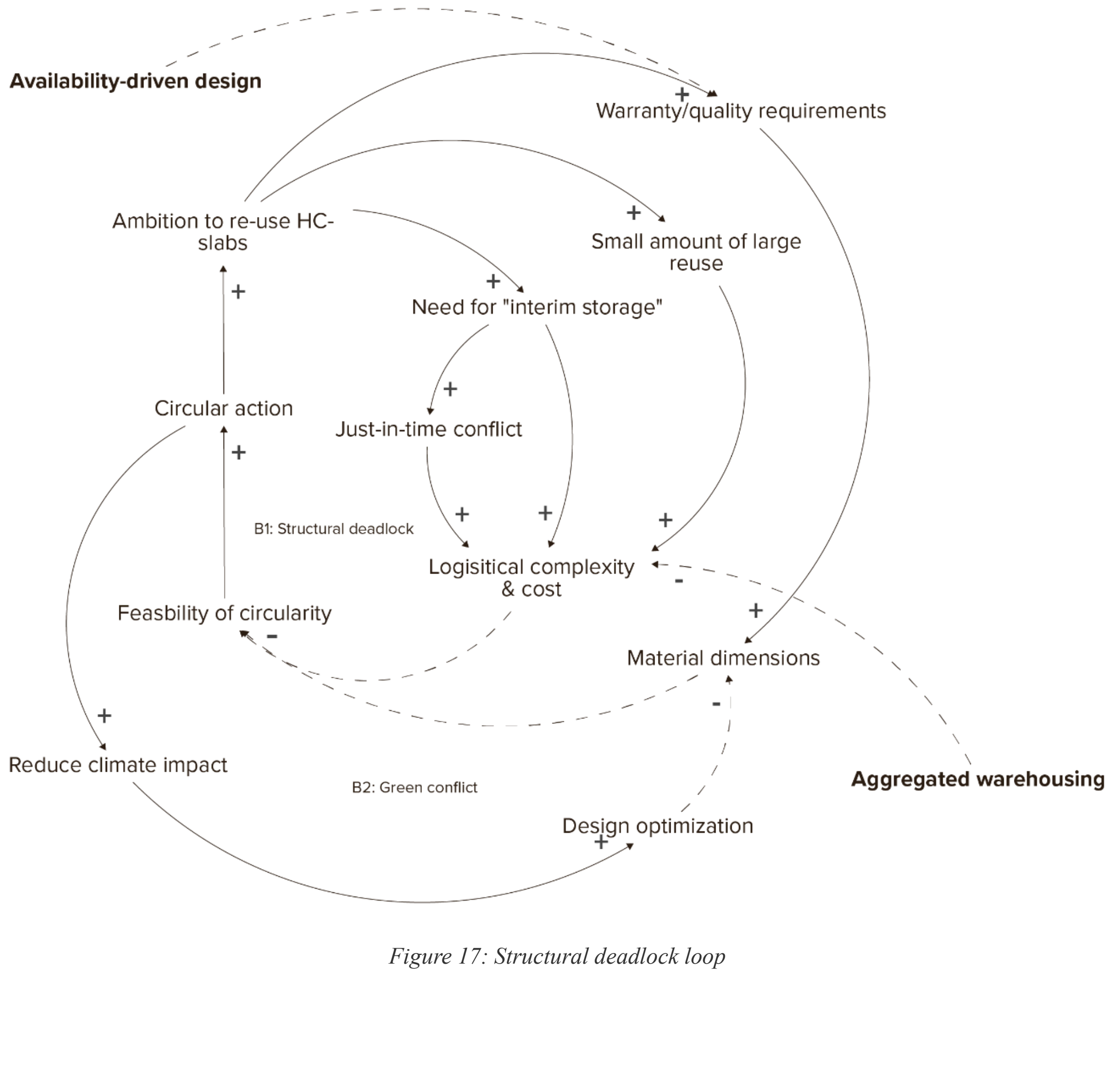

Figure 17: Structural deadlock loop

necessity conflicted with the goal of climate optimization. The system analysis confirms that circularity is not always sustainable, when the "thickening" outweighs the embodied carbon savings, the loop creates negative value. The leverage point here is "*Availability-Driven Design*", designing the grid based on available slab dimensions.

5.3 Gothenburg Grand Central

Gothenburg Grand Central (GGC) illustrates circularity at a major infrastructure scale. Developed by the state-owned Jernhusen AB, the project is situated above the West Link tunnel, imposing strict engineering constraints. Unlike the other cases, GGC operated within a robust institutional financial framework, governed by Green Bonds and EU Taxonomy alignment, making sustainability a binding financial requisite.

5.3.1 Strategy overview

The project's strategy was driven by the client's ambition to be a market leader in sustainable value creation. To achieve this, the project management actively "marinated" the team in the circular purpose to foster a collaborative culture (C1). This ambition was backed by a rigorous roadmap to climate neutrality of the contractor, setting a hard limit of 245 kg CO2/GFA, aligning with the client's goal of halving emissions by 2030 (C1, C2).

To operationalize these goals, the team architected a solution rooted in digital integration. They developed a specific "circular manual" that documents adaptability, flexibility, and demountability, transferring these metrics directly into the BIM model as a "circular index" (C1, C3). Additionally, office spaces were standardized with identical layouts to allow for future adaptation without renovation (C3).

A key sourcing strategy was to "mobilize the market" by demanding warrantied reuse products directly from suppliers (C1). This included collaborations for "zero-steel" (SSAB) and pragmatic fallbacks to CO2-reduced steel when reuse targets could not be met (C1, C2).

The execution yielded significant results: the project secured 100% reuse of façade bricks and aims for 100% reuse of cable ladders (C1, C2, C3). However, structural steel reuse targets (50%) were adjusted to a realized 20–30% due to supply chain leakage, where beams were sold to other buyers before the project could secure them (C2, C3). Additionally, the project successfully targeted recycled materials as well, securing glass with 65-90% recycled contents and 50% recycled ballast from construction sites in the proximity. All of the carpets used in the project needs to be composed out of recycled materials (C2, C3).

5.3.2 Process shifts

The process transformation began with "anchoring the mission." The circular purpose was "marinated" into the organization through presentations of climate calculations, fostering a culture where even the purchasing department proactively suggested reuse options (C1). To keep complexity manageable, the project focused on setting "three to five big, important goals" rather than diluting efforts. As Respondent C3 noted, trying to do everything results in "semi-skimmed milk" (C3).

The fundamental process shift was "front-loading" investment. Unlike linear projects, GGC released capital during the system phase to secure materials like bricks up to six months in advance (C1, C2). This required the team to accept longer lead times and invest significant resources in investigating product sustainability early in the process (C1, C2, C3).

The design process became iterative. Designers had to keep options open longer and frequently redraw plans when specific materials, such as steel beams, were sold to other buyers (C1, C2) However, manageable targets with rigid plans reduced the amount of design revisions significantly. To manage the volatility, the strategy favored purchasing directly from suppliers who could offer warranties, rather than relying on consultants who lacked real-time inventory knowledge (C1, C3). The team also had to adapt to material shortages, such as sourcing yellow bricks from Denmark when local stocks were depleted, forcing the purchasing department to handle foreign measurements and extra logistics (C2, C3).

5.3.3 Economic consequences

The project accepted a total cost increase of approximately 10% due to circular strategies (C2). However, interviewees described this not as a loss, but as a necessary "tuition fee" to build internal capability and a necessary expense to achieve long-term revenue (C1, C2).

Significant resources were consumed by the "learning curve", investigating materials, holding workshops, and hiring sustainability consultants (C1, C3). There was also an operational cost in "marinating" the team to shift the collective mindset (C1).

Market realities created a polarized economic landscape. While the market for reused steel had matured enough for suppliers to offer warranty-backed beams at prices comparable to new steel (C2), other items were exorbitantly expensive. The electrical contractor was contractually obligated to target reused cable ladders, and consequently, they had to absorb the consequential costs of such ladders, which were four times higher than that of new products (C1, C3). Respondent C3 admitted:

"The cable ladders have been super expensive... it hasn't been a plus-business materially at all." (C3)

Despite these premiums, the project remained financially viable. By valuing decisions in "crowns per kg CO2," the client justified higher unit costs through the financial leverage of Green Bonds. The lower interest rates provided by green financing effectively absorbed the construction premiums, converting the cost of circularity into increased asset value (C2, C3).

