THE FRUGAL CROSSING

Exploring frugality in the transformation of a vital pedestrian and cycle bridge in Frihamnen, Gothenburg

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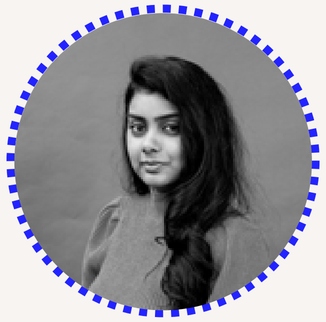

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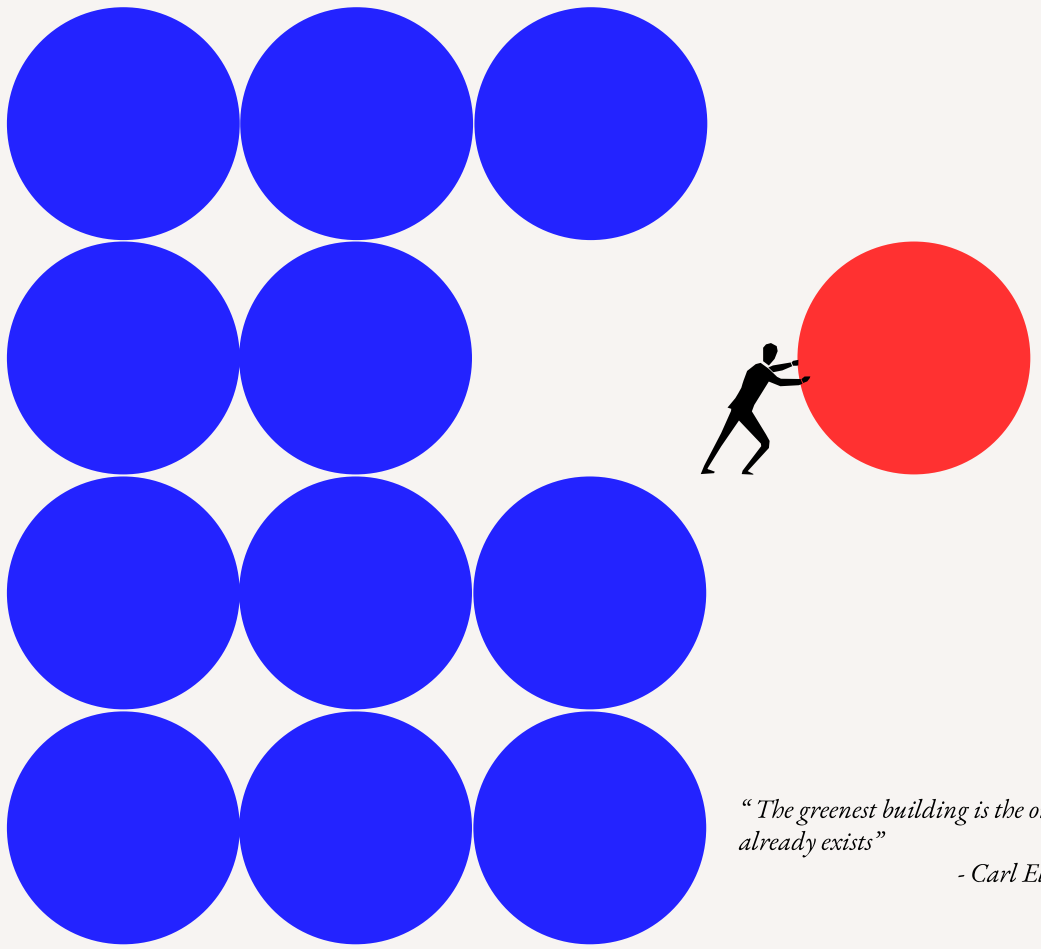

" The greenest building is the one that already exists"
- Carl Elefante

ABSTRACT

Frihamnen, one of the key areas in Gothenburg's River City development project also known as "Älvstaden Utveckling" is the focus area of this thesis. The City's development project involves the transformation of an industrial harbour into a sustainable urban district where the pedestrian and cycling connectivity plays a vital role in accessing the city across the infrastructure barriers. Ludvig Tingströms bro is the bridge that serves as the only pedestrian and cycling connection between the areas Kvillestan and Frihamnen which remains in a deteriorating condition, described by the local media as "old and wobbly," causing users to feel unsafe (Hankins, 2024). The City of Gothenburg has decided against renovation while awaiting potential future replacement which leaves the bridge in a substandard condition until further notice.

This situation creates a significant gap between Gothenburg's sustainability ambitions and the reality of inadequate infrastructure serving an increasingly important urban connection. The thesis proposes a conceptual redesign of the bridge grounded in frugality and material reuse. Rather than replacing the structure entirely with an entirely new construction, the project explores how elements from the existing bridge can be retained and reconfigured by using a clear framework by adopting frugal design principles from various literature, site observations, material inventorying and obtaining materials sourced from the other decommissioned projects in Gothenburg.

Frugality is approached as a deliberate architectural strategy that focuses on structural clarity, resource efficiency and careful intervention over excess. The design aims to transform second-hand materials into defining spatial and aesthetic qualities by embracing their textures and structural logic as part of a contemporary reuse-based ideology. The deliverables include contextual analysis, material investigations, and a conceptual bridge proposal that improves safety, accessibility, and overall user experience. The thesis imagines the bridge not only as a typical infrastructural element but as a potential vibrant public space, by utilising resource-conscious designs that strengthen the urban connection between Frihamnen and Kvillestan, while aligning with Gothenburg's larger sustainability ambitions.

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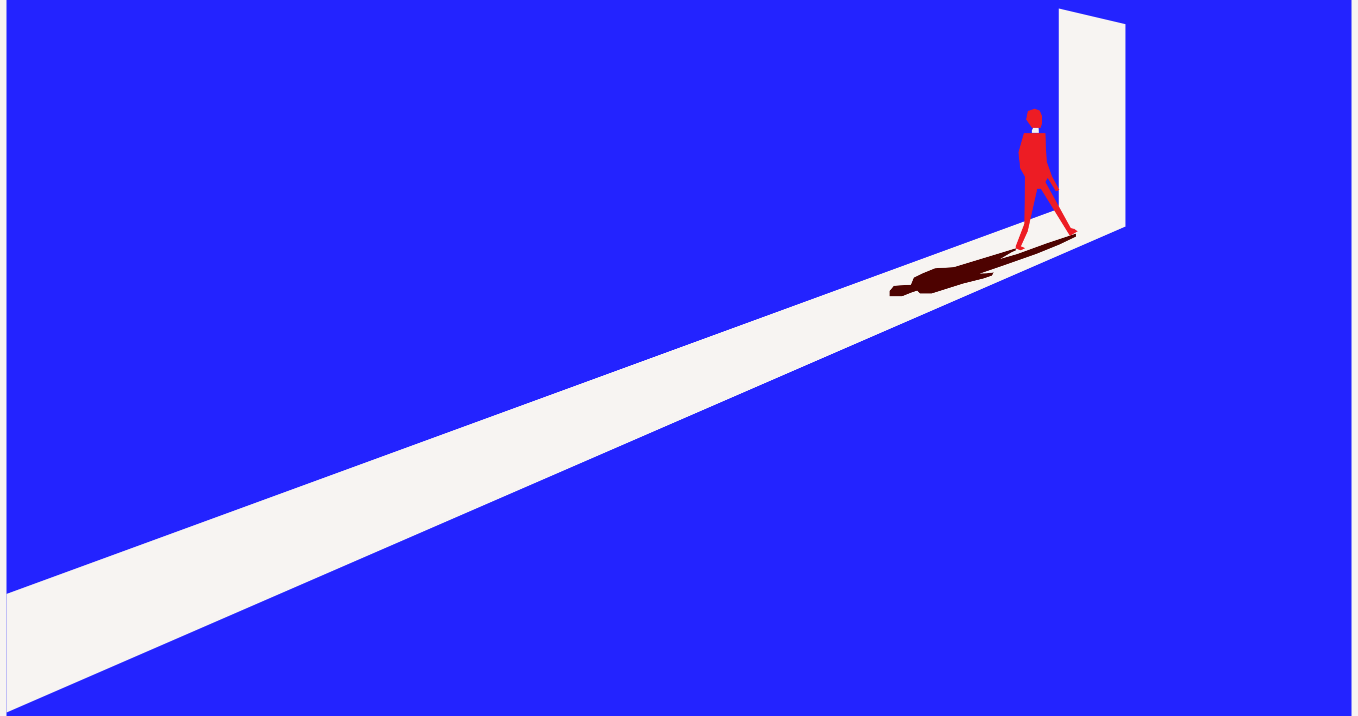
01

- BACKGROUND
- PROBLEM DESCRIPTION
- AIM
- RESEARCH QUESTION
- DELIMITATIONS



BACKGROUND AND PROBLEM DESCRIPTION

Frihamnen is one of the developing areas in Gothenburg, this area is undergoing a transformation from an industrial harbour into a sustainable urban recreational district. The non- motorised connectivity for the users from various neighbourhoods plays a vital role in Frihamnen's urban development.

Ludvig Tingströms bro is the bridge that serves as the only pedestrian and cycling connection between the areas Kvillestan and Frihamnen which remains in a deteriorating condition, described by the local media as "old and wobbly," causing users to feel unsafe (Hankins, 2024). The City of Gothenburg has decided against renovating it into a new structure while awaiting potential future replacement which leaves the bridge in a substandard condition until further notice. This situation creates a significant gap between Gothenburg's sustainability goals and the real world inadequacy of the infrastructure serving an increasingly important urban connection.

The thesis proposes a conceptual redesign of the bridge grounded in frugality and material reuse. Rather than replacing the structure entirely with an entirely new construction the project explores how elements from the existing bridge can be retained and reconfigured by obtaining materials sourced from the other decommissioned projects in Gothenburg. Frugality is approached as a deliberate architectural strategy that prioritizes structural clarity, resource efficiency and careful intervention over excess. The design aims to transform second-hand materials more into defining spatial and aesthetic qualities by embracing their textures and structural logic as part of a contemporary reuse-based ideology.

The deliverables include site analysis, critique of the previously obtained Mandaworks proposal, material investigations, material inventorying and a conceptual bridge proposal that improves safety, accessibility, and overall user experience. The thesis imagines the bridge not only as a typical infrastructural element but as a potential vibrant public space, by utilising resource-conscious designs that strengthen the urban connection between Frihamnen and Kvillestan, while aligning with Gothenburg's larger sustainability ambitions (City of Gothenburg, 2024; European Commission, 2025).

Figure 1: Image sourced from Hela Hisingen illustrated by the author

AIM & PURPOSE

The aim of this thesis is to explore how a frugal and reuse driven design approach can inform the conceptual development of a pedestrian and cycle bridge connecting Kvillestan and Frihamnen in Gothenburg. By focusing on the reuse of materials sourced from existing infrastructure and decommissioned construction projects, the thesis examines how design can emerge from what is available rather than from predefined specifications. This shift allows the project to engage directly with the material realities of the city, while addressing the need for a safe, accessible and user oriented crossing that supports everyday mobility.

The purpose of the thesis extends beyond the development of a single design proposal. It aims to establish a methodological framework that integrates site analysis, material cataloguing and research by design as interconnected tools. Through this process, the study investigates how constraints related to material availability, cost and spatial conditions can act as drivers of innovation rather than limitations. The bridge is treated not only as a functional connector but also as a potential public space that responds to user needs, environmental conditions and urban context. In doing so, the thesis seeks to demonstrate that frugal design can produce infrastructure that is both efficient and meaningful, without relying on excess or complexity.

Additionaly, the thesis places itself within the larger discourse on sustainable urban development and circular construction. Gothenburg's goals for reducing carbon emissions and promoting resource efficiency provide a relevant context in which to test these ideas. By proposing a design that minimizes material use, incorporates reclaimed materials and supports non motorised transport, the project aligns with these goals while also addressing local spatial and social conditions. The intention is to contribute to ongoing discussions about how cities can transition toward more responsible forms of construction, where design decisions are informed by environmental and economical considerations but also everyday user experience.

Ultimately, the thesis seeks to demonstrate that constraint driven design can transform limited resources into opportunities for architectural and urban quality. It highlights the potential of frugality not as a compromise, but as a deliberate and thoughtful approach that can redefine how infrastructure is conceived, designed and integrated within the city.

WHAT....?

The thesis focuses on developing a conceptual redesign of Ludvig Tingströms bridge which is the existing pedestrian and cycle bridge connecting Kvillestan and Frihamnen. The current situation is widely remarked as unsafe, noisy and visually uninviting due to its exposure to highway (lundbyleden), tram lines and railway infrastructure beneath it (Hankins, 2024). The thesis explores how principles of frugality and reuse of materials from the existing bridge and other decommissioned infrastructure in Gothenburg can lead to the creation of a safer, more attractive and socially inclusive mobility connection.

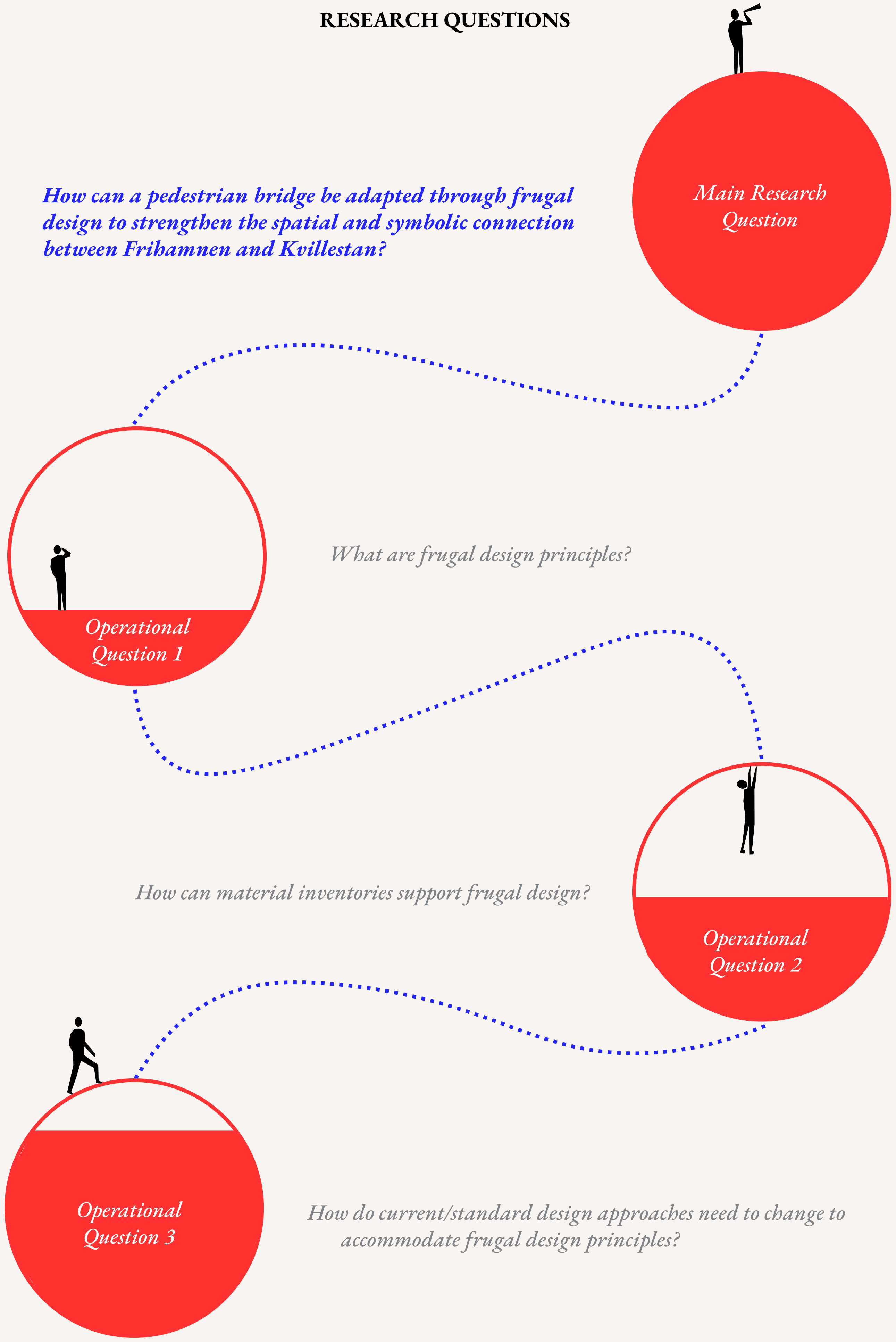
WHY....?