5.3.4 Dynamics

The GGC case demonstrates how financial structures can override process friction.

The success of the brick and steel procurement is explained by the "*Supply-Driven Success Loop*" (Reinforcing loop 1) (Figure 19). Standard projects wait for design to release funds, often missing market opportunities. GGC utilized the leverage point of "*Binding Financial*

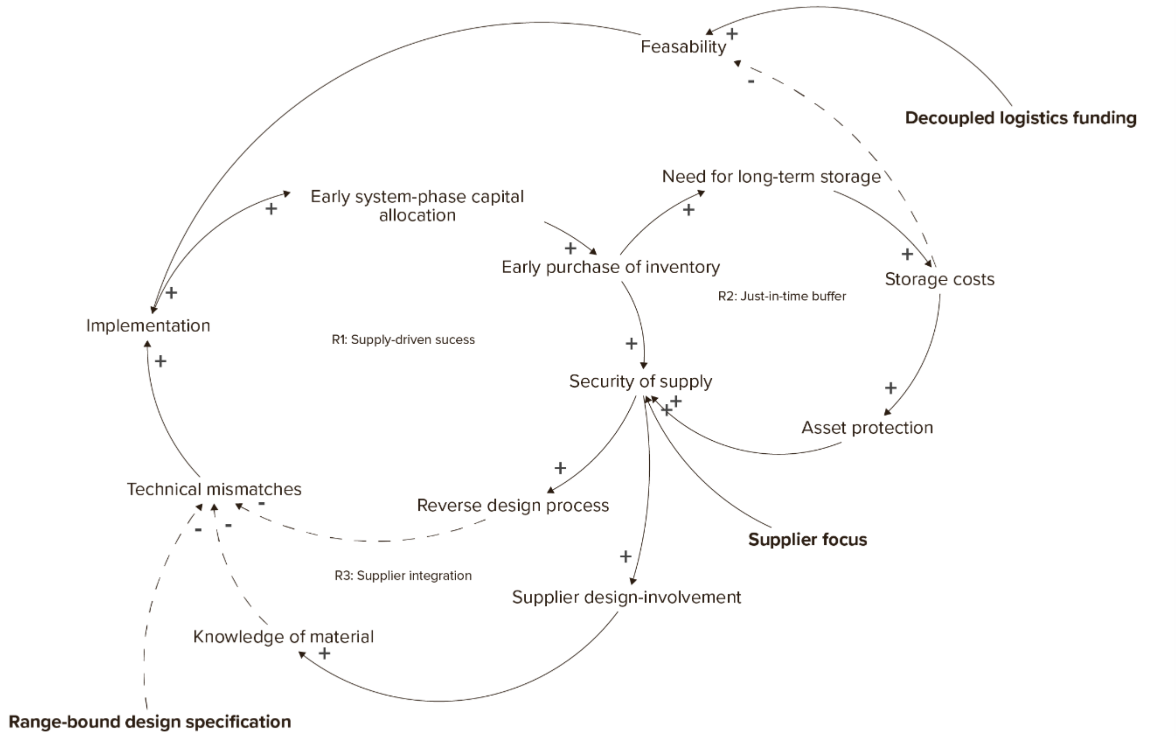

Figure 18: Supply-driven success loop

Commitment" in the system phase. By releasing funds early, the project eliminated the "*Probability of Stockout*", enabling a secure reverse-design process where the building was tailored to the secured bricks.

Conversely, the struggle with steel beams illustrates the "*Volatility Trap Loop*" (Balancing loop 1) (Figure 20). The delay between finding materials and finalizing the design created a "*Time Lag*", during which the materials were sold to others. The analysis confirms that without "*System-Phase Payout*" (buying immediately), the search for high-target reuse is

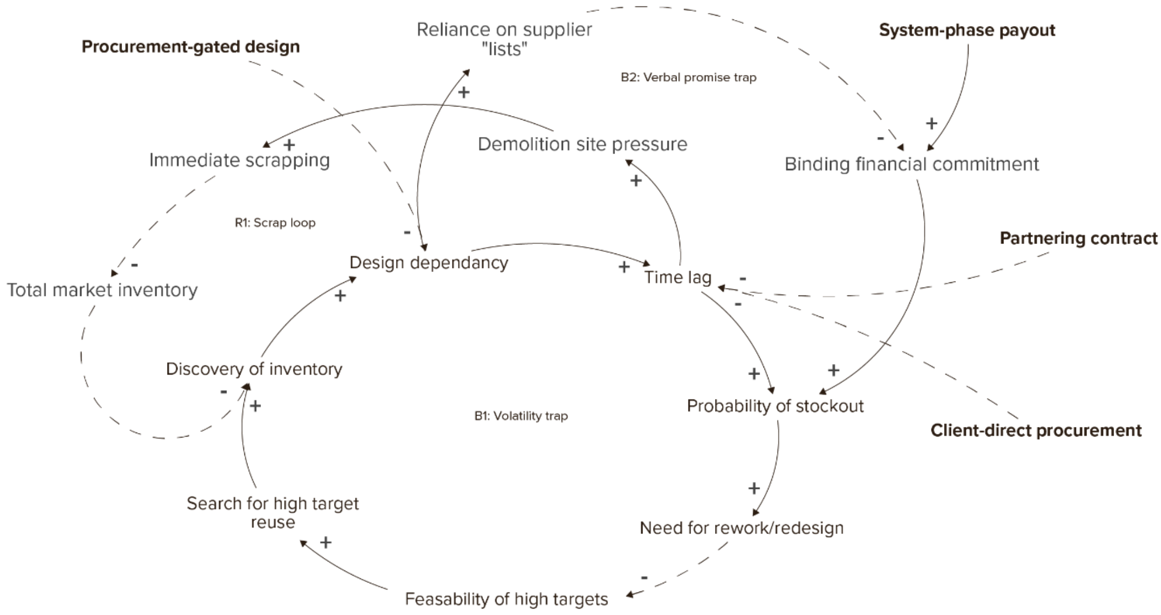

Figure 20: Volatility trap loop

constantly undermined by market speed.

Economically, the system is powered by the "*Green Profit Loop*" (Reinforcing loop 1) (Figure 21). High certification targets (BREEAM Outstanding and Excellent) unlock green financing. This creates "*Operational Profitability*" (via lower interest payments) that feeds back into a higher "*Budget Tolerance*" for construction premiums. This creates a virtuous cycle where the cost of circularity is financed by the value of sustainability. The leverage point stabilizing this loop could be "*TCO Accounting*" (Total Cost of Ownership), which ensures that these long-term savings are credited to the construction budget