This topic is relevant because the bridge serves as the only non-motorised link between a dense residential neighborhood and a rapidly developing waterfront district. Despite its strategic importance, its deteriorating condition (refer *Figure 1*) and the city's decision not to renovate it weakens the accessibility, user comfort and urban cohesion. At the same time, Gothenburg's climate ambitions and circular economy strategies emphasize the need for resource-efficient and low-carbon infrastructure. Addressing these spatial and environmental challenges situates the project within broader discussions on sustainable urban transformation, responsible material reuse and equitable access to public space.

HOW....?

The thesis approaches this challenge through research by design combined with material-driven investigation. The process includes analysing the spatial, acoustic and experiential shortcomings of the current bridge built on the proposal submitted by Mandaworks in 2019 and by identifying reusable components from the existing structure and other municipal deconstruction streams also by conducting material studies to evaluate their suitability and environmental implications. These investigations result in the development of conceptual yet feasible design proposals that integrate frugality, reuse aesthetics, and user-oriented spatial strategies. By rethinking the bridge as both infrastructure and public space the project aims to move beyond simple replacement and trying to position the intervention as an opportunity for circular, socially responsive and climate-conscious urban design.

RESEARCH QUESTIONS



RELEVANCE FOR SUSTAINABLE DEVELOPMENT

The project aligns closely with several UN Sustainable Development Goals (SDG) by addressing sustainability, social equity, and circular construction within Gothenburg's urban development. The need for a renewed pedestrian and cycle bridge between Kvillestan and Frihamnen emerges from current safety, comfort and accessibility problems identified in public reporting, especially the deteriorated condition and negative user perception of Ludvig Tingströms bro (Hankins, 2024).

By proposing a bridge constructed from reused materials sourced from the city's decommissioned infrastructure, the thesis is in line with the contemporary frameworks in place for circular infrastructure (Blomsma & Brennan, 2017; European Environment Agency, 2020). This methodology then directly contributes to SDG 11 (Sustainable Cities and communities) through improved non-motorised mobility and urban connectivity, and to SDG 12 (Responsible consumption and production) by advancing responsible material use and circular resource cycles.

The project also supports SDG 13 (Climate action) by the reduction of embodied carbon, through the implementation of reuse strategies (Pomponi & Moncaster, 2017). Furthermore, enhancing pedestrian safety and overall well-being links to SDG 3 (Good health and well being), while strengthening connectivity between socially and functionally different districts contributes to SDG 10 (Reduced inequalities). Collectively, these alignments position the thesis at the intersection of sustainable design, climate-conscious construction and socially inclusive urban development.

PRIMARY SUSTAINABLE DEVELOPMENT GOALS

SECONDARY SUSTAINABLE DEVELOPMENT GOALS

DELIMITATIONS

The thesis is limited to the conceptual redesign of Ludvig Tingströms bridge as a pedestrian and cycle bridge within the urban context of Gothenburg. The project primarily addresses architectural design questions related to spatial quality, accessibility and user experience. The focus is given to the potential reuse of materials from the existing bridge structure as well as from other decommissioned infrastructure within the city. The study therefore investigates how locally available reclaimed materials can lead to design decisions and support a frugal approach to infrastructure. The work focuses on the bridge as a vital connector between Kvillestan and Frihamnen and examines how design strategies can improve safety, comfort and the overall experience of the crossing.

The scope of the research remains at a conceptual and exploratory level. The project develops spatial proposals, diagrams and visualizations that illustrate how a redesigned bridge could function architecturally and socially. However the thesis does not include detailed structural calculations, advanced engineering simulations or comprehensive technical testing of materials. Structural feasibility is considered in a general and indicative manner based on existing literature and typical bridge systems rather than full engineering verification. Similarly, environmental considerations are discussed through comparative reflection on material reuse and potential reductions in embodied carbon rather than through full life cycle assessment modelling.

The research also does not extend to construction delivery or implementation processes. Detailed construction management, procurement strategies, contractor coordination and regulatory approval procedures are outside the scope of the thesis. While relevant Swedish regulations and accessibility standards are acknowledged to ensure that the proposal remains realistic, the project does not attempt to produce documents suitable for construction approval. Economic aspects are addressed through general cost awareness and discussion of frugal design principles rather than through detailed budgeting or financial feasibility studies.

In addition, the thesis does not undertake extensive social research such as large scale public surveys or long term socioeconomic impact studies. Social considerations are approached primarily through spatial analysis, accessibility mapping and scenario based exploration of everyday users such as pedestrians, cyclists, children and elderly residents. The work therefore reflects on how the bridge may support inclusive mobility and urban connection but does not attempt to measure these effects through empirical data collection over time.

Finally, the study concludes at the stage of conceptual design and critical reflection. The outcome of the thesis is a set of design proposals, methodological insights and observations about the role of frugal and circular thinking in infrastructure design. It does not include physical construction, real world testing or post occupancy evaluation. The intention is to contribute ideas and design strategies that could inform future discussions about sustainable urban infrastructure in Gothenburg rather than to produce a finalized engineering solution(refer to *Figure 2* for the delimitations diagram).

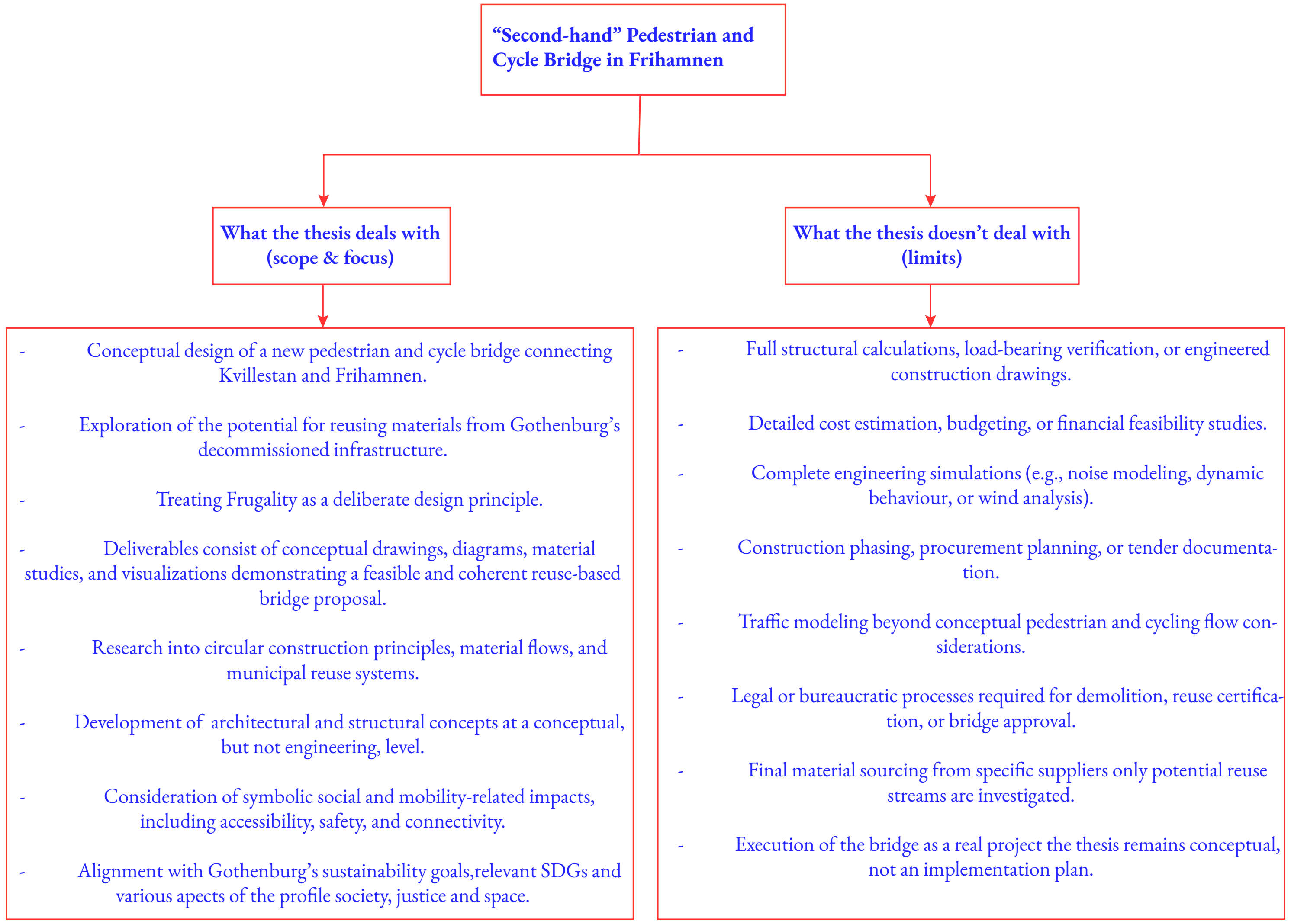
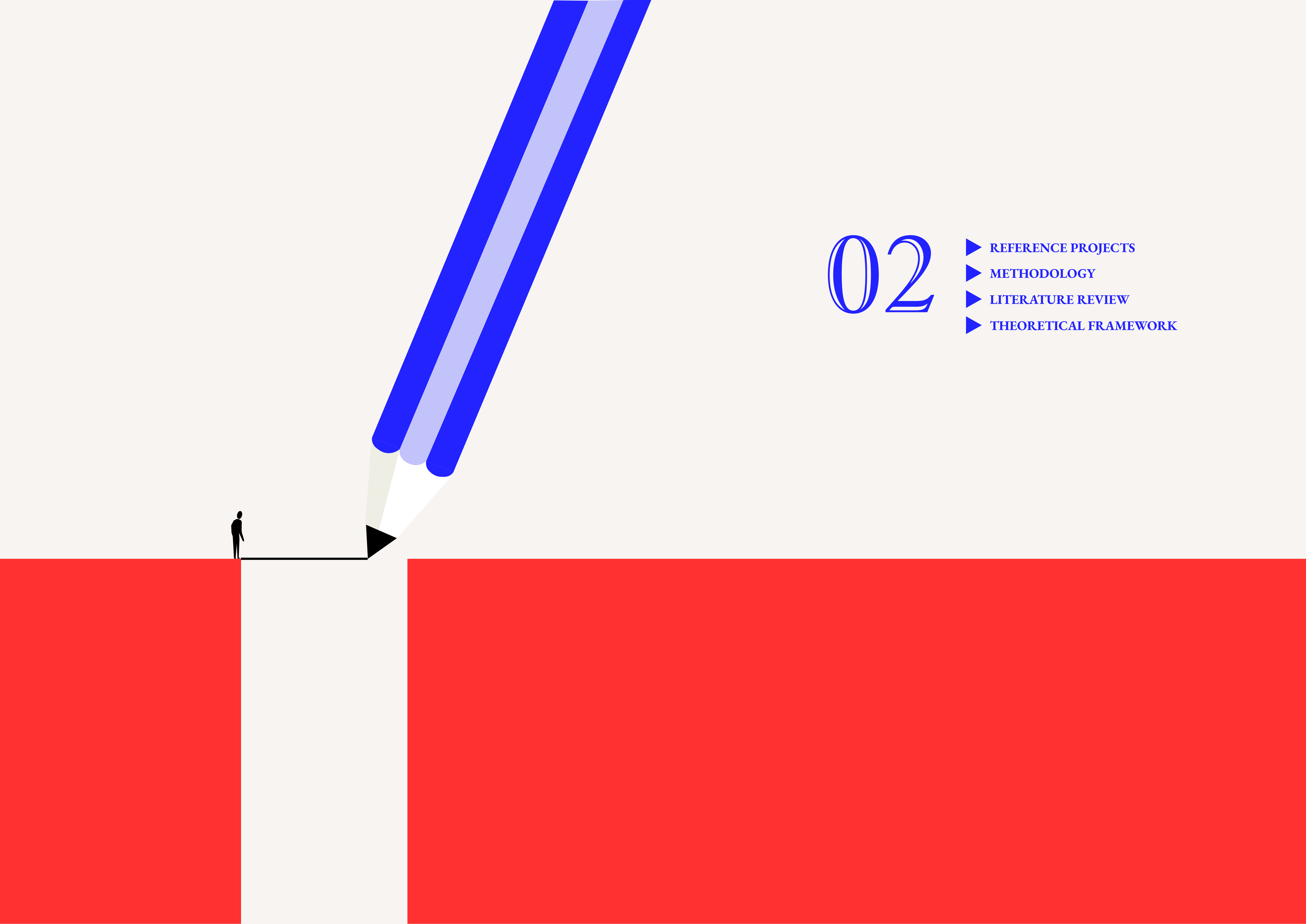


Figure 2: Delimitations diagram illustrated by the author



02

- REFERENCE PROJECTS
- METHODOLOGY
- LITERATURE REVIEW
- THEORETICAL FRAMEWORK

METHODS AND TOOLS

The diagram outlines the methodological structure of the thesis from problem definition to final production. It begins with defining the problem and establishing a theoretical foundation. This includes a literature review, the formulation of a main concept and the identification of seven frugal principles. These principles appear to act as the intellectual backbone of the project. At the same time the proposal critiques an existing bridge scheme and conducts a cost driver analysis. By placing these tasks early in the process helps to get the conceptual clarity and economic awareness guide in all subsequent decisions.

The next phase moves into site analysis and technical grounding. As shown in *Figure 3* both qualitative and quantitative inputs are considered. Site conditions are studied alongside technical reports and the dissection of the Mandaworks proposal. This combination indicates that the thesis does not treat the site as an abstract location but as a lived and regulated environment. Theoretical ideas are translated into practical constraints and opportunities which then shape the design logic.

One of the methods employed is inventorying materials. This stage includes creating a database supported by photographs drawings and cost charts. Each material is evaluated in terms of dimensions, quantities, cost condition, character and its significance. The emphasis on harvest mapping and local sourcing reinforces the circular ambition of the project. References to material substitution methods indicate that adaptation rather than ideal specification will guide design choices. The process likely requires careful judgment when balancing structural feasibility with availability.

Next comes the synthesis and design testing. Here material efficiency is linked to spatial analysis which implies that structural form evolves from available resources. The study models explore spatial and structural logic through iterative sketching and initial dimensioning. Each iteration is assessed against the seven frugal principles. This feedback loop indicates that design decisions are continuously measured against previously created values rather than aesthetic preference alone. The process appears exploratory but structured. It moves back and forth between analysis and speculation until a coherent solution emerges.