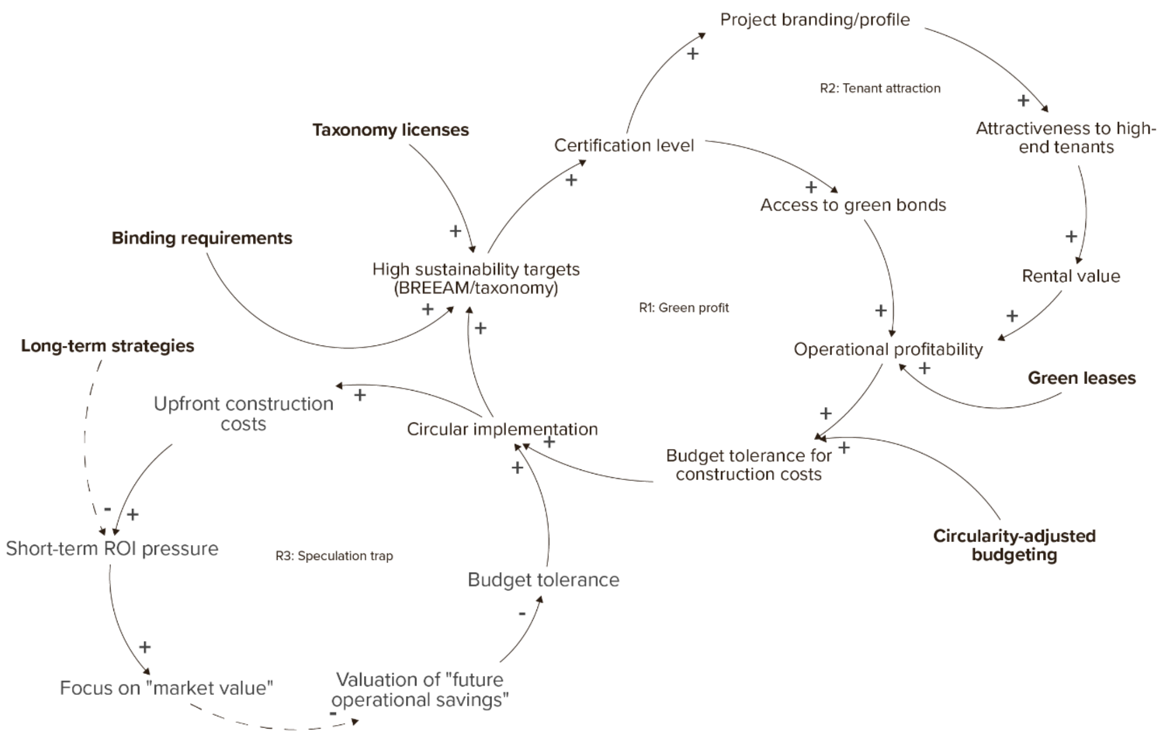

Figure 21: Green profit loop

5.4 Cross-Comparison Summary

This section synthesizes the findings across the three cases, analyzing divergences in circular strategies, process shifts, cost dynamics, and organizational interactions.

5.4.1 Circular Strategies

While all three projects converged on the necessity of targeting high-impact structural elements, such as façade bricks and heavy structures, and prioritizing "proximal" materials to reduce transport, their strategic frameworks differed significantly based on ambition and governance. The Botanical Garden adopted a compliance-oriented approach driven by political mandate, focusing heavily on utilizing the existing site as a "quarry" and leveraging an "internal market" of client-owned properties. However, this strategy was frequently undermined by vague goals that failed to create sufficient incentives within the standard contract structure.

In contrast, Sonyas pursued a philosophy of "Strategic Pragmatism" and "Radical Low-Tech." Rather than relying solely on the recirculation of existing components, the project prioritized material innovation, such as the use of clay blocks, and actively reduced technical complexity. This approach involved a deliberate decision to bypass formal certifications, prioritizing tangible environmental performance over administrative accolades, and investigating space innovation as a leverage point to reduce the total built area.

Göteborg Grand Central (GGC) adopted an "Institutional Market Leader" approach that stood in stark contrast to Sonya's informal pragmatism. GGC leveraged high-level financial mechanisms, specifically Green Bonds and EU Taxonomy alignment, to drive circularity. This strategy relied on high-tech integration, utilizing BIM-based "circular indexes" and standardizing office layouts to future-proof the asset. Furthermore, GGC minimized risk by targeting simpler reuse targets sourced directly from suppliers to ensure reliability, rather than experimenting with unproven innovations.

5.4.2 Process Shifts

The fundamental process shift observed across all cases was the abandonment of linear "order-and-arrive" workflows in favor of iterative, circular cycles. Standard procurement sequences were disrupted, necessitating the identification and security of materials, such as façade bricks, well before design completion. This created a shared logistical bottleneck that interrupted the industry's "just-in-time" mindset, necessitating intermediate processes for off-site storage and reconditioning.

The management of this shift varied sharply between the projects. The Botanical Garden operated through a reactive and fragmented process where the inability to define targets early forced ad-hoc solutions and iterative redrawing. The fixed-price contract structure created a "Turnkey Paradox," forcing the client to assume direct responsibility for purchasing and managing materials to secure them. This introduced severe administrative friction, characterized by constant scope revisions and increased labor for managing priced Project Management (PM) documents.

Conversely, Sonyas employed an agile pivoting strategy. After initially finding official marketplaces fraught with uncertainty, the team pivoted to a direct-relationship model, contacting manufacturers like *Ecophon* to bypass the open market. This agility extended to governance, where the team negotiated directly with legal authorities to reclassify waste as reuse, solving regulatory hurdles that might have stalled a more rigid project. GGC implemented a systematic "front-loaded" process, focusing on "marinating" the organizational culture early to align decision-making. Unlike the manual interventions of the Botanical Garden, GGC formalized the workflow by securing materials up to six months in advance through direct supplier contracts and integrating these decisions into digital tools to manage complexity at scale.

5.4.3 Cost Dynamics

Across all projects, circularity introduced universal cost drivers rooted in the breakdown of industrial economies of scale. Logistics emerged as a consistent burden due to the need for off-site storage and extra transportation, while labor intensity increased universally due to the physical adaptation of materials, such as cleaning and adjusting uneven components. Additionally, the investigation phase consumed substantial resources as "search-and-verify" work replaced the efficiency of catalog ordering.

Despite these shared drivers, the financial outcomes differed. The Botanical Garden incurred costs primarily through administrative inefficiencies and process frictions. The mismatch between circular ambitions and the rigid fixed-price contract resulted in a disjointed workflow where financial resources were consumed by the administration of option orders and the labor-intensive exchange of priced PMs.

Sonyas faced costs driven by "Innovation Premiums" and unfamiliarity. The decision to employ low-tech strategies resulted in contractors billing high risk premiums, such as 1800 SEK/m^2 for clay plaster. Additionally, capital was effectively "wasted" investigating ambitious solutions that later proved unfeasible, a cost inherent to their short experience and lack of information. GGC, however, intently absorbed cost increases of approximately 10%. Rather than absorbing the risk of "scavenging," GGC paid market premiums to secure warrantied materials directly from suppliers. Unlike the reactive spending in the Botanical Garden, these expenses were a calculated investment to secure "market leader" status, offset by the beneficial loan terms provided by Green Bonds.

5.4.4 Organization and Market Interaction

The context and timelines of the projects deeply influenced their risk appetite and success. The Botanical Garden, under planning since 2017, was defined by its political mandate and lack of revenue pressure. However, it suffered from "diluted goals" following budget cuts, partly due to the Covid-19 pandemic. In contrast, Sonyas and GGC operated under strict timelines with completion scheduled for 2026/2027 and clear revenue imperatives. GGC's long-term ownership strategy allowed it to capitalize upfront costs, whereas Sonyas drove value through development agility.

Contractual structures further distinguished these outcomes. The Botanical Garden employed a traditional turnkey contract, creating a distinct separation between the contractor and management that generated tensions and uncertainties during implementation. Conversely, Sonyas and GGC adopted partnering contracts. The involvement of contractors from the earliest stages enabled holistic planning and superior detailed design, though it required significantly greater time and effort upfront.

Finally, market interaction varied by necessity. Due to time constraints, GGC focused on effective, achievable strategies backed by business partnerships. Sonyas, limited by experience, faced inefficiencies in identifying impactful solutions. The Botanical Garden, lacking time pressure but driven by prestige, pursued high-risk experimental approaches. A notable example was the dismantling and resale of the old greenhouses, a costly initiative that ultimately generated minimal economic return, highlighting the risks of exploration without calculation.

6 Discussion

This thesis set out to investigate the systemic effects of circular interventions on Swedish new development projects. By analyzing three distinct cases, The Botanical Garden, Sonyas, and Gothenburg Grand Central (GGC), through the lens of the theoretical synthesis established in Chapter 3.4, the study highlights that circularity acts as a disruptive input that destabilizes the traditional linear project system. The following discussion synthesizes these findings to answer the research questions, connecting process shifts and cost dynamics through the integrated framework of Systems Thinking and Transaction Cost Theory.

6.1 Reshaping Processes and Cost Dynamics

Answering RQ1: How do construction processes in new development change when circular strategies are implemented, and how are these changes linked to project costs?

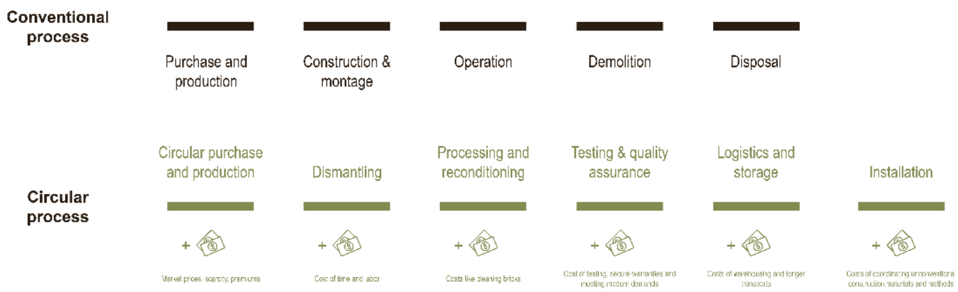

Figure 22: Example of process shift in circular construction

As exemplified in (Figure 22), the implementation of circular strategies forces a fundamental deviation from the standard "pre-study, planning, production" linearity described by Eringstam and Sandahl (Eringstam & Sandahl, 2022). The process transforms into a complex system where the "input" of circular ambition triggers iterative feedback loops that disrupt established workflows. The most significant process shift observed is the transition from a streamlined "order-and-arrive" procurement model to an exploratory "search-and-verify" model. This shift verifies Finamore and Oltean-Dumbrava's (2024) theory that circularity extends early planning phases, but more critically, it explains the explosion of costs not as production expenses, but as transaction costs.

As defined by Coase (1937) and Dahlman (1979), transaction costs arise from search, information gathering, and enforcement. In all three cases, the "friction" of circularity was primarily informational. For instance, the Botanical Garden’s strategy of using the site as a quarry required extensive manual inventory and verification processes. This aligns with Williamson’s (1981) concept of uncertainty, because the material quality was unknown (unlike new factory products), the project incurred high costs in "searching for information" and upcycling to acceptable standards. Similarly, the "Just-in-Time Conflict" identified in the analysis is a process shift where the logistical flow of materials no longer matches the construction schedule. This misalignment forces the creation of intermediate processes, specifically off-site storage and extra transport, which generate direct costs that would not exist in an ideal linear model.

Furthermore, the study confirms Ottosson’s (2013) warning regarding "neglected uncertainties." In cases where circular goals were not fixed early (as seen in the Botanical Garden), the process shifted into a reactive "Uncertain Ad-Hoc" loop. Here, the cost dynamic is driven by the inefficiency of late implementation as attempting to integrate circular targets during the production phase created severe administrative friction and scope revisions. Conversely, GGC demonstrated that when the process is "front-loaded", moving the expenditure, planning and decisions to the system phase, the project aligns with the complex use of circular strategies and effectively avoids friction. By buying elements/materials early, the cost transforms into a strategic investment, shielding the project from market volatility. Thus, the primary link between process and cost is that linear processes optimized for efficiency generate high transaction costs when forced to handle circular complexity, unless the process itself is re-engineered to manage uncertainty. More importantly, many of the incurred costs of circular implementation are hidden as costs of longer labor time, complexities and agendas, as seen in (Figure 23).

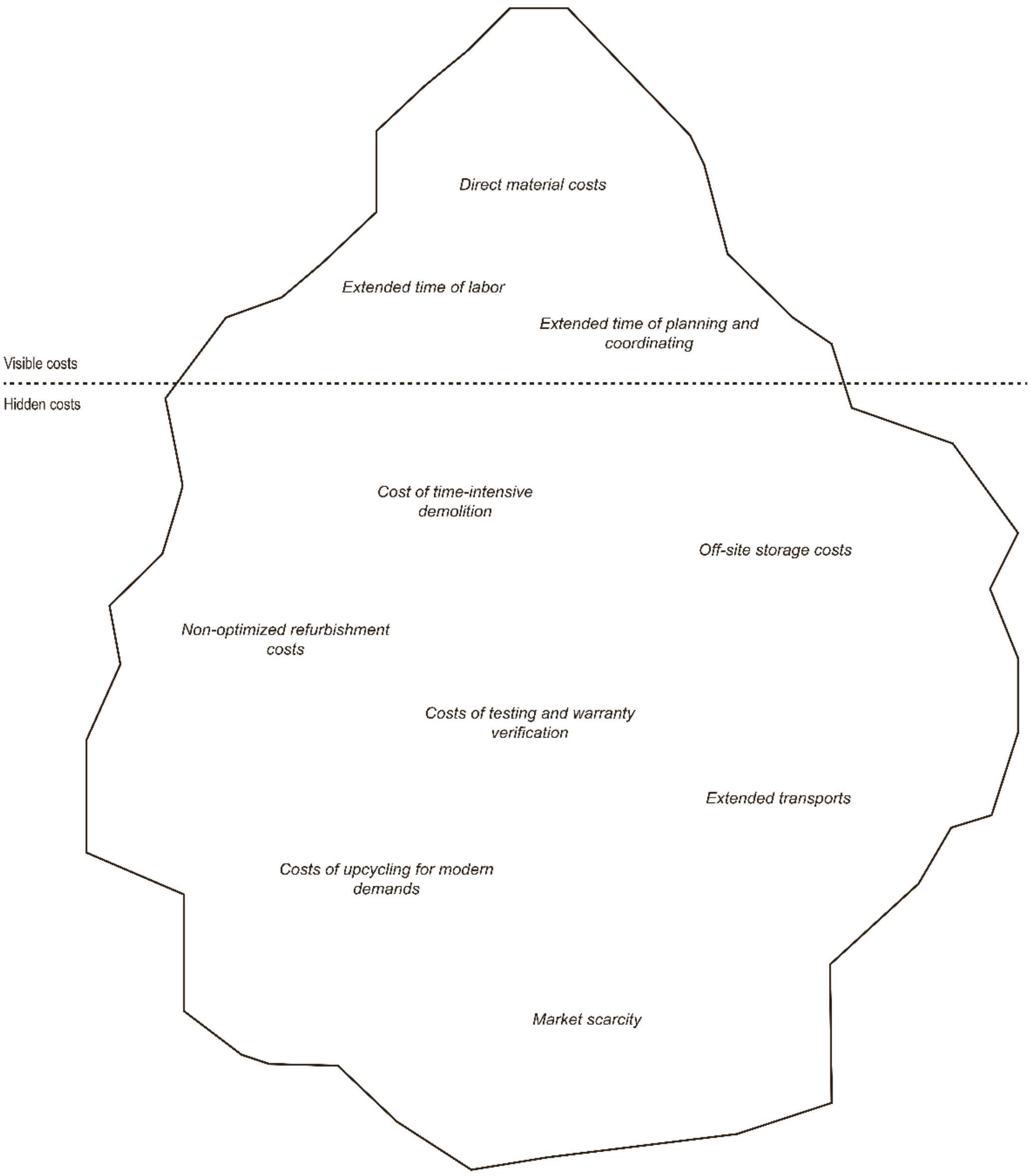

Figure 23: Hidden and visible costs of circular construction

6.2 Systems Thinking as a Diagnostic Tool

Answering RQ2: How can systems thinking be applied to analyze and understand the interrelationships between project processes, costs, and values in circular interventions?

Systems thinking, and specifically the use of Causal Loop Diagrams (CLDs), proved to be a important diagnostic tool for revealing the non-linear dynamics that standard cost-benefit analyses miss. While the methodology of this thesis faced a limitation, namely, the author's own cognitive tendency to revert to linear causal explanations, the CLDs successfully visualized how specific interventions trigger complex side effects across the system, confirming Meadows’ (2008) assertion that complex systems often behave counter-intuitively.

For example, the application of CLDs allowed for the identification of the "Green Profit Loop" in the GGC project. A linear analysis might view the high upfront cost of circular materials simply as a loss. However, the systems map revealed a reinforcing loop where these costs, coupled with high certification targets, unlocked "Green Bonds" (lower interest rates). This financial feedback loop demonstrated that the process shift of certification created an economic value (operational savings) that neutralized the initial material cost.

Similarly, the CLDs clarified the "structural deadlock" in the Sonyas project. The diagram illustrated how the well-intentioned intervention of reusing hollow-core slabs created a balancing loop, the uncertainty of the material required thicker dimensions for safety, which paradoxically increased the CO_2 impact, defeating the purpose of the strategy. Without mapping these interrelations, or running parallel calculations, the project might have pursued a costly strategy that yielded negative environmental value. By visualizing these dynamics, system thinking moves the understanding of costs from a static ledger to a dynamic behavior, showing that costs are often symptoms of unmanaged feedback loops rather than fixed prices.