The final stages focus on evaluation and production. Cost estimates circular economy implementation and carbon footprint calculations are used to assess the proposal's broader impact. This suggests an effort to ground the design within environmental and economic realities rather than leaving it at the level of concept. The outcome is communicated through conceptual drawings plans sections and three dimensional views with attention to modularity. Reflection is built into the process through critical analysis of what worked and what did not. This closing phase acknowledges limits and shortcomings which strengthens the academic rigor of the work.

Overall, it is a research by design methodology that is iterative and evidence informed. While incorporating theoretical framework, material investigation, spatial analysis and environmental evaluation into a continuous loop rather than a linear sequence. This structure suggests that frugality is not merely a theme but an operational framework shaping each stage of inquiry.

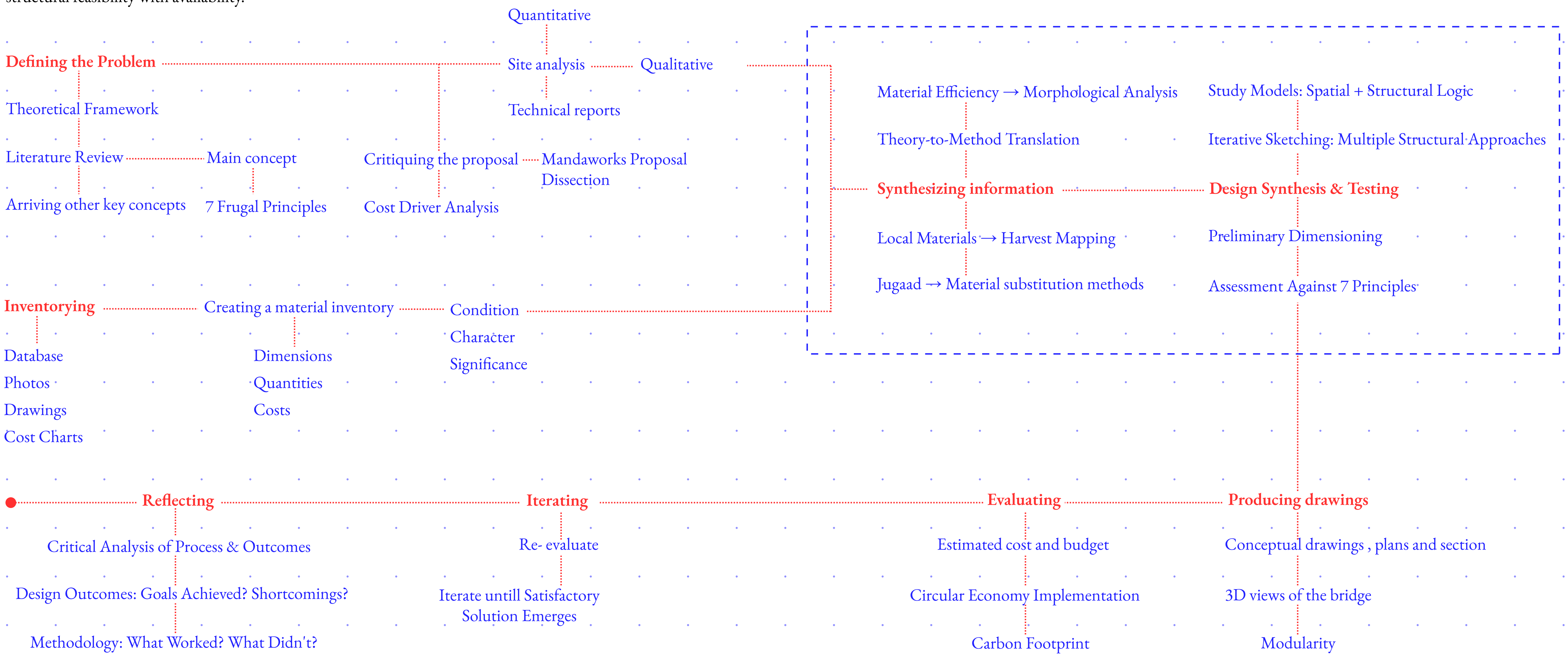


Figure 3: Methodological diagram illustrated by the author

RESEARCH PAPER	SUMMARY OF THE PAPER	KEY CONCEPTS
Creative Frugality as a Sustainable Circular Pattern in Architecture and Building Construction [Montalbano, G., & Santi, G. (2023)]	It explores creative frugality as a sustainable design model for architecture and construction, particularly focusing on affordable housing challenges. The authors define frugality across four domains: energy, materials, technology, and territory, drawing from the "Frugalité Heureuse et Créative" manifesto. Through case studies of residential buildings in France, they demonstrate how frugal design principles utilising local materials, bio-based insulation, and low-technology solutions can achieve cost-effectiveness while maintaining sustainability. The research emphasizes self-construction capabilities, dry construction systems, and the integration of passive thermal solutions.	Frugal innovation in architecture; Local material sourcing; Low-technology design strategies; Circular economy practices; Adaptability and flexibility in design; Cost-effective sustainable solutions
Criteria for Sustainable Pedestrian Bridge Development [Hendrawan, H., & Amelia, S. (2022)]	They develop and evaluate sustainability criteria for pedestrian bridge implementation in Indonesia through an "eco JPO" prototype in Surakarta City. Their research establishes two primary criteria categories: planning criteria (addressing needs and location suitability) and design criteria (encompassing seven measures: attractive design, environmental friendliness, energy self-sufficiency, safety, artistic value, comfort, and security). Using Likert scale questionnaires and interest-performance analysis with 60 respondents, the authors validate the importance and satisfaction levels of these criteria, finding overall satisfaction ratings between 3.67-4.61 and importance ratings between 4.47-4.85.	Planning criteria (needs analysis, site selection); User satisfaction and importance assessment; Design criteria (aesthetics, environmental features, safety); Accessibility and comfort standards; Energy self-sufficiency (solar panels, LED lighting)
Exploring Jugaad in Architecture [Kumar, V., & Mukerji, A. (2025)]	The authors explore Jugaad, an Indian concept of improvised, frugal innovation within architectural contexts. Through systematic literature review using the PRISMA method and Fuzzy Delphi Method validation with 16 experts they identify nine key aspects defining Jugaad. The authors propose three implementation strategies which are element substitution, material substitution and multiplexing validated through case study analysis and expert consensus.	Jugaad innovation and frugal design; Element and material substitution strategies; Resource-constrained design solutions; Multiplexing for increased functionality; Adaptive material reuse and repurposing; Low-cost inclusive design
Bridges in Urban Planning and Architectural Culture [Salamak, M., & Fross, K. (2016)]	It examines the complex role of bridges in urban development and architectural culture. The authors analyse how bridges function beyond mere infrastructure, serving as symbols of technical progress, economic potential, and urban identity. Through case studies of major cities including Budapest, New York, Paris, Prague and Shanghai, they demonstrate how bridge construction has historically shaped urban layouts and influenced property values. The paper discusses how bridges have evolved from just functional structures to iconic landmarks that define city skylines and serve as tourist attractions.	Bridge multifunctionality; User-friendly design considerations; Bridges as city icons and landmarks; Aesthetic integration with urban environment
Conceptual Design of the Pedestrian Bridge [Lu, P., Zhou, Y., Lu, Q., Wang, J., Shi, Q., & Li, D. (2022)]	The paper addresses design defects and construction challenges in contemporary pedestrian bridge development. The authors propose a conceptual design framework centered on holistic engineering construction principles. Their research identifies key design considerations including landscape innovation, structural modeling and environmental integration. The study emphasises the application of cutting-edge technologies such as new materials, innovative construction processes and Building Information Modeling (BIM).	Conceptual design framework; Multi-functional integration; Landscape innovation and environmental coordination; Structural innovation and optimization; Aesthetic principles and architectural configuration; Digital rendering and modeling
Formalising Reduce in Circular Economy Design [Anastasiades, K., Lambrechts, T., Mennes, J., Audenaert, A., & Blom, J. (2022)]	The paper deals with the "Reduce" as a principle in circular economy-oriented design methodology for pedestrian and cycling bridges through morphological indicators. Developing an automated MATLAB-based design tool. They tested 72 steel bridge structures against Diamond's finite element software where the authors demonstrate that their tool effectively identifies optimal structural configurations, enabling designers to converge on material-efficient solutions more rapidly.	Circular economy (4R's: Reduce, Reuse, Recycle, Recover); Conceptual design stage optimization; Sustainability in bridge construction; Material efficiency and volume reduction
Translating Circular Economy to Bridge Construction [Anastasiades, K., Blom, J., Buyle, M., & Audenaert, A. (2020)]	The authors conduct a critical literature review examining the translation of circular economy principles to bridge construction, addressing the end-of-life challenges of aging concrete pedestrian bridges. They clarify definitions of sustainability and circular economy, positioning CE as a means toward sustainable development through moderate sustainability approaches. Their analysis identifies significant gaps in meso-scale research, advocating for Design for Adaptability (DfA), Design for Disassembly (DfD), and combined DfAD approaches.	Circular economy principles (4R framework); Construction and demolition waste (CDW) management; Design for Disassembly (DfD) and Design for Adaptability (DfA); Meso-scale circularity assessment; Life Cycle Assessment (LCA) limitations for circularity

DESIGN PRINCIPLES

- Material Efficiency and Resource Optimization
- Local Materials and Context-Specific Design
- User-Centered and Human-Scale Design
- Jugaad
- Cost-Effectiveness and Affordability
- Aesthetic and Cultural Integration
- Circular Economy and Reuse Principles

FRUGALITY AND THE SEVEN FOUNDATIONAL PRINCIPLES

What is Frugality?

Frugality in architecture refers to a design approach that uses resources carefully while still achieving functional, social and spatial quality. It encourages architects to work within constraints such as limited budgets, available materials and local conditions turning these limitations into opportunities for efficient and thoughtful design. Rather than focusing on excess or complexity, frugal architecture emphasizes material efficiency, simplicity in construction and responsiveness to context. This approach is closely linked to the idea of doing more with fewer resources while maintaining usability and value for users. The concept builds on the broader theory of frugal innovation, which describes solutions that deliver maximum value with minimal resource use (Radjou and Prabhu, 2015).

1. Material Efficiency and Resource Optimization

Material efficiency represents the foundational principle of the circular economy's hierarchy, prioritising reduction as "the most important R in the CE" before reuse, recycling, or recovery (Anastasiades et al., 2020, p. 2). For pedestrian bridges specifically, spatial indicators including volume, displacement, buckling and natural frequency indicators enable designers to "converge more quickly towards the best performing structure, thus saving time, materials, and corresponding costs and energy" through systematic optimization in the conceptual design stage (Anastasiades et al., 2022, p. 48). This approach challenges modern practice where "the method for choosing the most optimal structural design is usually vague and subjective," with professionals often generating designs "based on intuitive knowledge and experience" rather than systematic evaluation of material efficiency (Lu et al., 2022, p. 470). By formalizing material reduction strategies, bridges can be designed to be "fully stressed and stripped of all redundant material," which "limits the structure's energetic impact, and decreases procurement, transportation and construction costs" while reducing environmental footprint and post-use waste (Anastasiades et al., 2022, p. 36).

2. Local Materials and Context-Specific Design

Local material sourcing reduces transportation-related environmental impacts while stimulating regional economies and preserving cultural identity through technologies and labor typical of a region (Montalbano & Santi, 2023). Frugal design in materials "encourages the use of local, bio-based, and low embodied energy materials" which "promote technologies and labor which are typical of a region, thereby preserving cultural identity and supporting local economies," while simultaneously requiring "shorter supply chains, resulting in reduced CO2 and GHG emissions." (Montalbano & Santi, p. 3). This principle extends beyond material availability to encompass "locally sourced or built" solutions that are "adaptive or repurposing usage of limited resources or materials available at hand," characteristic of resource-constrained innovation approaches (Kumar & Mukerji, 2025, p. 12). Context-specific design also requires understanding that bridges must demonstrate "harmony with the environment" and adapt to "the specific environment in which the bridge is to be placed," ensuring that standardization for circularity does not become "an architectural obstruction" (Anastasiades et al., 2020, p. 6; Salamak & Fross, 2016, p. 210).

3. User-Centered and Human-Scale Design

Pedestrian bridges differ fundamentally from highway bridges in that they "also serve pedestrian traffic and therefore must satisfy additional safety and comfort conditions," requiring explicit attention to "user-friendly structures" designed at the human scale (Salamak & Fross, 2016, p. 208). User-centered design encompasses multiple dimensions identified as critical sustainability criteria: "attractive design, environmentally friendly, energy self-sufficient, safe, artistic, comfortable and safe" (Hendrawan & Amelia, 2022, p. 175). Humanized design specifically addresses accessibility requirements including "the height design steps, ramp lines, shade/roofs and the distance to other facilities that meet the requirements or standards," ensuring structures accommodate "people who have special needs or have limited physical abilities in terms of age, sensory capability, and limb limitations" (Lu et al., 2022, p. 479; Hendrawan & Amelia, 2022, p. 179). Beyond functional accommodation, user-friendly design recognizes that "people move along the bridge slower than cars do, so they have a direct contact with the structure," necessitating "greater attention to detail and interesting aesthetic solutions" that create meaningful experiential qualities (Salamak & Fross, 2016, p. 210).

4. Jugaad Innovation Strategies

Jugaad represents "a low-cost, inclusive solution developed in response to adverse conditions" through "an unsystematic approach for finding adaptive or repurposing usage of limited resources or materials available at hand," offering practical strategies for resource-constrained architectural interventions (Kumar & Mukerji, 2025, p. 14). Three primary implementation strategies characterize Jugaad in architecture which are element substitution (using different components to replace conventional building elements), material substitution (replacing standard materials with locally available alternatives) and multiplexing (increasing usage efficiency by assigning multiple functions to single elements) (Kumar & Mukerji, 2025). These strategies embody "creativity, improvisation, resourcefulness, and flexibility" while often involving "makeshift, good enough, make-do, jury-rigged, or quick-fix solutions" that prioritize immediate functionality over long-term permanence (Kumar & Mukerji, 2025, p. 12). Importantly, Jugaad validation through expert consensus (16 architecture professionals using Fuzzy Delphi Method) confirmed that such approaches achieve acceptance rates of 81.25-100% across key aspects, demonstrating that "low-cost inclusive solutions" and "adaptive usage of limited resources" represent professionally recognized design strategies rather than just improvised expedients (Kumar & Mukerji, 2025, p. 13).

5. Cost-Effectiveness and Affordability

Cost-effectiveness emerges as essential for addressing "the increasing demand for houses that should be affordable to meet the needs of low-income people" while simultaneously achieving environmental sustainability goals (Montalbano & Santi, 2023, p. 1). Frugal innovation "promotes the idea of making more with less," focusing on "low-technology design strategies capable of extending the building life cycle" which "allow easy modification and adaptation of buildings to the needs of the occupants" while "reducing operational costs" through enabling "self-maintenance and self-construction" (Montalbano & Santi, 2023, pp. 1-3). For bridge infrastructure specifically, cost analysis must transparently distinguish between construction costs and additional expenses: documented cases show bridge extensions estimated at "approximately 20 thousand SEK/m^2" for steel construction, while emphasizing that "additional costs for, for example, design and foundation are not included" (Hellberg, 2020a, p. 1). Importantly, affordability cannot justify compromising quality or sustainability, as "low material consumption limits the structure's energetic impact, and decreases procurement, transportation and construction costs," demonstrating that economic efficiency and environmental responsibility align when material optimization is pursued systematically (Anastasiades et al., 2022, p. 36).