In conclusion, System Thinking models proved important and powerful to quickly and early define the affecting parameters of dynamics. This could be done in early stages of projects to anticipate what effects to account for when making decisions. Ideally, this mapping would be done in workshops where several perspectives can be accounted for instantly and in collaborative discussions. However, it is important to note from this thesis that when working with System Thinking models, it is vital to clarify and define what parameters you are looking for and exactly what system in what scope you’re analyzing.

6.3 Organizational Fit and Market Interaction

Answering RQ3: What additional insights can be identified regarding deeper reasons and factors that improve or hinder circular success?

The analysis reveals that the success of circular strategies is heavily dependent on "organizational fit," a concept that can be understood through Transaction Cost Theory

(Williamson, 1981). The study highlights a clear divergence in how different organizations manage the asset specificity and governance of circular materials.

For large institutional actors like those in the GGC project, high asset specificity (the need for exact, guaranteed performance) creates massive transaction costs if they attempt to manage reuse internally. Large institutions require long administration time and make decisions slowly, increasing transaction costs. Their governance structures require warranties and certifications to mitigate risk. Therefore, the most effective strategy identified is a shift to supplier-led circularity. By forcing the market to standardize testing and warranties (The "Supplier Optimization Loop"), large actors can reduce their internal transaction costs. Similarly, the Botanical Garden found viable economic targets when buying supplier-managed bricks (*Bruksspecialisten*) and Sonyas found more effective workflows when abandoning labor-intensive marketplace scavenging and turned to suppliers. This aligns with Williamson's theory that standardized market transactions are more efficient than internal governance when uncertainty is high.

Conversely, smaller, agile organizations like Sonyas operate quicker and is able to manage complex circular targets which require much administration and planning back and forth. Smaller organizations can leverage "trust" as a substitute for expensive formal governance and take advantage of asking questions over the desk instead of sending several mails. This allows them to act as "plowers," innovating through "learning by doing" where larger actors are halted by risk. However, the study strongly suggests that for low-volume, high-complexity components (such as specific technical installations), the transaction costs of verification and direct purchase costs remain high due to economies of scale. This validates the need for aggregated market hubs, as suggested by Charef and Lu (2021), to externalize these costs.

Furthermore, the "contract" serves as a critical leverage point (Meadows, 1999). The "Turnkey Paradox" observed in the Botanical Garden illustrates that fixed-price contracts (transactional governance) are incompatible with the high uncertainty of circularity, creating friction and disincentives as the contract structure meant continuous budget negotiations and scope revisions. In contrast, "collaborative" contracts (relational governance) utilized in other cases successfully lowered transaction costs by aligning incentives and sharing risks and reduced the need to negotiate on every strategical shift, confirming Turner and Simister’s (2001) findings.

Finally, a vital learning from the cross-case analysis is the importance of focus and locking in goals. Projects that attempted to "do it all" often drowned in administrative friction. The most successful strategies involved selecting a manageable set of high-impact targets (e.g., just bricks and steel) and "locking" them into the program early. This prevents the "Uncertain Ad-hoc" loop from forming and ensures that the organization focuses its limited energy on strategies that yield the highest systemic return, rather than diluting effort across marginal gains.

Gothenburg Grand Central demonstrates the most operationally successful application of circularity by targeting tangible, high-volume flows offered by suppliers. However, a critical systems analysis suggests this success comes with a caveat. By focusing primarily on material substitution (e.g., reused steel instead of new), the project operates at a relatively low leverage point (Meadows, 1999), essentially changing the "parameters" of the system without altering its fundamental structure. In contrast, "bolder" strategies attempted in other cases, such as Sonyas' questioning of technical standards to reduce built volume or the Botanical Garden's ambition to treat the site as a quarry, target higher leverage points related to system design and goals. While GGC's approach minimizes transaction costs and enables immediate market scaling, the industry must eventually embrace these more disruptive interventions to achieve genuine decoupling. The challenge, therefore, lies not just in optimizing the flow of materials, but in restructuring the project delivery models to make these high-leverage interventions economically viable.

6.4 Synthesis

In conclusion, circular interventions reshape Swedish construction projects by forcing a transition from linear efficiency to systemic adaptability. The costs associated with this transition are largely "transaction costs" driven by the friction between circular flows and a linear industry structure. However, these costs can be mitigated or converted into value through specific systemic interventions, like adopting relational contracts to manage uncertainty, shifting the burden of verification to suppliers, and locking in manageable goals early to prevent administrative difficulties along the project lifespan. Future success lies in recognizing that "one size does not fit all", process strategies must be tailored to the specific organizational scale and governance structure of the project.

7 Conclusions

The transition to a CE in the construction sector represents a paradigm shift that extends far beyond simple material substitution. By applying a systems thinking lens to three distinct Swedish development projects, this thesis has mapped the complex interdependencies between circular strategies, project processes, and economic outcomes.

The study concludes that circular interventions fundamentally destabilize the traditional, linear construction process. The efficiency of the standard "take-make-waste" model is replaced by a resource-intensive "search-and-verify" workflow. This shift manifests primarily as increased transaction costs, the costs of searching for reliable materials, negotiating novel contracts, and verifying compliance in an immature market. In projects like the Botanical Garden, where circular goals were applied within rigid, linear contract structures, these transaction costs manifested as administrative burden and financial inefficiency. Conversely, in projects like Gothenburg Grand Central, these costs were effectively managed by "front-loading" investment and utilizing financial instruments like green bonds to convert short-term friction into long-term asset value. Furthermore, collaborative contracts applied in Sonyas (Partnering) and Gothenburg Grand Central (Turnkey with ECI) allowed for early identification and detailed planning, leading to successful and effective implementation of circular strategies.

Furthermore, the application of Systems Thinking and Causal Loop Diagrams proved to be a powerful diagnostic tool. It revealed that cost increases are often not inherent to circular materials themselves but are symptoms of systemic misalignments, such as the "Just-in-Time Conflict" where circular flows clash with linear logistics. The analysis highlights that successful circularity requires specific leverage points, locking in goals early to prevent scope creep, utilizing relational contracts (partnering) to share risk, and shifting from project-managed logistics to supplier-integrated solutions.

Ultimately, this thesis demonstrates that there is no single "correct" circular strategy, but a variety of strategies can be adapted to local and project conditions. Success depends on organizational and contextual fit. Large institutional developers require standardized, warranty-backed market solutions to manage risk, while smaller developers can utilize agility and trust to pioneer innovative, low-tech solutions

8 Future research

This study focused on the qualitative mapping of process shifts and cost drivers. However, the lack of accessible quantitative data limited the ability to verify specific costs. Therefore, future research should focus on:

- Full costs analysis: Finding and analyzing the actual costs in numbers would provide a deeper understanding of the complex issue. Such results could fortify or puncture the findings in this thesis.
- Deep Life-Cycle Cost (LCC) Analysis: conducting longitudinal studies that quantitatively track the actual costs of circular interventions against standard baselines to validate the "transaction cost" theory with hard data. It would also be interesting to investigate the use of LCC models in combination with LCA and other tools for decision-making purposes in early project development.
- Developing MCDA Models: Creating Multi-Criteria Decision Analysis tools based on the loops and leverage points identified in this study (e.g., weighing "transaction friction" against "green value") to support decision-making in early project stages.
- Contractual Frameworks: Investigating how specific contract clauses in partnering versus turnkey contracts can be optimized to distribute the risks of circularity more equitable, specifically in relation to new development projects.
- Measurement and valuation of circularity: To accelerate and push for the circular transition, the industry needs to gather knowledge on the economic and procedural consequences of adopting circular strategies, to combat them and optimize the circular industry. Thereafter it will be important to investigate the effects and value of said strategies. Are we aiming at the correct targets? Does the effect provide best value for money?

Since this thesis would benefit from an analysis of the actual costs related to circular activities, the most relevant and important future research would therefore be to investigate the actual costs that emerge from shifted construction processes. This would alter or strengthen the findings of this thesis, giving it more weight and importance.

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Appendix 1: Interview guide

Intro – Bakgrund & syfte *(5 min)*

1. Kan du/ni kort berätta om din/era roll i projektet och din bakgrund i ditt företag?
2. Vad är dina tidigare erfarenheter av cirkulära strategier eller cirkulär design?