6. Aesthetic and Cultural Integration

Bridges function beyond infrastructure as cultural artifacts that "co-create the image of an area" and can "become a very distinct and recognizable icon of the city," requiring design that integrates aesthetic ambition with functional performance (Salamak & Fross, 2016, p. 212). Aesthetic integration encompasses both "aesthetic principles and local wisdom" where conceptual design must balance "attractive design" with "artistic" qualities that reflect regional identity and "local culture/wisdom" (Lu et al., 2022, pp. 472-473). This cultural dimension manifests through design elements such as "cultural ornaments" and "fences with architectural accents that carry local culture/wisdom," though notably these elements received slightly lower importance ratings (4.47-4.61) compared to functional criteria, suggesting users recognize aesthetic value while prioritizing practical performance (Hendrawan & Amelia, 2022, p. 183). Critically, aesthetic quality need not require expensive materials or elaborate detailing, as "second-hand aesthetics" can emerge from honest expression of material reuse and visible construction logic, where "frugality is combined with creativity to promote innovative and sustainable design strategies, capable of achieving low carbon emissions" while maintaining visual and experiential richness (Montalbano & Santi, 2023, p. 3).

7. Circular Economy and Reuse Principles

Circular economy fundamentally redefines construction as a closed-loop system "based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes," operating across micro (product), meso (building), and macro (city) scales (Anastasiades et al., 2020, p. 2). For bridge construction specifically, circularity requires implementing Design for Disassembly (DfD) where "none of the building components are permanently fixed" and instead "the use of reversible connections is advocated," enabling components to be "directly reused in new buildings elsewhere, in order to increase their lifetime at their highest value" (Anastasiades et al., 2020, p. 5). The construction sector's generation of "25-30% of all waste generated in the EU" comprising "numerous materials of which many are reusable and recyclable" presents both and urgent challenge and a significant opportunity for circular practices (Anastasiades et al., 2020, p. 5).
However, current practice shows critical gaps: "only the micro-scale and macro-scale have gained a lot of attention within the CE discourse," while "the meso-scale, the scale of the construction in general, seems to be discussed and investigated very limitedly," necessitating development of bridge-specific circular design strategies and corresponding meso-scale circularity indicators to effectively assess value retention beyond simple recycling rates (Anastasiades et al., 2020, p. 9).

Note : The seven principles are the identified common themes of the analysed research papers, and the text above is the compilation of quotes (in blue) as stated in the papers with citation. For understanding the fundamental principles refer Page 13.

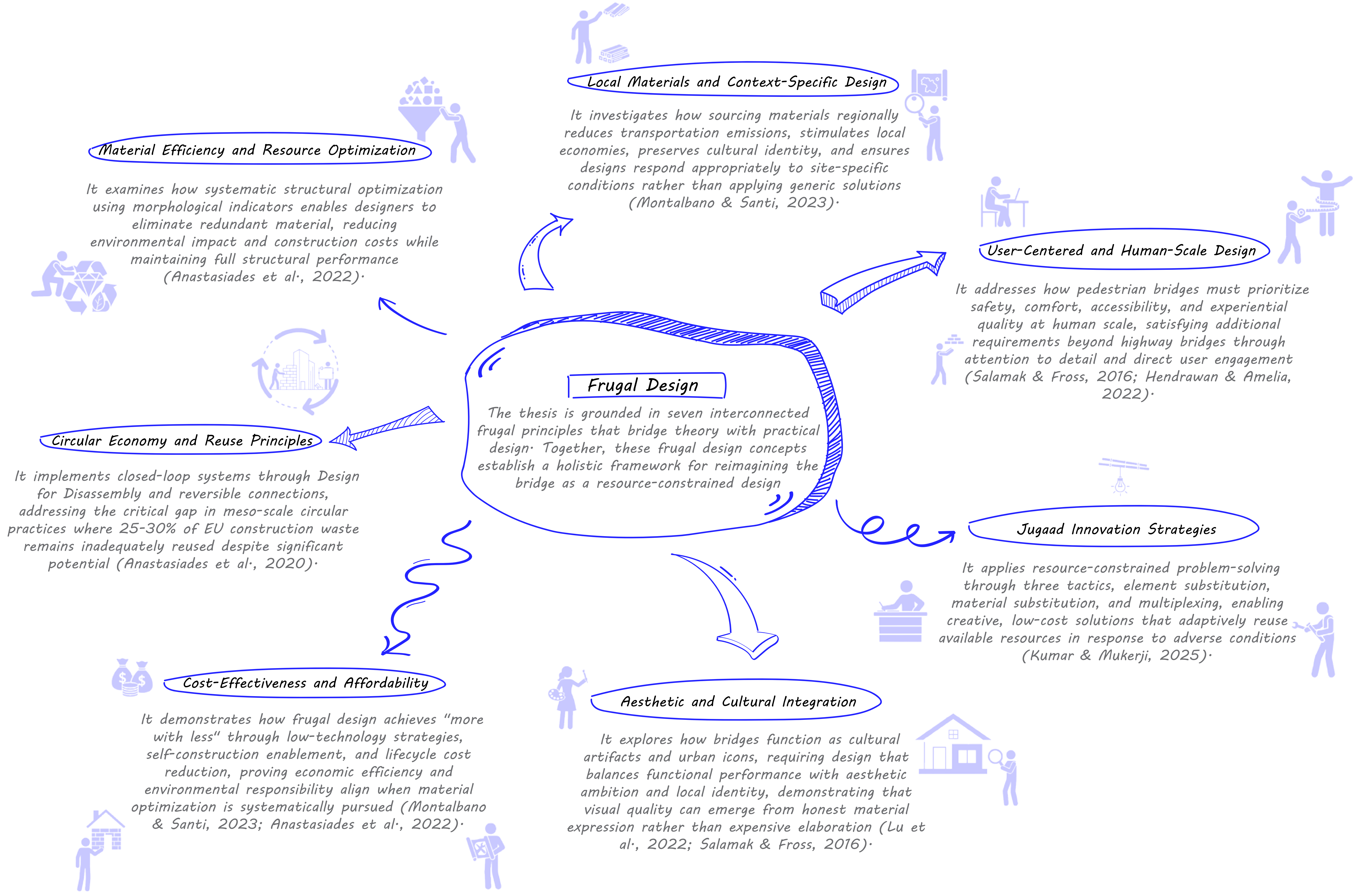
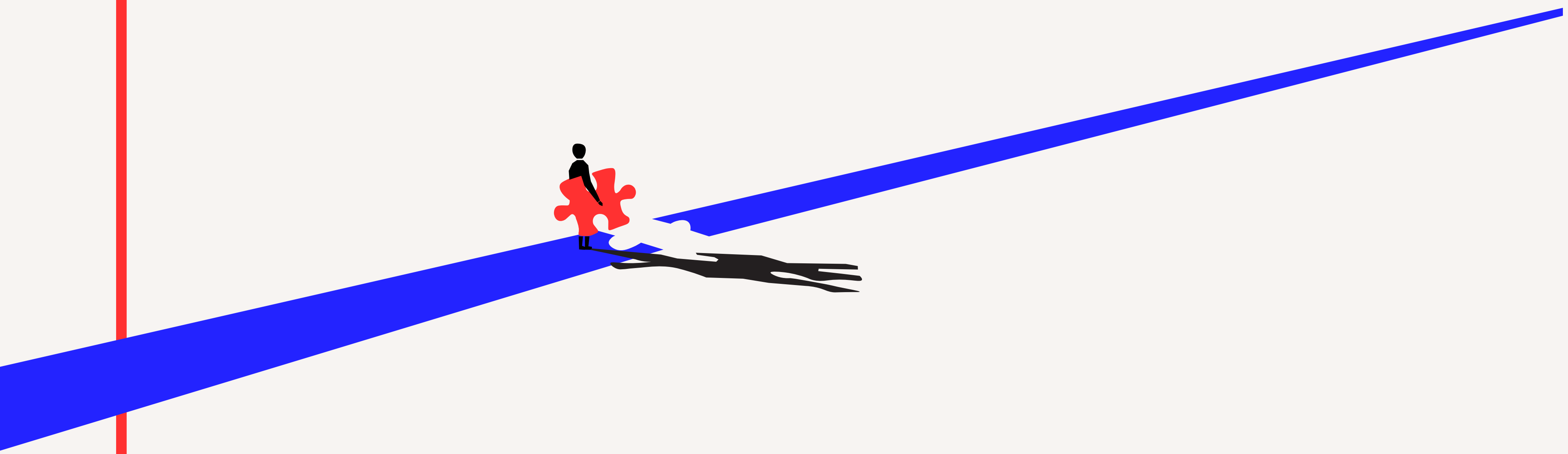


Figure 4: Theoretical framework diagram illustrated by the author



03

- CONTEXT OF THE SITE
- SWOT ANALYSIS
- CRITIQUE OF THE PREVIOUS PROPOSAL
- SITE OBSERVATIONS

CONTEXT OF THE SITE

The project site is located in the northern part of Gothenburg and focuses on a bridge named Ludvig Tingströms gångbro, a pedestrian and cycle bridge that crosses a major transport corridor. The bridge connects the residential neighborhood of Kvillestan with Frihamnen, a waterfront district currently undergoing urban transformation within the Älvstaden development area. Beneath the bridge run several layers of infrastructure including Lundbyleden highway, railway tracks and tram lines which creates a strong physical barrier between the two areas. As a result the bridge plays an important role in maintaining non motorized connectivity across this infrastructure zone as we see in *Figure5*. It's position between an established residential area and an emerging mixed use waterfront district makes it a key link for everyday mobility as well as recreational access to the harbor and surrounding public spaces.

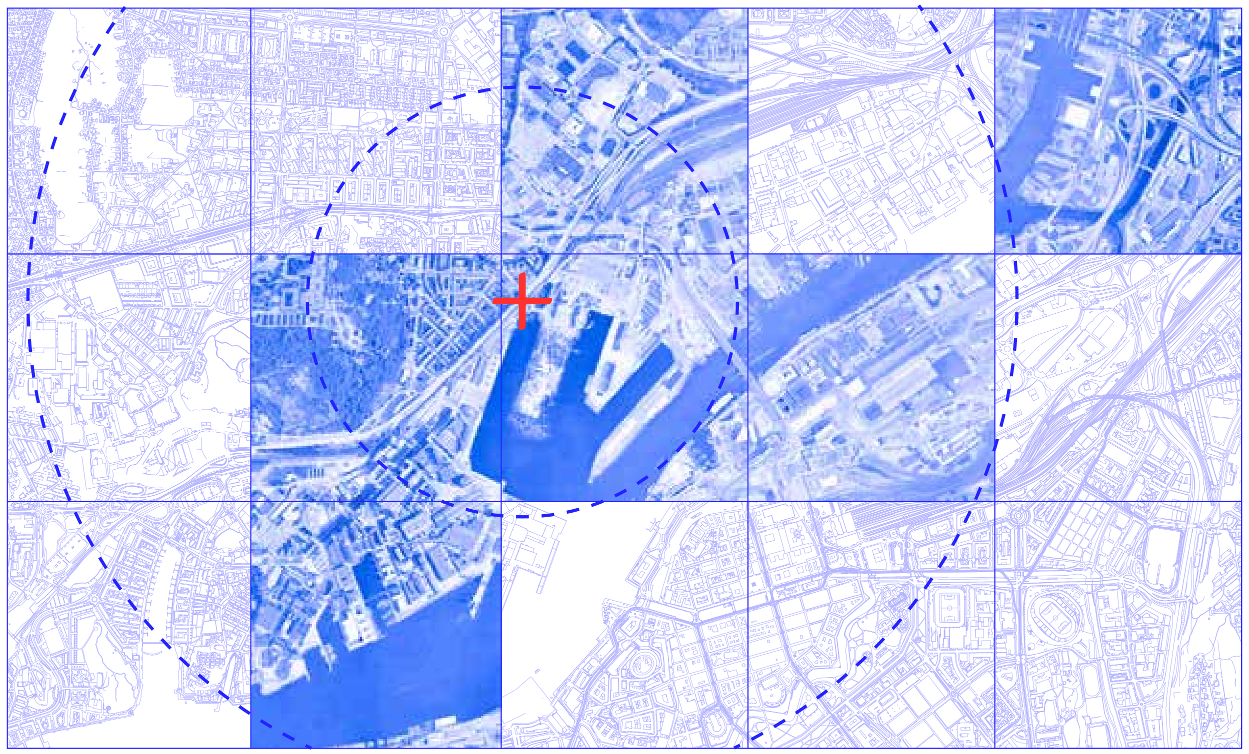


Figure 5: Project location map illustrated by the author

This bridge functions as the only pedestrian and cycling connection between two neighbourhoods with different urban conditions and daily rhythms. On the Kvillestan side the bridge connects to an established residential district with old and new apartment buildings housing families, elderly residents and young professionals. Many residents depend on the crossing to reach workplaces, schools and local services. Daily pedestrian and cycling flows increase during morning and evening commuting hours. Accessibility is particularly important because elderly residents often use the bridge to access healthcare and social services located across the infrastructure corridor.

On the Frihamnen side the bridge links to a district that is currently undergoing transformation from an industrial harbor area to a mixed use urban waterfront. The area increasingly attracts visitors who use the bridge to reach the facilities on this side. Jubileumsparken draws families and recreational users especially during warmer months. Sauna and the outdoor pool area is also famous for their visitors throughout the year. There are also other facilities like the waterfront cabins which are used as the temporary accommodations for expats and the visitors of Gothenburg city. The presence of this accommodations is another strong reason to prove the importance of this bridge connection which makes it possible for the users to go across the neighbourhoods to access the amenities and other services.

There is also a community garden and a kids play area widely used by the residents of the neighbourhood and the city(refer to *Figure 6*).The new tram lines to Lindholmen and other future planned transportaion lines are expected to increase bridge usage as the area becomes more integrated with Gothenburg's public transport network.

The waterfront context creates a diverse group of users in this area. Harbor employees and workers in emerging businesses use the bridge for daily commuting often during early morning or late evening hours. Recreational cyclists, walkers and the visitors use the crossing to access continuous paths along the waterfront. Tourists and occasional visitors also rely on the bridge and benefit from clear wayfinding through the connection. Because of this variety of users and travel patterns the bridge must function safely, comfortably and reliably throughout the day for different groups.