Del 1 – Workshop: Byggprocessen och cirkulära strategier *(20 min)*

1. Här är en schematisk bild av en standard byggprocess. Stämmer den med er bild?
2. Vilka cirkulära strategier eller interventioner har använts i detta projekt? (visa på processen var de påverkat)
3. Hur har processerna förändrats på grund av cirkulära startegier? (design, upphandling, kontrakt, kommunikation, risk) – markera i diagrammet.
4. Fanns det strategier som diskuterades men inte implementerades? Varför?
5. Har några nya aktörer eller expertiser kommit in i projektet p.g.a. dessa strategier?
6. Vilka typer av beslutsunderlag för cirkularitet har funnits i projektet?

Del 2 – Kostnader och värden *(20 min)*

1. Från ditt perspektiv, vilka kostnader (ekonomiska eller andra) har uppstått p.g.a. de cirkulära interventionerna? (lista gärna)
2. Hur skiljer sig dessa kostnader från kostnader i en vanlig process ("business-as-usual")?
3. Påverkade cirkulära strategier tidscheman, upphandlingar eller koordinering (transaktionskostnader)?
4. Vilka värden har skapats av de cirkulära strategierna? (ekonomiska, miljömässiga, sociala, anseendemässiga; kortsiktiga/långsiktiga)
5. Hur skiljer sig dessa värden mot projekt utan cirkulära mål?

Del 3 – Reflektion & synergi *(10 min)*

1. Kan kostnader/värden kopplas till specifika processmoment i diagrammet?
2. Hur väger sig de olika kostnaderna och värdena mot varandra? Skulle du säga att det "var värt" de cirkulära insatserna?
3. Vad kan göras bättre i nästa projekt? Hur startar ett byggprojekt på bästa sätt med cirkulära mål?
4. Finns det något viktigt kring cirkulära strategier, kostnader eller värden i detta projekt som vi inte pratat om än?

Appendix 2: Results

The Botanical Garden

Type	Synthesis	Analys	Property
Strategies	Site as a quarry		
		Extensive reuse of existing hardscape (curb tiles and stones, granite bollards, limestone and granite stairs) and site elements (sinks, utility sinks) (A1, A3, A4). Off-site reuse targets (e.g. small cobblestone, sinks, utility sinks and toilets) were sourced from other client-owned properties (A1, A3).	R3
	On-site remanufacturing		
		Trees from the site were harvested and sent to Derome for drying and manufacturing into interior wall panels. The scope of this strategy has been increased by the client (A1).	R6
	Labor-intensive restoration		
		Materials like exterior wall bricks, concrete tiles, cobble stone and floor bricks are being stored by the client for use in Phase 3 of the project (A3).	R4
		Facade and floor bricks were cleaned and stored at Bruksspecialisten (A1, A3, A4). This was considered a simple, cost-effective process with high CO2 benefits (A1, A3).	R4
		Reusing cable ladders was abandoned because the old ones were skewed (requiring extensive repair) and did not meet the large dimension requirements of the new project (A1, A3, A2).	R4
		A number of doors are being cleaned, adapted to new openings, repainted (A1, A4). In some project, doors may be treated with fire protection (A1).	R5
	Sourcing optional reuse		
		Additional reuse targets were classified as "options" to be implemented if the budget allowed (granite tiles/walls instead of concrete, bathroom sinks, toilets) (A1, A3).	R3
		Reused forged steel has been sought after but never found in correct dimensions for the new greenhouse (A3).	R3

	Circular workflow & Material optimization		
		The Botanical Garden's focus on ecosystems and circular flows emphasized a circular approach, reshaping the design process (A2).	R1
		The project lead holds recurring reuse meetings with all stakeholders (A1).	R1
		Consultants in the project have shifted roles to become reuse coordinators and help with initiation of the clients reuse warehouse (A4).	
		The contractor operates under new frameworks prioritizing prevention, reuse, and recycling over landfill (A3).	R1
		Strategies focus on minimizing material intake and preventing waste, a practice actively imposed on subcontractors (A3).	R2
		The project selects environmentally smart products, such as low-impact concrete or materials containing recycled content (A3).	R2
	Recycling & Recovery		
		The contractor consistently applies waste reduction frameworks to their processes (A3).	R2
		The greenhouse demolition was complex, requiring careful disassembly and management for resale. Roof tiles and spiral stairs could have been reused (A1).	R3
		The contractor returns waste (foam plastic, mineral wool) and pallets to original suppliers (A3).	R8
		The contractor investigated designing with materials containing high recycled content, such as ventilation ducts (80% recycled material), but higher costs shut it down (A3).	R8
Processes	Strategic foundation		
		Extensive early planning with stakeholder groups and client-formulated goals facilitated implementation and allowed the client to push for reuse, even against contractor resistance. However, some goals	

	were formulated to vague which lowered incentives for reuse (A1, A2).
	Material assessment processes expanded to include thorough measuring and upcycling potential, but proximal targets (e.g. bricks from Sahlgrenska) simplified investigations (A1, A2).
	While reuse targets were specified in early drawings, the project learned to prioritize 'easier' products over complex ones. For instance, technical requirements complicated door reuse, whereas the inability to find correct dimensions forced the abandonment of cable ladders entirely (A1, A2).
	The lack of standard supplier processes created administrative burdens; standardized workflows from suppliers or producers would simplify the current non-standard solutions (A1, A2).
	Early planning groups and strict circular goals sharpened the project's ambition but created a heavy administrative workload, further slowed by suppliers providing delayed or erroneous EPDs (A2, A3).
	The turnkey contract created a paradox: while it facilitated necessary early contractor involvement, its fixed-price model made tendering difficult due to the lack of data for calculating reuse targets. To mitigate this, calculations were simplified by handling some targets as contract variation agreements. And because the client assumed direct responsibility for material management of the bricks, those only had to be calculated for the labor (A1).
	Non-standard reused materials introduced work environment questions regarding construction methods and handling. Deep-rooted construction norms also contributed to longer transitioning processes (A4).
	Extended process due to missing reuse data; long timelines increase uncertainty; extra fund applications needed to secure circular options (A1, A2).

	Budgeted as new, replaced if reuse option found; creates low incentive for reuse and constant scope revisions (A1, A2).
	Some reuse handled as variation jobs, simplifying tendering but increasing registration work. Priced PMs were sent to the client for new options during production to keep track of costs (A1, A3).
	Having products and prices set from the start is the most optimal process, but because of lack of data and urge to keep it in the budget, it was budgeted as new materials with options for implementing reuse later, increasing administrative labor (A1, A3).
Design dynamics	
	Initial drafts lacked circular strategies, but the second draft aligned with client goals; detailed design overlaps production due to incomplete drawings and constant updates and scope revisions (A1, A3, A4).
	Tight spaces and specific requirements made finding correct products difficult; architects struggle to produce accurate early drawings without knowing future material availability or specific measurements (A1).
	Optimal process would use "interval designs" or adapt design to available materials; consultants constantly investigate reuse possibilities and coordinate heavily for correct design (A3, A4).
	While uncertainty of circular projects makes it hard to estimate time needed for the work, the possible signal value of the project increases the motivation for putting more time and effort in ensuring success (A4).
Execution logistics	
	Unlike standard "order-and-arrive" flows, circular projects suffer from tracking multiple sources, perhaps possible in smaller projects; reuse materials stored in multiple locations (psychiatric institution, off-site warehouses) causing access and transport hassles (A1, A2, A4).
	Client took unusual responsibility for management and logistics of the reused bricks, finding it burdensome and unlikely to repeat; ideally, suppliers handle

	upcycling/storage and sell project-ready items (A1, A2, A3).
	Bricks sent to Bruksspecialisten for washing/storage; granite stairs stored at external site; future reuse (e.g., roof tiles for 2027) faces major warehousing questions due to tight site space (A1, A3, A4).
	Purchasing departments coordinate demolition, upcycling, and quality; consultants spent significant time scouting demolition sites but many options misaligned in time (e.g., Sahlgrenska) (A3, A4).
	Doors booked for reuse was "grabbed" by other internal projects. Decisions on where to perform upcycling (on-site vs. off-site varnishing) add complexity (A3, A4).
Technical delivery	
	As drawings had to be completed early with lacking information of the reuse targets, the search for reuse targets had to relate to set dimensions, but uncertain reuse data led to complexities adding upcycling and adaptation needs (e.g. fitting doors to openings) (A1, A3, A4)
	Multiple actors constantly investigate suppliers and availability; often products are occupied or unsuitable (A3, A4).
	Reuse introduces more documentation regarding product properties, installation methods, and maintenance (e.g. types of locks and hinges, fire protection properties etc.) (A3).
	Negative attitudes toward reuse elongate processes, suggesting need for mindset shifts (A4).
	The team realized doors were harder than thought due to strict requirements (fire, sound, locks, automation); testing, classifying, and documenting properties significantly extend timelines. The project has therefore focused on the "dumb" doors for reuse (A1, A2, A3).
	Reused products often involve more processes due to cleaning, testing, transport, and storage; toilet furniture required new mixers, introducing more processes (A3).