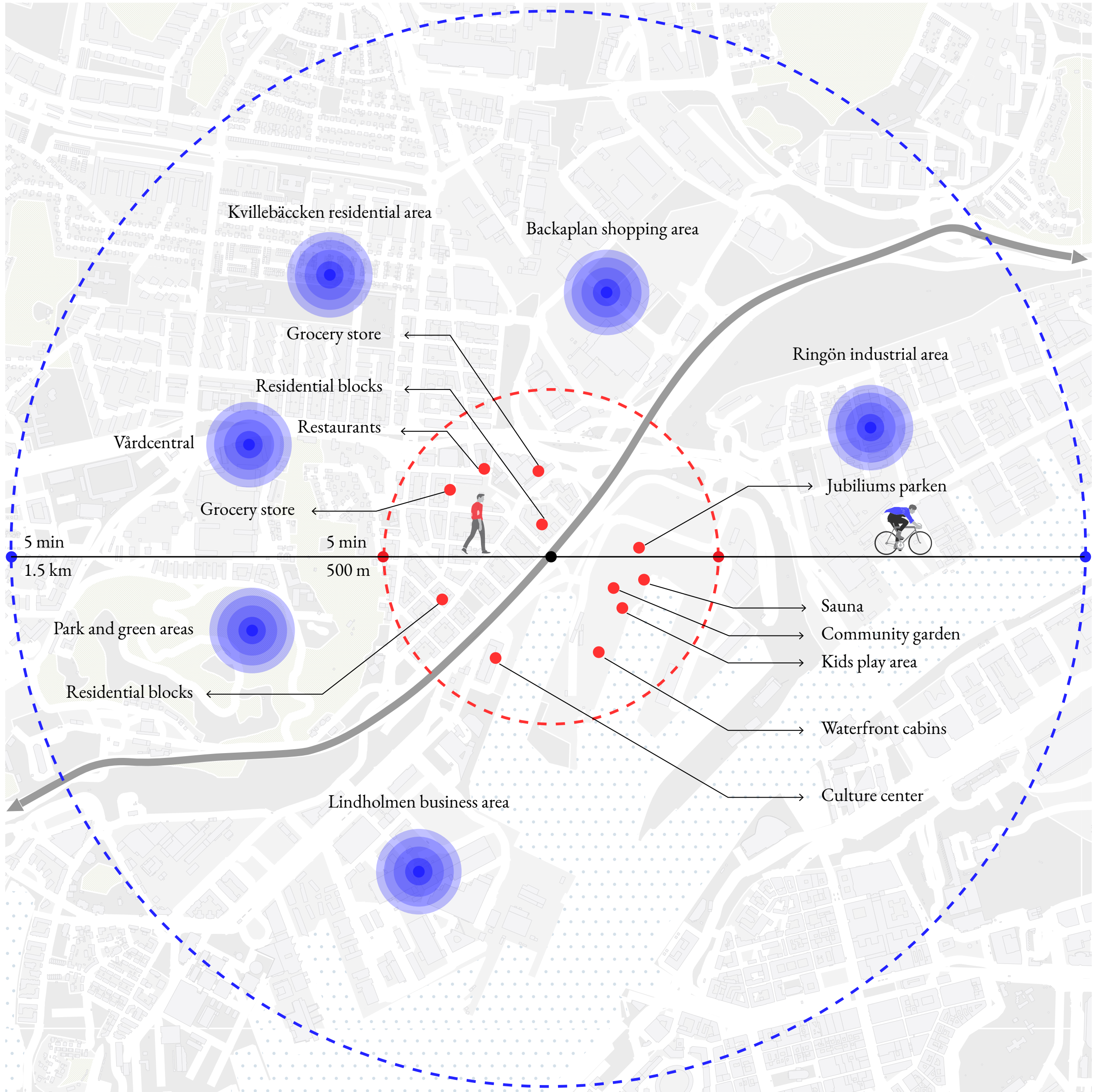
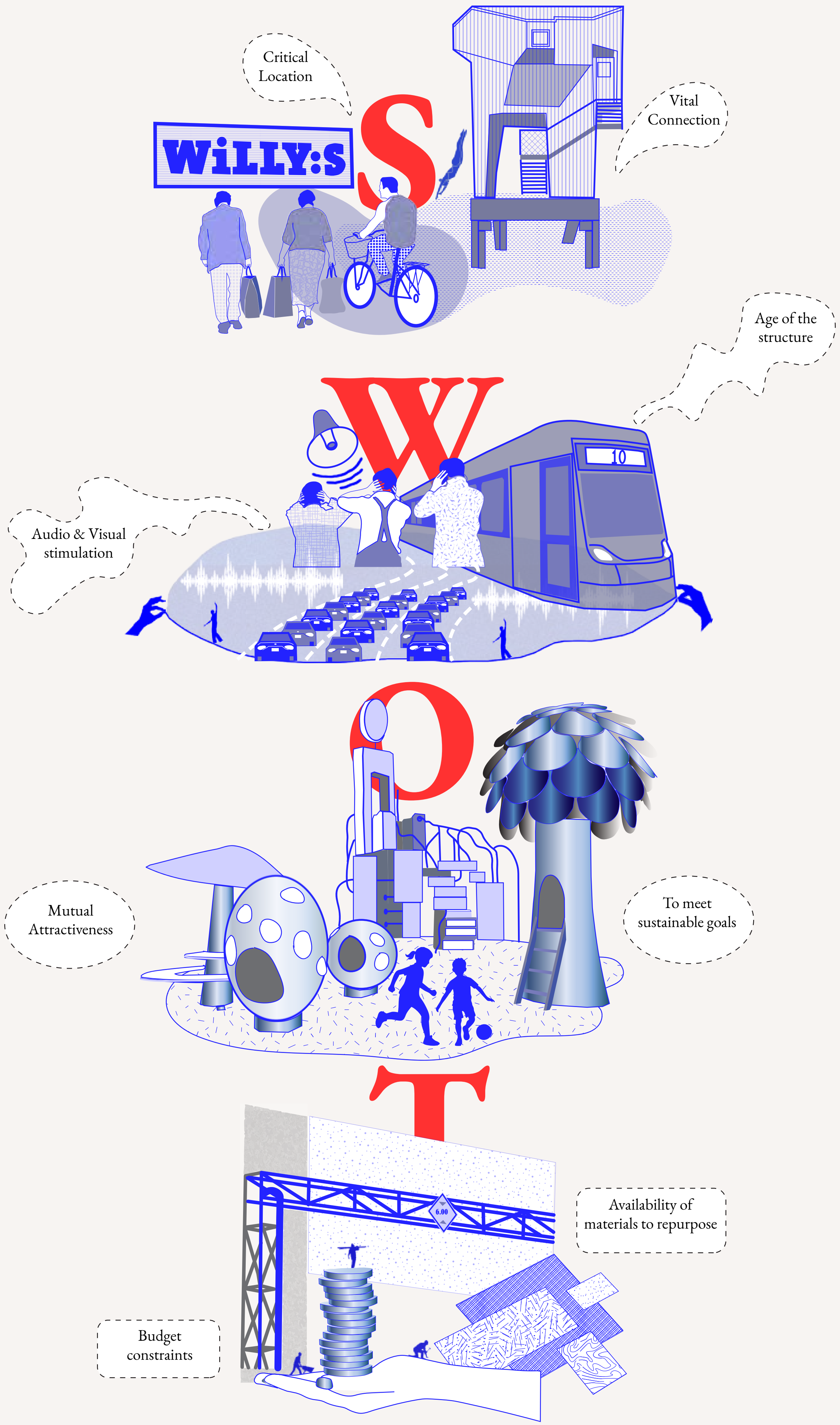


Figure 6: Proximity map for different services illustrated by the author



SWOT ANALYSIS

- The bridge serves as the only pedestrian/cycle connection between Kvillestan and Frihamnen making it a critical piece of local mobility infrastructure.
- Its strategic location between a dense residential area and an emerging recreational and waterfront district.
- The structure is important in everyday movement patterns, ensuring consistent use and relevance.
- The bridge also offers potential long-span crossing that avoids conflicts with vehicular traffic below.

- The structure is perceived as poor in terms of safety and comfort due to noise,
- vibration and visual exposure from highway, tram, and rail infrastructure beneath the bridge.
- It is an aging structure with limited maintenance and leading to negative user experience and lack of aesthetic appeal.
- Uninviting bridge landings that lack spatial quality and programmatic activation.
- The current design does not support inclusive, welcoming or socially engaging public space.

- The redesign allows integration of circular construction and reused materials, aligning with Gothenburg's sustainability goals.
- It has a potential to activate landing zones on both sides through spatial design, seating, lighting, and connection to surrounding amenities.
- It also possesses the ability to address noise mitigation, visibility, and safety through architectural strategies rather than purely technical fixes.
- The bridge can function as a symbolic project demonstrating circular infrastructure and climate-conscious urban design.
- It presents an opportunity to balance density in Kvillebäcken with openness and waterfront access in Frihamnen by strengthening mutual attractiveness.

- One of the threats is the uncertainty regarding the long-term municipal plans for a future replacement bridge may limit investment or implementation.
- The budget constraints could restrict material choice, construction methods and the scale of intervention.
- The structural and regulatory requirements for reused materials may complicate approval processes.
- There is a risk that without careful design the bridge remains perceived solely as transit infrastructure rather than a public space.

THE MANDAWORKS + RUNDQUIST ARKITEKTER PROPOSAL

The proposal presents a comprehensive analysis of the Kvilletråket developed by Mandaworks in collaboration with Rundquist Architects for the City of Gothenburg in May 2019. The proposal was commissioned by the City Planning Office and Trafikverket as part of a broader design assignment addressing social and urban connections in the developing Frihamnen and Backaplan districts. The project sought to create a pedestrian and cycling connection that would serve not merely as infrastructure but as a social bridge capable of healing the urban fabric divided by Lundbyleden highway and Hamnbanan railway tracks.

The proposal envisions a 340 meter-long, 6-9 meter-wide (expanding to 25 meters at balconies) trying to connect Frihamnen and Kvillestan districts within the broader Älvstaden urban healing vision (refer to *Figure 7*).

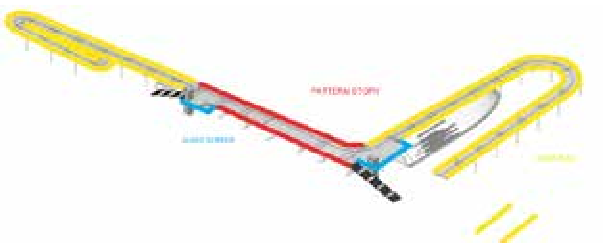


Figure 7: Ramps and rails (Mandaworkd & Rundquist Architects, 2019)

The design is synthesized from two finalists concepts called "The Serpentine" and "The Loop" (refer to *Figure 9*) which organizes the crossing as a journey through five distinct places like Kvillegatan (lush park street), bridge deck with two viewing balconies, Bäckparken (terraced landscape), The Square (transit plaza), and Canal Street (harbour aesthetic) each featuring custom materials, elaborate planting palettes with an extensive landscaping design, sophisticated multi-layer lighting systems (refer to *Figure 8*).

Figure 8: Five places along the Kvilletråket (Mandaworks & Rundquist Architects, 2019)

The structure employs cast-in-place slab-reinforced concrete construction requiring almost fourteen support piers, two elevators, dual staircases, complex foundation work in soft harbour soils and phased implementation coordinated with surrounding development scheduled for 2022 till 2030.

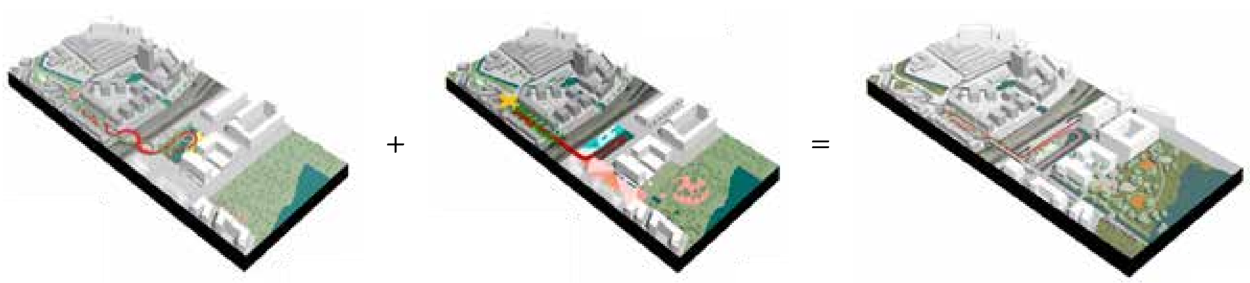
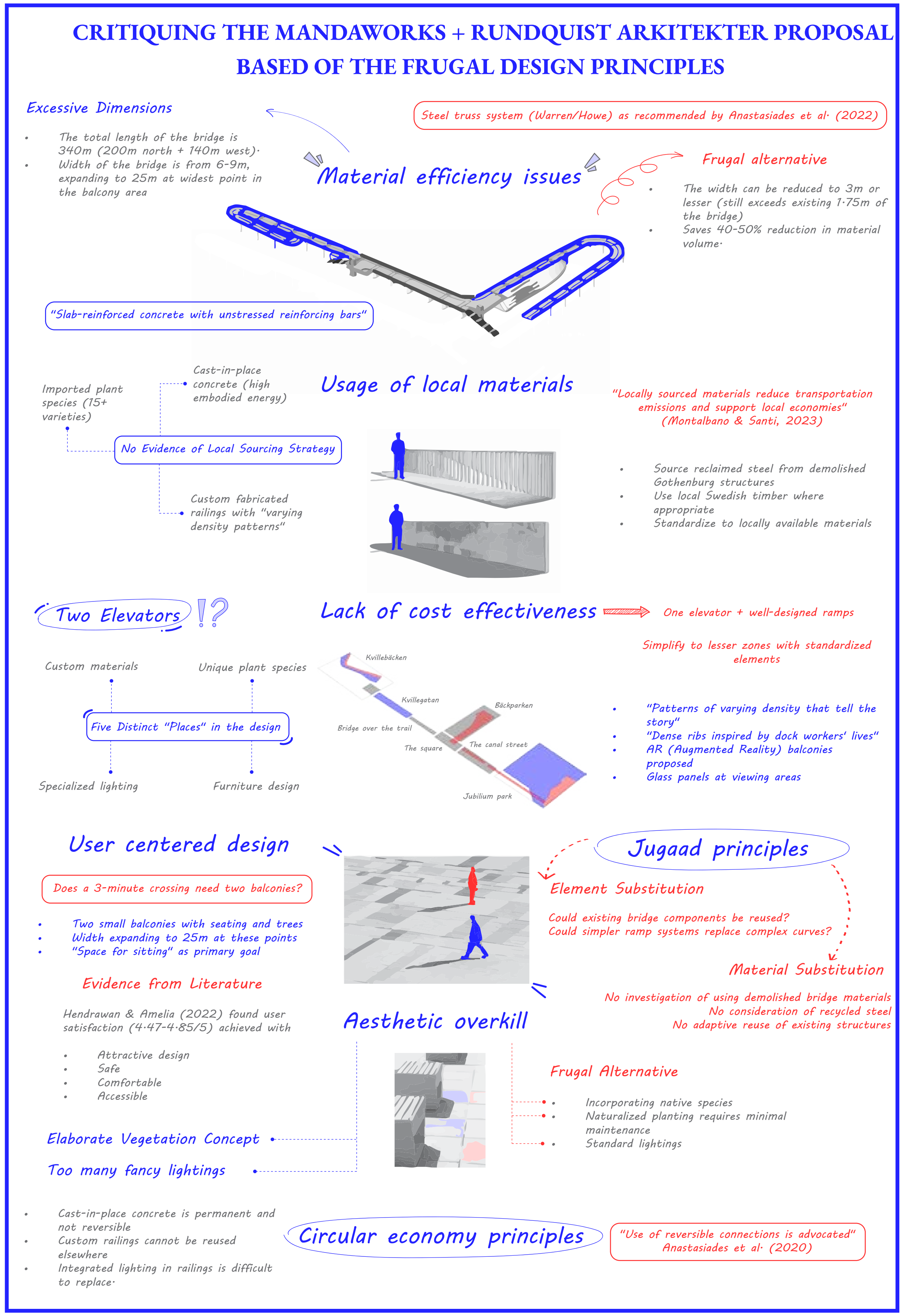


Figure 9: The serpentine + the loop concepts = Kvilletråket (Mandaworks & Rundquist Architects, 2019)



SYNTHESIS OF THE CRITIQUING AND FRUGAL ALTERNATIVE FRAMEWORK

The Mandaworks proposal demonstrated strong knowledge of urban design, landscape architecture and place making. Their idea of a "Kvilletråket" aimed to transform the bridge into a social meeting space rather than only a crossing which is what this project requires. The problem was the mismatch between ambition and the available resources. The project treated the bridge as an architectural landmark instead of an infrastructure that eases the everyday mobility. This eventually led to a long and complex structure with terraces, planting systems, special lighting and custom materials. Environmental features were added on top of an already expensive design.This approach reflects luxury in sustainability. Environmental elements were included, but they depended on complex and costly construction. Such projects are difficult to implement within public infrastructure budgets. Cities must fund many projects at the same time, so solutions that cost far more than standard construction rarely becomes widely adopted.