		Few suppliers/producers has experienced reconditioning products, leading to inefficiencies; organizations can learn from maintaining products internally (A2, A4).
Costs	Governance and planning uncertainty	
		Conflicting political budgets vs. circular goals leads to costs; unclear planning leading to unplanned purchases; late identification/acquisition of circular targets drives admin costs (A1, A2, A3).
		Missing reuse data extends processes and forces time-consuming estimates, inciting costs; long timelines raise availability risk, which led to extra fund applications, giving possibility for many reuse targets (A1, A2).
		Budgeting as new and replacing if reuse is found reduces incentive to seek reuse and causes constant scope revisions (A1, A2).
		Costs drop when pricing/products are set early, reducing administration and uncertainties (A1, A3).
	Budgeting, tendering & contracting	
		The turnkey contract with fixed price renumeration has required the contractor to make calculations for the tendering, which has been difficult because of the uncertain data of circular targets, increasing early planning costs. Client taking responsibility for management and logistics of bricks, simplified process of tendering by only calculating labor (A1).
		Treating reuse as variation jobs simplifies tendering but adds administration costs (A1).
		Suppliers may charge more to cover demolition or novel production methods and design (A3).
	Logistics, storage & transports	
		Cost occurs because of distant warehouses which also were difficult to access, meaning a lot of hassle. Unnecessary transport between two warehouses raised costs.

	Recycling transport containing, for example, mineral wool raised costs of pure transport and warehousing. Taxes were added because it was sent to Norway. On-site or proximal reuse targets could be cheaper options (A1, A3, A4).
	Large products is hard and costly to store which often leads to them not being reused; durable materials that can be stored outdoors are easier to deal with and reduce admin and costs; better warehousing solutions are key to cost reduction (A2, A4).
	Sensitive dismantling is costly, but resale of materials can offset costs (especially if valuable); upcycling steps (e.g., fireproofing) and increased interaction time with materials drive costs. Upcycling costs could be lowered if done in streamlined processes at producers/experienced craftsmen and not at construction site (A1, A3).
	Clients taking responsibility for management and logistics is burdensome and costly. Ideally a supplier provides project-ready reused items (A1, A2, A3).
Upcycling, testing & technical compliance	
	Careful dismantling and labor-intensive upcycling (cleaning, painting, adjusting, fireproofing) are costlier than streamlined new production (A1, A2).
	Reused products, often even from suppliers, require costly testing (e.g., load-bearing checks) (A3).
	Costs drop when direct reuse avoids repair/refurbish/testing which aligns with higher circular value according to R10; leveraging experienced craftsmen/producers (not on-site improvisation) lowers costs (A3).
	Strict requirements of, for example, doors (fire, sound, locks, automation) extend timelines and costs (A1, A2, A3).
	Some items (e.g., skewed cable ladders) are costlier to restore than to buy new; simpler doors are easier (and cheaper) to reuse (A3).

	Lack of standard warranties and the need to document properties, installation, and maintenance increase administrative costs (A3).
	Negative attitudes to reuse prolong processes and add indirect cost (A4).
Administration, standardization & human capital	
	Extensive collaboration/meetings; investigations into usability/properties; “awkward realities” of booking warehousing visits etc. add costs (A1, A2, A3).
	Costs from balancing targets vs. budgets and building new processes amid industry inertia (A1, A4).
	Early decisions on preconditions and early planning of availability/storage reduce costs; mature reuse markets and standardized supplier solutions unlock economies of scale (even if transaction costs rise) (A1, A2, A3).
	Significant hours for collaboration, administration/supervision, and consultants, increasing costs, sometimes disproportionate to end-goal value (A2, A3, A4).
	High effort on low-stock/high-cost items is inefficient; focus work on high-reward targets and leave low-reward items to the market (A2).
Market dynamics & innovation	
	High demand for popular reuse products raises prices; done correctly, reuse can save material costs; resale of dismantled materials can offset project costs (A1, A4, A1).
	Lack of established circular practice leads to errors and higher admin costs; costs could drop if producers streamlined circular processes or expanded into circular services (A4).
	Investigations and novel methods (e.g., mock-ups for reused brick) typical of pilot projects, add costs (A1, A2).

Sonyas

Type	Synthesis	Analys	Property
Strategies	"Radical Low-Tech" & Material Innovation		
		The project introduces clay blocks, clay plaster, and clay paint as a strategy to reduce the environmental footprint (B1).	
		The design strategy actively challenges the need for advanced technical systems, resulting in a reduction of ventilation piping and control devices, and also challenges the use of super advanced solutions (B1).	
		Decision-making favors social/environmental sustainability and cultural programs over formal certification systems, which were skipped to save costs (B1).	
	Optimization of Space & Structure		
		Engineering efforts focus on optimizing load-bearing structures (e.g., using thinner hollow-core decks via shorter spans, 4,8m) to reduce concrete use and allow for lighter piling (B1).	
		The project targets the problem of offices standing empty 70% of the time by prioritizing co-use and smart programming, which requires careful client matching to avoid failure. This also aims at reducing the amount of built space needed (B1).	
	Strategic Pragmatism		
		The project consciously limits its scope (e.g. ceramic tiles), avoiding the pursuit of reuse to "absurd amounts" to prevent the project from becoming unmanageable (B1).	
		The team remains flexible, abandoning initial plans for hollow-core deck reuse due to logistics/warranties issue but also increased climate impact caused from the thicker slab dimensions required. However, the project successfully pivoted to plan for slate tiles for the roof (B1).	
		A key strategy involves rethinking what officially counts as "reuse," noting that some	

		waste materials must pass through a "marketplace" to officially qualify (B2).
Processes	Agility, Culture & "Fighting Spirit"	
		The client organization uses its small size to its advantage, making decisions faster than large companies because key players sit close together and bypass administrative hassle (B1).
		Success is driven by a problem-solving mindset and a "fighting spirit," often spurred by early, tough environmental demands from the municipality (B1, B2).
		A partnering contract established during the land allocation phase was essential to enable early circular work (even though the timeline was short) and has been successful for the project (B2).
		The process is characterized by "learning by doing", creating uncertainty and more labor hours, and continuous improvement (e.g., bi-weekly sustainability meetings), as the team acknowledges a lack of prior circular experience (B1, B2).
	Managing Market Immaturity & Logistics	
		Designers have shifted to working with "interval measurements" rather than fixed dimensions to accommodate the variable nature of reuse targets found later in the process (B2).
		The construction sector includes a lot of informal tips between consultants and actors, meaning the best reuse products often never reach the open market (B2).
		Instead of searching the open market with high uncertainty, the team finds it more effective to turn directly to suppliers (like Ecophon with suspended ceilings) who are beginning to resell reused materials (B2).
		The team has negotiated with lawyers or municipalities to classify left-over materials as reuse without sending them through a formal marketplace (B1, B2).