Research on frugal design suggests a different direction. Montalbano and Santi (2023) argue that sustainability should also reduce cost through material efficiency, local resources and simple construction methods. These principles can also guide in the frugal pedestrian bridge design.

From Ambition Driven to Constraint Driven Design

The focus of the thesis is towards a constraint driven approach. Instead of starting with architectural ambitions, the design will begin with realistic limits such as budget, available materials and maintenance capacity. These constraints can be a driver to innovation as stated by Kumar and Mukerji (2025) in which they show that limited resources often produce creative solutions. The first step is identifying the available materials. This begins from examining the existing structure and assessing its potential for reusability and creating a material inventory. Later continuing the process by scouting for materials from other decommissioned projects. Reclaimed structural steel from demolitions and industrial closures in the Gothenburg region could provide a major resource. Reclaimed steel often costs 30 to 50 percent less than new steel and avoids the energy required for new production. Parts of the existing Ludvig Tingströms bridge could also be reused in this case.

Budget limits are the next parameters that guide the design. Hellberg (2020) reports typical steel bridge costs around 20,000 SEK per square meter in Gothenburg. A bridge about 4 to 5 meters wide and 100 to 120 meters long as suggested by the Mandaworks proposal would cost roughly 8 to 12 million SEK within this benchmark which contradicts from the frugal design principles. Maintenance capacity is also another constraint. Municipal maintenance teams rely on standard equipment and suppliers. The redesign therefore focuses on simple and familiar components.

Strategic Design Decisions

The bridge could follow a direct route straight from point A to B between Kvillestan and Frihamnen. The Mandaworks design reached about 340 meters in total length. A more direct alignment could reduce the bridge to about 100 to 120 meters lowering material use and cost.The width of the bridge chould remain consistent and minimal upto 3 meters. This still allows separated pedestrian and cycle paths while reducing deck area significantly. The structure could use steel trusses instead of reinforced concrete. Research by Anastasiades et al. (2022) shows that truss systems often achieve better material efficiency for pedestrian bridge spans. Trusses can also be prefabricated and assembled quickly.
This system allows integration of reclaimed steel members in the structure. A hybrid structure using both reclaimed and new steel could realistically achieve about 30 to 40 percent reused material.

Spatial Organization

The previous proposal included five designed places along the bridge. Each used different materials and design elements. This increased the cost significantly and also the complexity in the design.
The redesigned bridge will simplify the sequence but still achieving the same sense of attractiveness to the public and maintaining the aesthetics.

Material Strategy

The design will follow the idea of second hand aesthetics described by Montalbano and Santi (2023). Reclaimed steel members shall retain their weathered surfaces instead of being fully refinished. Light cleaning and protective coatings provide durability while keeping the visible history of the materials. The deck surfaces can use simple materials to distinguish the cycle path and the pedestrian path. This avoids complex paving patterns that increase cost and maintenance. Landscaping can be limited to a small number of native species. The lighting can be settled with standard LED pole and strip lights spaced along and throughout the bridge to ensure ample illumination and a sense of safety.

Performance Targets

The redesign will be mindful of the measurements of the structure in terms of its width and length. Bridge width will be either maintained to same as it already exists or slightly widened if it requires. The total length will be maintained only ensuring the end to end connection without exaggerating the structure. These changes will significantly reduce material use.The truss structure could reduce overall in this case resulting in the structural weight by about 30 percent and will also limit the number of support piers to roughly four to six in total. The construction cost should be 20,000 SEK per square meter as mentioned in the extension approval document of the bridge. The new design of the bridge might be around 540 square meters which equals to 10 to 11 million SEK which is far below the estimated cost of the earlier proposal. The environmental impact of the design will also decrease through lower material use and reclaimed steel. The preliminary estimates suggest reductions of about 40 to 60 percent in embodied energy and about 45 to 65 percent in carbon emissions.

Broader Contribution

This thesis serves as a test case for frugal infrastructure design and contributes to bigger discussions on sustainable and circular construction in mobility infrastructure. While circular economy strategies are often applied to buildings this exploration demonstrates how similar principles can guide pedestrian bridge design through material efficiency, reclaimed structural elements and design for assembly and disassembly. The project also shows how resource constraints such as limited budgets, available materials and its reuse potential can function as productive design drivers rather than barriers. By linking design decisions with measurable targets for cost, material use and environmental impact the research illustrates how research by design can translate abstract sustainability principles into practical infrastructure strategies. These findings points out that pedestrian/cycle bridges can achieve strong functional quality, lesser environmental impact and reduced construction costs through simple design and efficient material use which offers a practical model for municipalities seeking affordable approaches to sustainable infrastructure.

SITE OBSERVATIONS

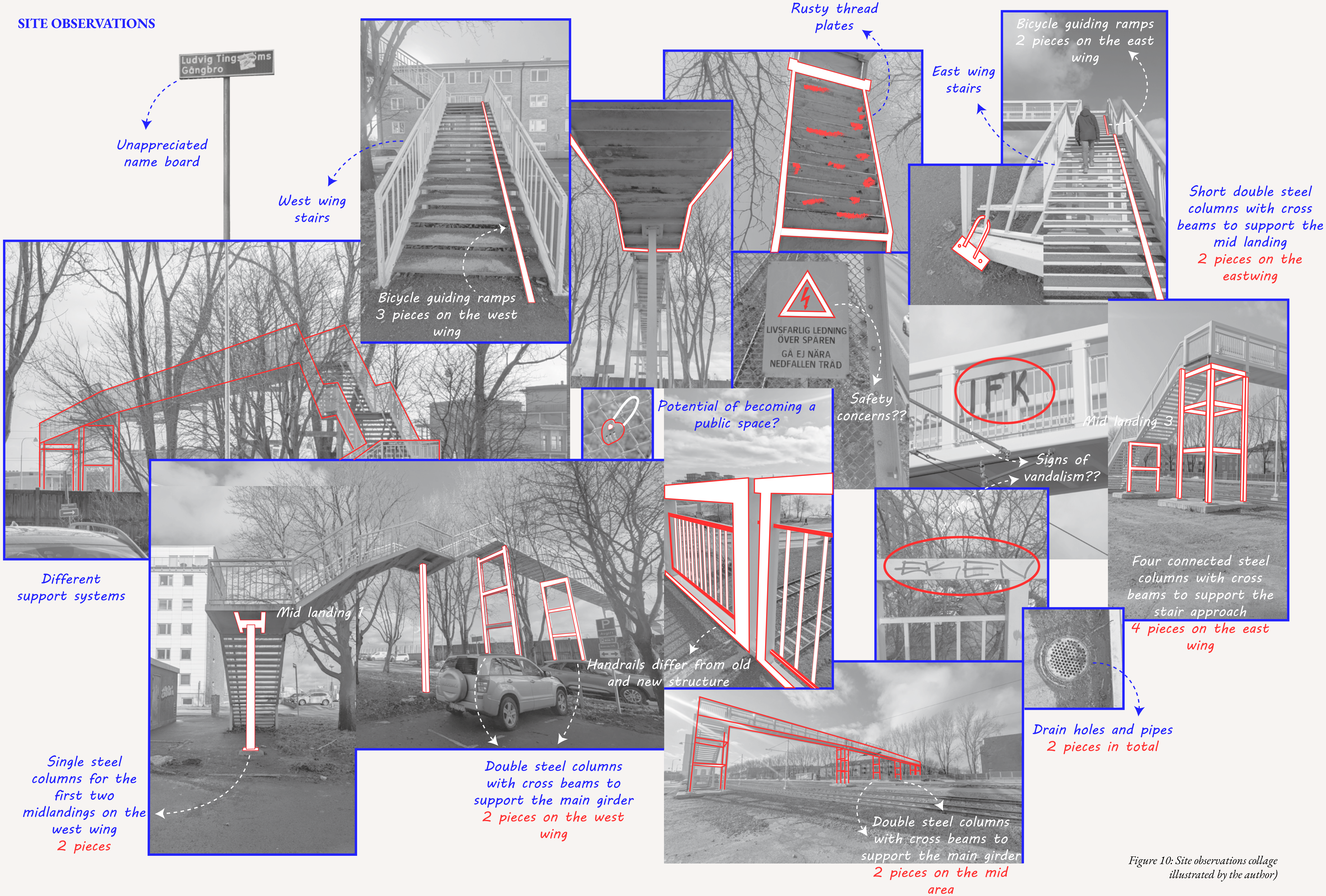


Figure 10: Site observations collage illustrated by the author)

USER OBSERVATIONS

As a user, the experience of crossing the bridge shows several spatial and functional concerns that extend beyond its basic role as an infrastructural element. The existing Ludvig Tingströms bridge has undergone certain changes over time with its original length of approximately 64 meters which was recently extended by an additional 16 meters to accommodate new tram connections toward Lindholmen (refer to *Figure 11*). This development highlights the bridge's role within the city, yet it also exposes inconsistencies in performance and quality. The older section of the structure shows clear signs of aging and requires maintenance, while the overall crossing experience remains long and monotonous. Rather than replacing the bridge entirely, these conditions suggest the value of refurbishing and adapting the existing structure, building upon what is already in place while addressing its current shortcomings.

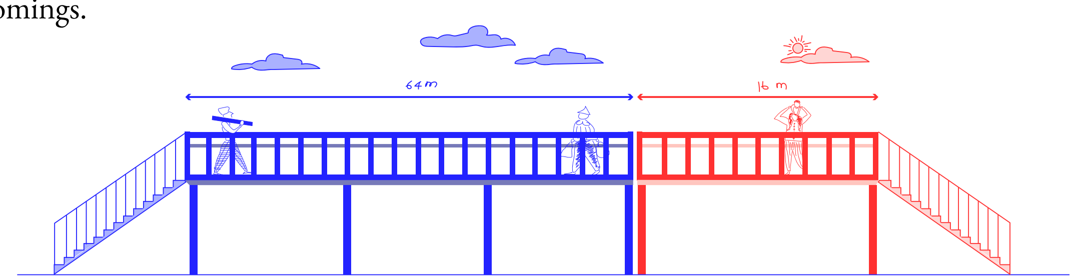


Figure 11: The old and the new structure

The observations from on-site indicates several critical areas for improvement. One of the most immediate needs shown is the provision of bicycle parking at both ends of the bridge. Given the high volume of cyclists using the crossing as part of their daily commute, the absence of secure and accessible parking reduces its overall functionality. At the Kvillestan landing, densely covered trees creates a shaded and pleasant environment, yet it also limits visibility and raises concerns related to safety and surveillance. This condition highlights the need for carefully integrated lighting that enhances visibility without compromising the existing character of space (refer to *Figure 13*).

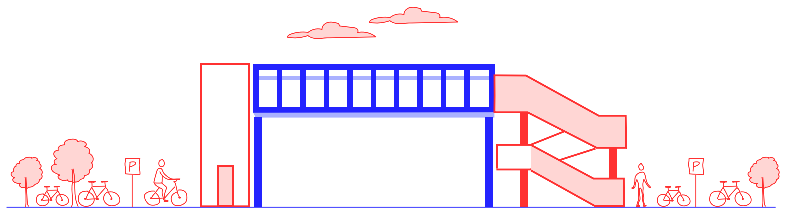


Figure 12: The need for accessibility

Accessibility comes as another key issue, particularly in relation to the current stair-based crossing. The existing provision for cyclists, in the form of a narrow track along the stairs proves inadequate. Observations of children struggling to push their bicycles emphasize the lack of inclusivity in the current design. This suggests the need for a more universally accessible solution such as a continuous ramp system or improved circulation strategy that accommodates users of all ages and abilities (refer to *Figure 12*).

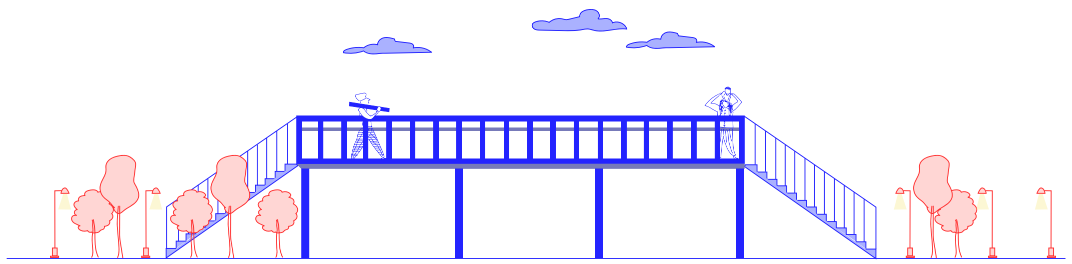


Figure 13: The need for light fixtures

At the same time, the bridge indicates potential as a place of engagement rather than just a passage. The presence of photographers capturing views from the structure indicates an existing appreciation of its visual vantage point. This suggests that the bridge could be reimagined to include designated viewing areas, allowing users to pause and engage with the surrounding cityscape (refer to *Figure 14*). Similarly, the midsection of the bridge is experienced as a high degree of exposure both visually, sensorily and in terms of weather conditions. Introducing a shaded pavilion in this location could provide protection from sun, wind and rain while also creating a space for rest and interaction (refer to *Figure 15*).

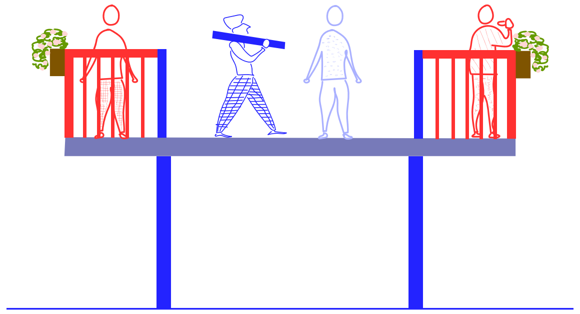


Figure 14: The placement of view decks

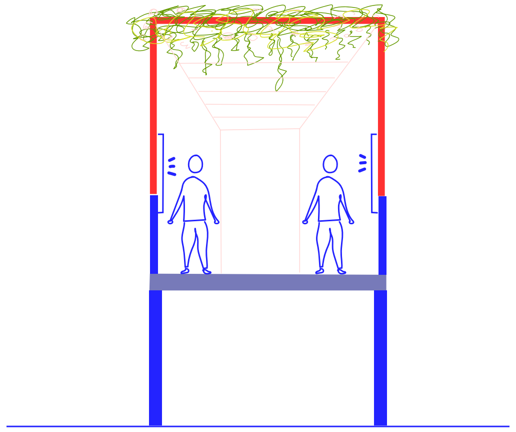


Figure 15: The placement of pavilion

Finally, the current narrow width of the bridge is inadequate for a comfortable movement. While it functions as a route, it lacks the spatial generosity required to operate as a public space. A moderate widening of the structure could improve both accessibility and user comfort, allowing for clearer separation between pedestrians and cyclists and enabling moments of pause without obstructing movement (refer to *Figure 16*). Through these observations, it becomes evident that the bridge holds the potential to evolve into a more inclusive, comfortable and socially active space.

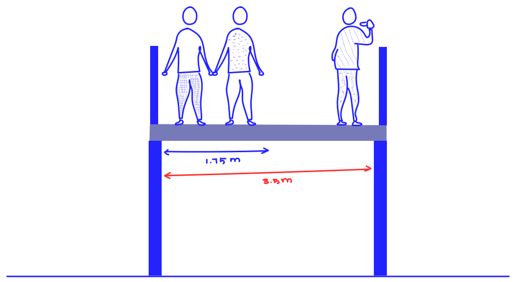


Figure 16: The bridge extension

04

- EXISTING MATERIAL INVENTORY
- SITE CONSIDERATIONS
- STRUCTURAL CONSIDERATIONS
- DESIGN ITERATION

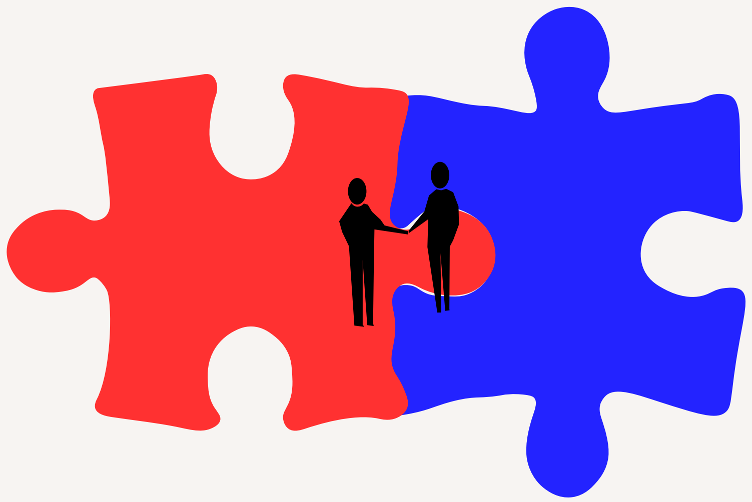
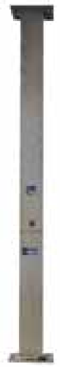
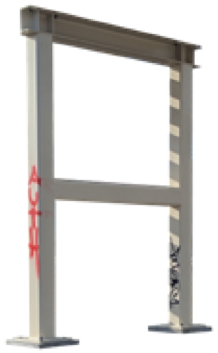
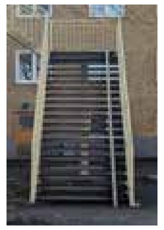
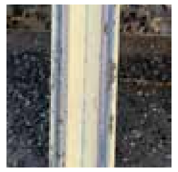
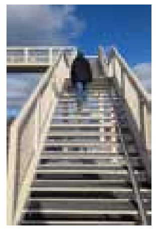


Figure 17: Material matrix

EXISTING MATERIAL INVENTORY

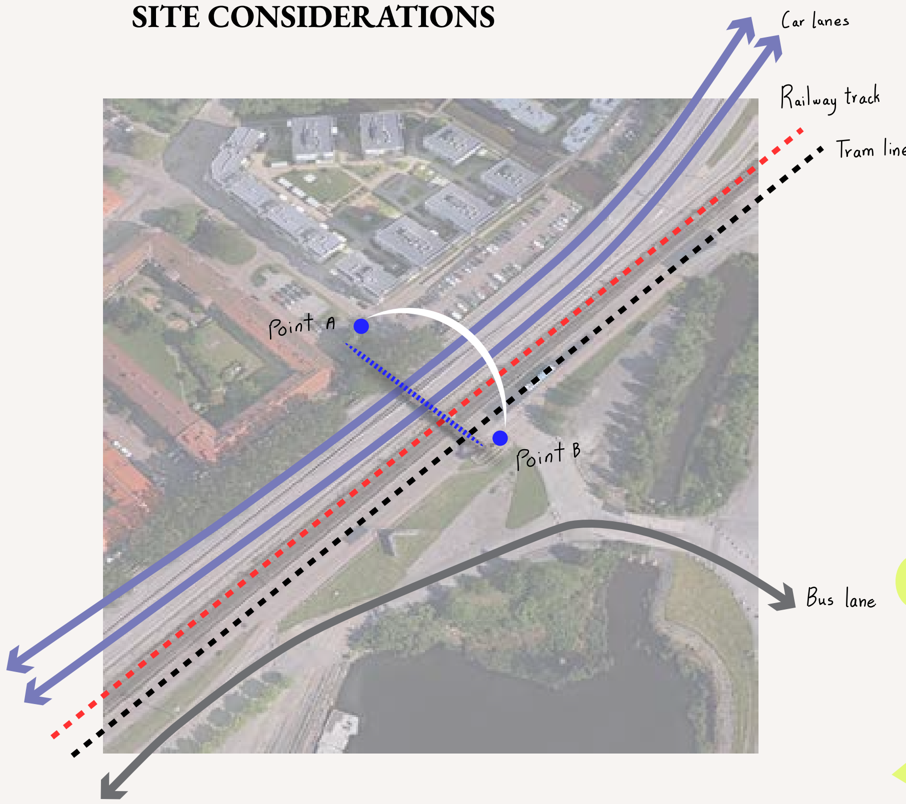
Material	Evidence in photos	Location	Condition observations	Qunatity and units	Reuse potential
Single steel column(painted)		Supports two mid landings on the west wing	 Cream/beige painted coating, visible rust at coating failures, bolted connections	2 pcs	Can be reused Must be treated to remove the rust and other formations on the surface
Double steel column with cross beams (painted)		6 pcs supporting the main girders and 1 pc supporting the mid landing on the east wing	Varied in height and thickness. Seemingly in good condition. 2 pcs close to each other in order to the connection of the new and the old structure.	7 pcs	Can be reused but maintenance action might be required
Four steel column withinterconnected cross beams (painted)		Positioned on the east wing connecting the main girder to the stairs.	The interconnected support is witheld by a solid concrete footing as a base with proper reinforcement.	1 pc	Can be reused The extension is a newly made so it still can be retained and used in a long term
Concrete		Column bases, foundations and footings	Exposed at ground level and appears to be sound	11 pcs	Can be reused
Asphalt\Bitumen		On surfaces over the steel plates (stair threads)	  Worn with puddles and debris	Sq.m	Maintenance required. Uneven and damaged due to weather conditions

Note : The reuse potential of the listed materials is based on the author's assessment and not based on any certified technical verification. The reuse potential of materials is assessed to understand their capacity for reusing them in various applications which supports the circular design strategy.

Material	Evidence in photos	Location	Condition observations	Estimated quantity	Reuse potential
Drain hole and Drain pipes		Placed in both east and west ends of the bridge	Good in condition and functional	2 pcs	Can be reused since its functional
Cycle rolling ramp Type 1		 West wing (Kvillestan side)	Old, functional and smooth	3 pcs	Can be reused
Cycle rolling ramp Type 2		 East wing (Frihamnen side)	New, functional and corrugated	2 pcs	Can be reused
Steel stair thread plates		Flights on both the West and the East wings	 Thread plates on the west wing are old and the ones on the east wing are apparently new	77 pcs in total 44 on the west wing 33 on the east wing	Can be reused Must be treated to remove the rust and other formations on the surface
Aluminium (Chequered plate)		Stair treads, landing surfaces	Diamond plate pattern, good condition, mechanical fastening with screws	1 pc	Can be reused

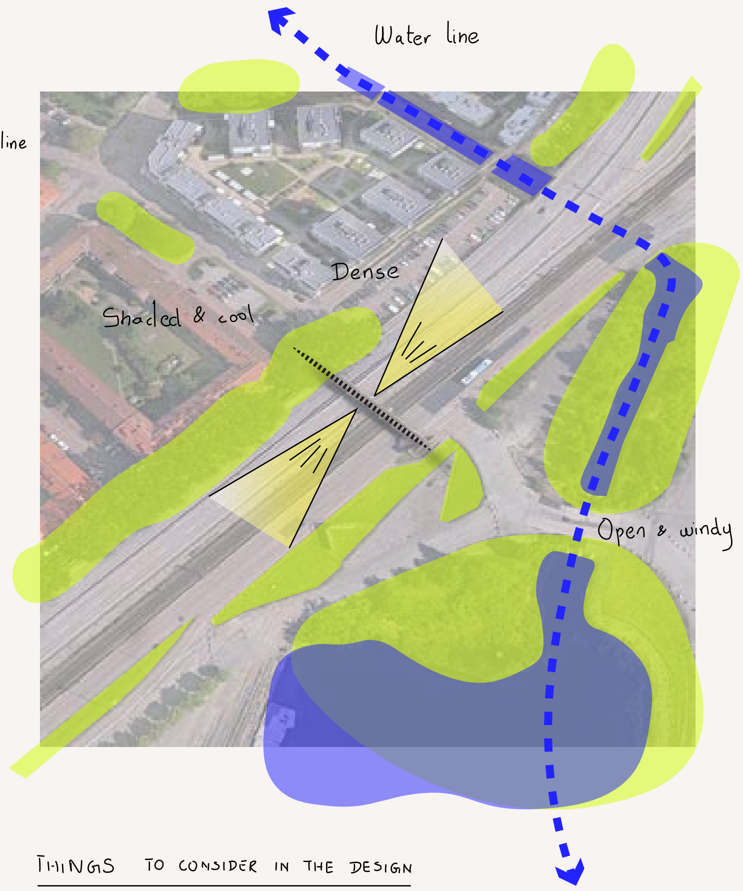
Note : The reuse potential of the listed materials is based on the author's assessment and not based on any certified technical verification. The reuse potential of materials is assessed to understand their capacity for reusing them in various applications which supports the circular design strategy.

SITE CONSIDERATIONS



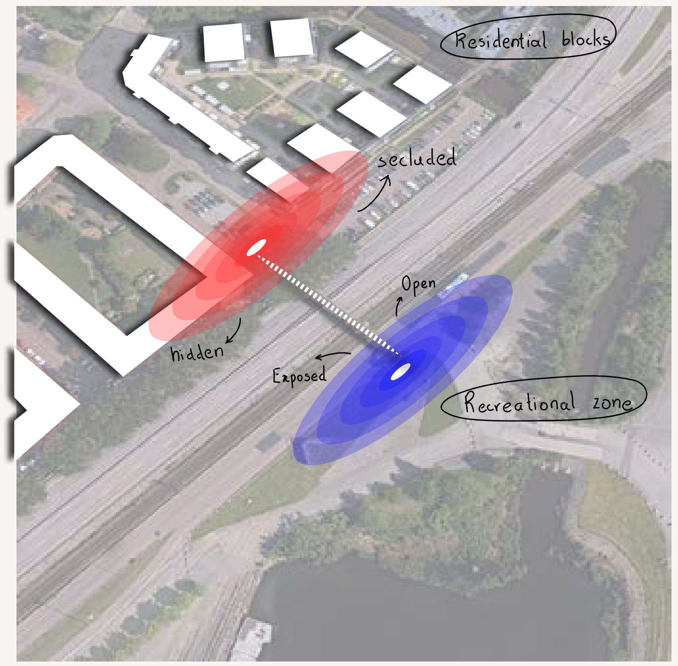
THINGS TO CONSIDER IN THE DESIGN

- Heavy traffic
- Increased exposure to sound and vibrations
- Openess of the bridge



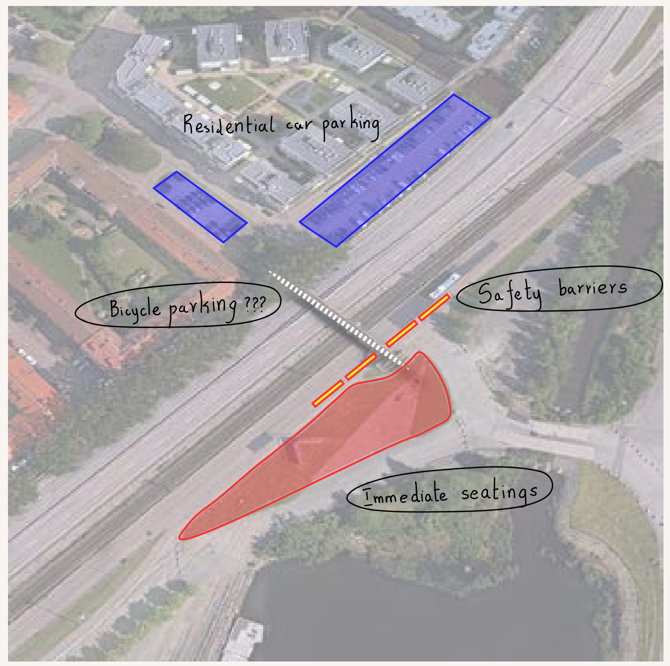
THINGS TO CONSIDER IN THE DESIGN

- Surrounding waterbody
- Vegetation and landscapes
- Views and vistas from the bridge



THINGS TO CONSIDER IN THE DESIGN

- Safety and security
- Create good visibility & lighting
- Feeling safe throughout the day



THINGS TO CONSIDER IN THE DESIGN

- Finding more potential ideas to incorporate
- Additional elements
- Seating & landscaping

Figure 18: Site considerations illustrated by the author

STRUCTURAL CONSIDERATIONS

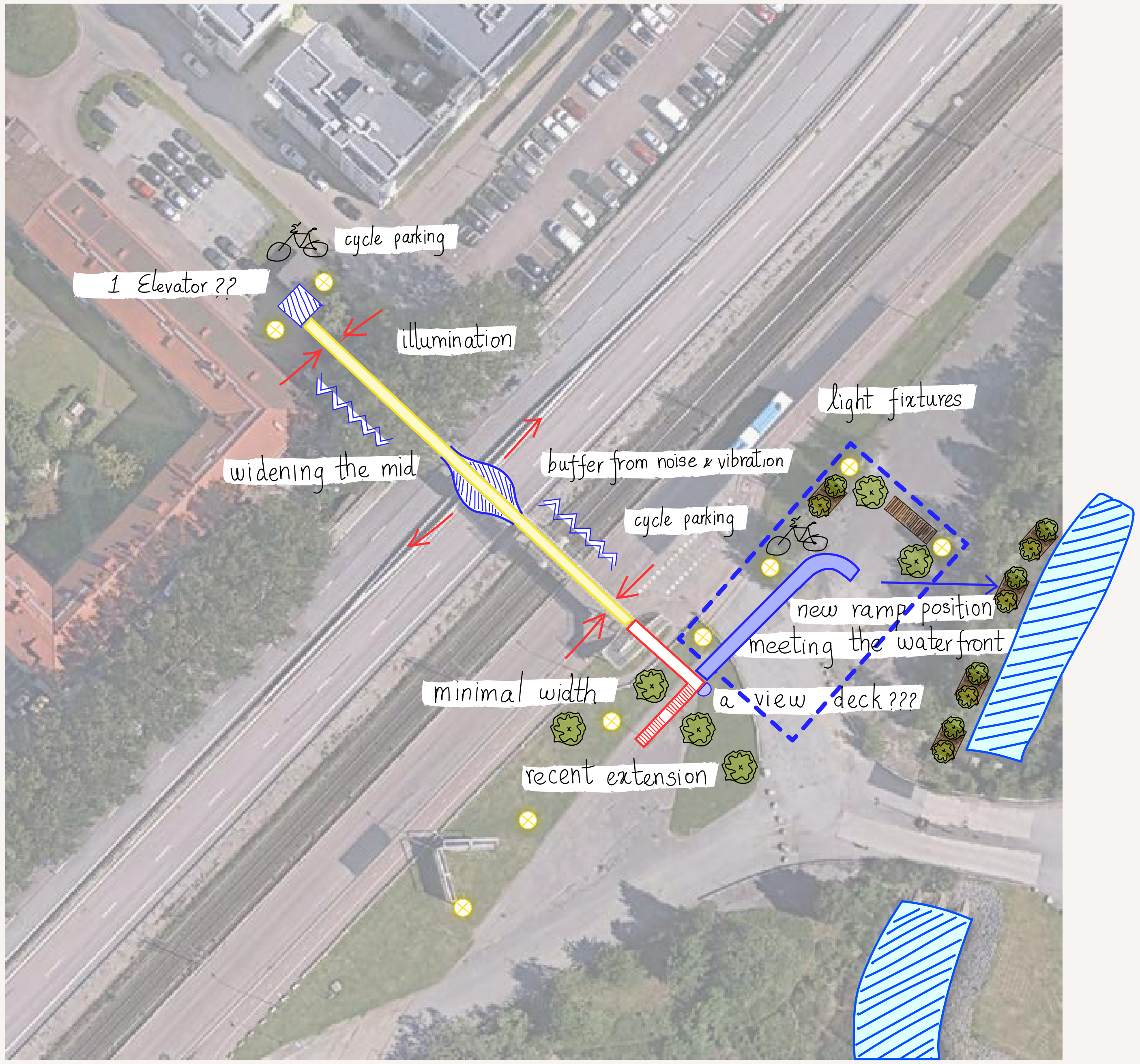


Figure 19: Structural considerations illustrated by the author

There is a variety of structural considerations to be made to begin with the design of the bridge. The initial distinction is between the neighbourhoods and their spatial qualities. The Kvillestan region is tightly packed with the residential colonies allowing a limited space to work on the around the west wing landing of the bridge. Still there are some necessities that can be provided like a space for bicycle parking and an elevator to meet the requirements of the users. The landing is also densely covered by trees hindering the visibility which might arise the question of safety. Lighting fixtures must be provided to tackle the existing conditions. The heavy traffic beneath the bridge creates excessive vibration to the structure which can be minimised by providing an extra buffer material over the surface of the main girder. The bridge is widely used as a view point for the visitors in the area which creates an opportunity to expand the width of the bridge at a mid point to act as a view deck. This can also act as a resting point to stop and stare. The east wing will comprise a set of stairs on one side and a ramp on the other side to ease the movement. Frihamnen side provides us with ample space for a desirable landing area. It also meets the waterfront to create a proper public space with landscaping and seating areas also with enough bicycle parking and lighting to support the temporal nature of the public movement.The connection also ensures a clear height of 6 meters to let the public transportation beneath to function smoothly without hindrance (refer to 18 and 19).