		Logistics demand active management from the client, as the inability to store sensitive materials (like hollow-core slabs) between demolition and construction can kill reuse options, requiring iterative decision-making (B1, B2).
	Navigating Friction in Execution	
		The production process is slowed by material irregularities, such as brick dimensions or the need to mount reused bricks one by one rather than using efficient pre-assembled blocks (B1, B2).
		The process involves friction with sub-contractors (e.g., locksmiths), and sometimes finding new ones, who may resist reusing items due to technical hurdles (recoding) or because it disrupts their optimized "just-in-time" workflows (B1).
Costs	The High Cost of Labor & Unfamiliarity	
		Labor is currently the largest cost driver. Contractors bill high premiums to cover the risk and learning curve associated with novel materials (B1). • *Example: Clay plaster is billed at ~1700–1800 SEK/m².* • *Example: Clay paint is billed at ~900 SEK/m² (vs. ~220 SEK/m² for standard).*
		With labor rates around 1000 SEK/hour, the longer time required to work with reused materials or fix irregularities significantly pushes up the total budget (B1, B2).
		Significant money is "wasted" on investigating solutions (like slate roofing) that are initially deemed impossible but later pursued, or finding warehouse solutions that already exists (B1).
	Systemic & Logistical Inefficiencies	
		Project management costs rise due to the time required to search through fragmented marketplaces and find new subcontractors willing to work with reuse (B2).
		Small quantities of reuse materials lack economies of scale, making storage

		disproportionately expensive compared to standard bulk orders, however individual targets like toilets may offer cheap solutions (B2).	
		The project incurs costs for external warehousing because circular strategies conflict with the industry's standard "Just-in-Time" delivery model (B2).	
		High process costs are incurred during competitions for central land allocations due to strict CO2 budgets and reference checks that needs to be fulfilled and require a lot of resources (B2).	
	Direct Material & Risk Premiums		
		Reused materials often cost 20–30% more than new ones (e.g., bricks), although some specific items like toilets can be cheaper (B1, B2).	
		Financial risk is increased by the lack of warranties, leading actors to bill premiums to cover potential liabilities or to refuse warranties entirely (B2).	
		Costs increase due to the time required to physically adjust materials, such as cutting interior glass or performing third-party structural testing (B1, B2).	

Gothenburg Grand Central

Type	Synthesis	Analys	Property
Strategies	Setting the ambition		
		Driven by the client's goal to be a market leader and role model in sustainable value creation. The project lead actively "marinated" the team in the circular purpose to foster a collaborative culture (C1).	R1
		The project is fully funded via green bonds, securing favorable financial loan terms by committing to EU Taxonomy alignment and BREEAM "Outstanding/Excellent" certification (C1, C3).	R1
		The project is guided by a strict roadmap to climate neutrality (e.g., limit of 245 kg CO_2/GFA) and aligns with the client's goal of halving emissions by 2030 (C1, C2).	R1

Architecting the solution		
	The team developed a circular manual with for example measures of adaptability, flexibility and demountability that is transferred into the BIM model. The guide measures a "circular index", documents properties and costs and provide dismantling instructions (C1, C3).	R1
	Office spaces are standardized with identical designs to allow future adaptation without renovation or tenant-specific adjustments (C3).	R1
	A wooden load-bearing structure was chosen over steel or concrete specifically to reduce environmental impact and weight, critical for building above a tunnel (C1).	R2
	The strategy extends beyond the building envelope to include green roof spaces that support local biodiversity (C1).	R1
Mobilizing the market		
	A key strategy involves pressing suppliers to understand the business value of circularity and shifting market boundaries (C1).	R1
	The strategy prioritizes purchasing reused products that come with warranties, directly from suppliers, mitigating risk (C1, C2, C3).	R3
	Collaborations for "zero-steel" (SSAB) are used. When reuse targets cannot be met (e.g., structural steel), the strategy shifts to CO2-reduced steel or recycled materials as a fallback (C1, C2).	R2
	"Reduce" strategies are largely driven by the contractor's perspective on waste minimization and on-site recycling (C2).	R2
Realizing the impact		
	The project has successfully secured 100% reuse of façade bricks and aims for 100% reuse of cable ladders, alongside recovering 50–80% of existing ventilation ducts (C1, C2–C3).	R3
	Structural steel proved more difficult due to supply chain leakage; the intended 50% reuse goal was adjusted to a realized 20–	R3

		30% after beams were sold to other buyers (C2, C3).	
		Recycling metrics significantly outperformed expectations, with façade and atrium glass reaching 65–90% recycled content and local ballast usage for groundworks exceeding 50% (C2, C3).	R8
		The circular commitment extends to the interior fit-out, where specifications require that 100% of office carpets be composed of recycled materials (C3).	R8
Processes	Anchoring the Mission		
		The project's circular purpose has been deeply "marinated" into the entire organization through climate calculations and presentations, fostering an understanding culture where even the purchasing department proactively suggests reuse options, which is vital since most knowledge of the market lies with purchase personnel or specialist contractors (C1).	
		Success relies heavily on a "partnering" contract that establishes a common goal; without this collaborative framework, the circular journey would have been significantly harder, whereas a fixed-price contract would have turned every decision into a fight (C2, C3).	
		The process is sustained by a client who is deeply involved, measuring economic and environmental impact equally and refusing to back down on sustainability goals (C1, C2, C3).	
		To manage complexity, the project relies on setting 3–5 clear, reasonable targets at both requirement and goal levels, which helps bring all stakeholders, including initial doubters, on board (C2, C3).	
	Front-loading investment		
		Unlike traditional linear projects, this process requires risking capital early to book materials like bricks during the system design phase, a necessary step to secure supply within tight deadlines (C1, C2).	
		Budgeting processes recognize value at the same level as price, with decisions based on constant evaluations of "crowns per kilo	

	CO_2-equivalents" and environmental analysis weighed on the same level as economic data (C2, C3).
	The team must accept longer lead times, booking materials like glass and bricks up to six months in advance to reserve them, while also investing significant time in investigating product sustainability and defining reasonable targets (C1, C2, C3).
	To be most effective, circular visions need to be introduced as early as the detailed development plan stage to influence major parameters like building size and spans (C1).
Navigating market uncertainty	
	The design process has moved from a linear path to an iterative one, where designers must keep options open longer and frequently redraw plans when specific materials (like steel beams) are sold to other buyers (C1, C2).
	Unlike the certainty of ordering new materials, the team faces a market where availability fluctuates, requiring active engagement to scout marketplaces and demolition projects for items like cable ladders (C2).
	The strategy favors purchasing directly from suppliers who can offer warranties and manage industrial demands, rather than relying on consultants who lack real-time inventory knowledge (C1, C3).
	The project has had to adapt to material shortages, such as sourcing yellow bricks from Denmark when local "Gothenburg classic" stocks were depleted, requiring the purchasing department and designers to handle foreign measurements and extra logistics (C2, C3).
Operationalizing the flow	
	Because the construction site lacks space, the project requires off-site storage solutions where materials like bricks are held locally or by suppliers until they are needed for installation (C1, C2).

		While the actual on-site installation processes remain largely similar to standard projects once materials arrive, the management focus shifts heavily toward mitigating the risks associated with supply disruption and material quality (C2).
		The team faces limitations with detailed plans that "box in" the project, as well as challenges of strict regulations on acoustics and fire safety that require extensive testing of reuse materials (C1).
		The operational process involves navigating certifications and new goals through interpretation and experimentation (C3).
Costs	Funding the learning curve	
		The interviewees describe the initial cost increases not as losses, but as a necessary "tuition fee" or investment required to build the internal knowledge and capability needed for future market leadership (C1, C2).
		Significant resources are consumed by the time-intensive process of investigating materials and holding workshops, as well as hiring sustainability consultants to verify that potential reuse options meet project requirements (C1, C3).
		There is an operational cost in the hours spent "marinating" the team and the market, requiring education to shift the collective mindset from traditional purchasing to circular thinking (C1).
	Confronting market realities	
		The project faces a reality where certain reused alternatives, such as cable ladders, are exceptionally difficult and four times as expensive to source compared to new products due to high demand and scarcity (C1, C3).
		The market for reused steel has matured to a point where suppliers test, warranty, and resell steel at prices comparable to new steel (C2).
		The cumulative effect of these purchasing challenges, premiums, and risk mitigations

	results in an estimated total project cost increase of approximately 10% (C2).
Operationalizing the material flow	
	Costs are incurred in the physical refurbishment of materials, such as the handling of non-optimized elements like mortared brick façades that require processing (C3).
	The project pays a premium for risk mitigation, which includes the costs of testing materials, verifying technical properties (like steel strength), securing warranties and meeting modern regulations on acoustics and fire safety (C1, C2).
	Operational expenses are driven up by the need for off-site storage and extended transportation routes, such as the added cost of shipping specific yellow bricks from Denmark when local sources run dry (C1, C2).
	The schedule must account for the "cost of time," as careful dismantling and preservation of existing materials take significantly longer than traditional demolition methods (C3).