DESIGN ITERATION

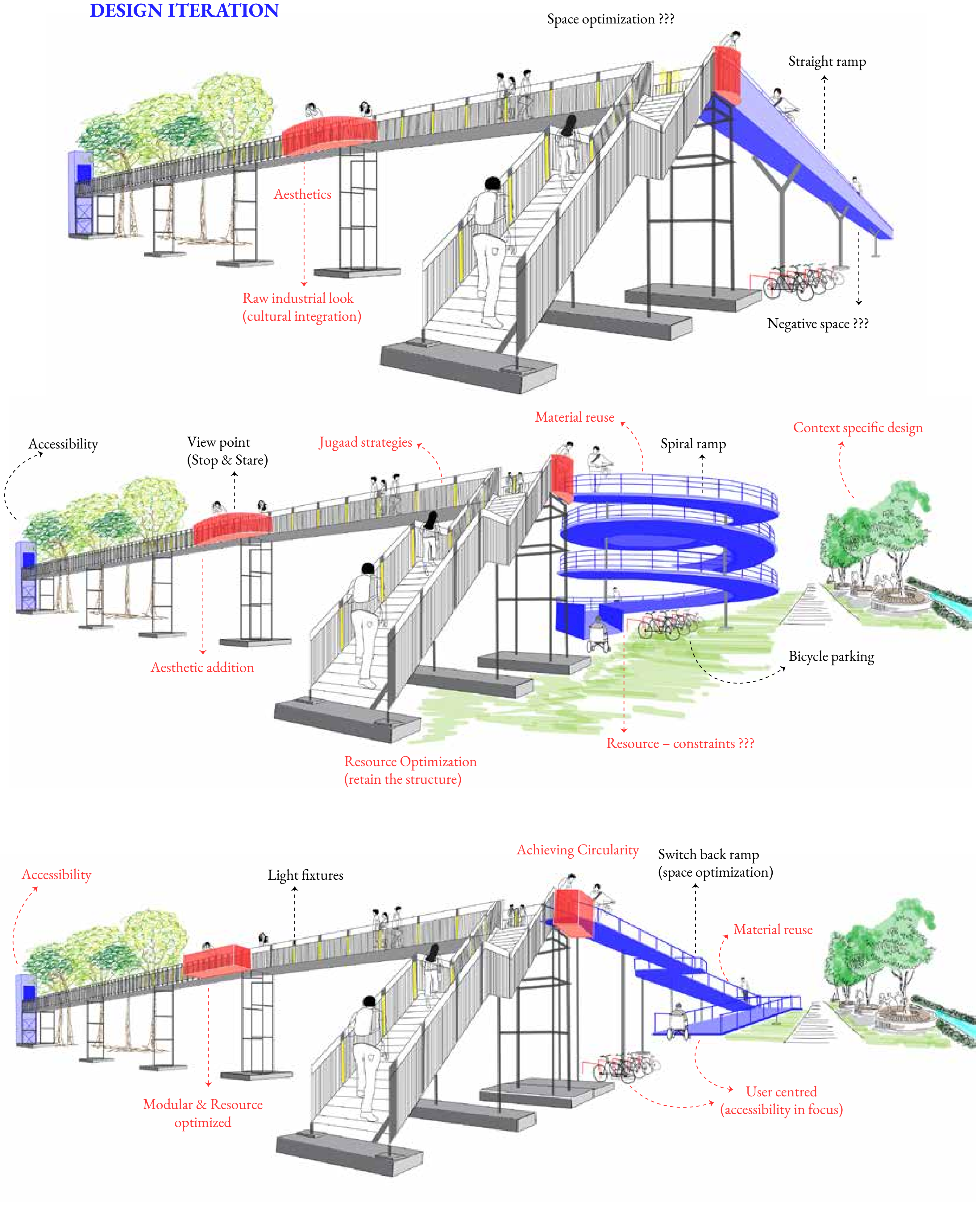
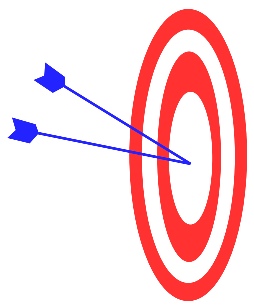


Figure 20: Design iterations illustrated by the author

05

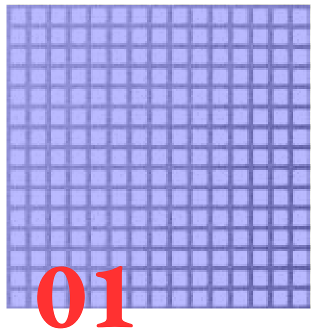
- HARVEST MAPPING
- ADDITIONAL MATERIAL INVENTORY
- SITE PLAN
- VIEWS

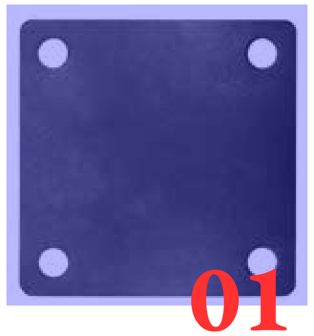


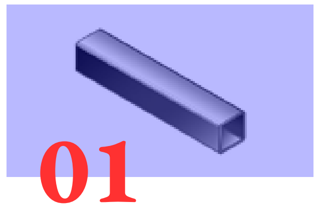
HARVEST MAPPING

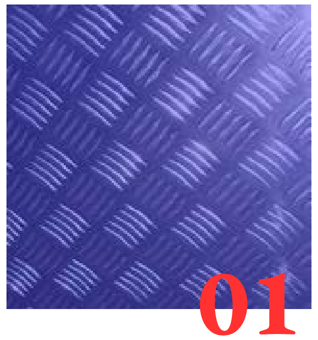
This mapping is done to efficiently explain how the material procurement is done in a frugal way. The map shows that most of the procurement is made within a certain zone from the site to address the transportation costs and its related emissions

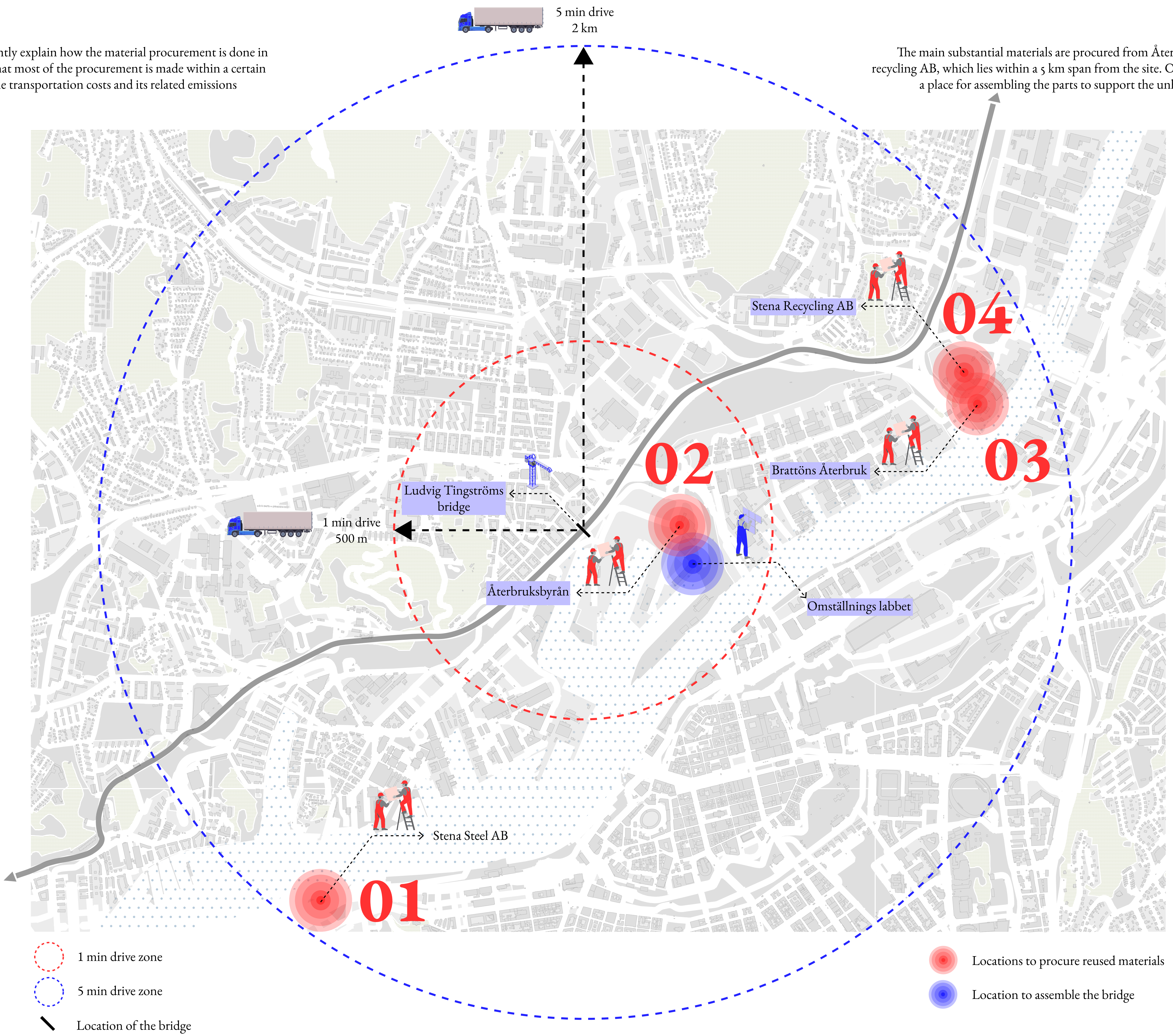
The main substantial materials are procured from Återbruksbyrån, Stena steel AB and Stena recycling AB, which lies within a 5 km span from the site. Omställningslabbet is recommended as a place for assembling the parts to support the unhindered movement of lundybyleden.

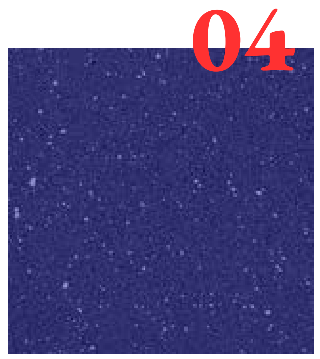


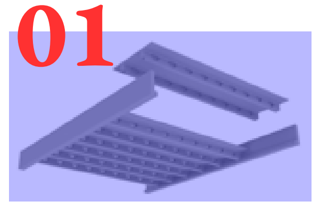


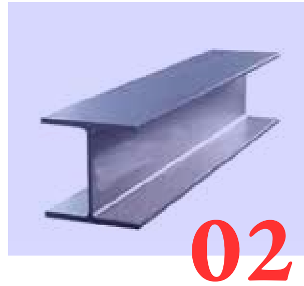












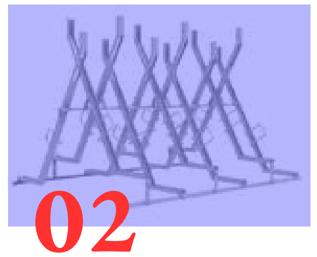
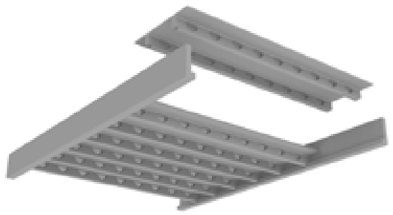
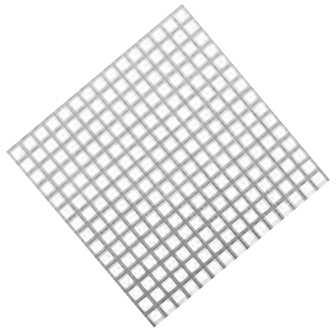
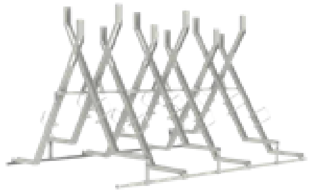


Figure 21: Harvest mapping

ADDITIONAL MATERIAL INVENTORY

Material	Image of the material	Purpose / Properties	Source / Availability / Longevity	Quantity and units	Reuse / Recycle potential	Listed price SEK	Estimated cost
Primary steel beam		**Purpose :** Primary load bearing structural element. **Properties :** Durable and suitable for medium span applications.	**Source** : Commonly sourced from demolished bridges, industrial buildings and structural frames. **Availability** : Stena steel AB **Longevity** : Lasts 30 to 50 years	Required quantity = 16 pcs (bridge + ramp)	High reuse potential if beams are not deformed or heavily corroded. Recyclability is high	31,70 sek/kg	68,200 sek
Secondary steel joists		**Purpose :** To support the deck surface and transfer loads to primary beams. **Properties :** Lightweight, modular and easy to space regularly.	**Availability** : Stena steel AB **Longevity** : Lasts 25 to 40 years	Required quantity = 272 pcs (bridge+ramp+-deck)	High reuse potential if beams are not deformed or heavily corroded. Recyclability is high	32 sek/pc	2,900 sek
Steel column		**Purpose :** Primary vertical load bearing element that transfers loads from beams to the foundation. **Properties :** High strength and stiffness, suitable for exposed structural applications.	**Source** : Commonly sourced from demolished buildings, industrial structures and infrastructure frames. **Availability** : Stena steel AB **Longevity** : Lasts 30 to 50 years	27 pcs (includes the widened bridge + ramp structure)	High reuse potential if columns are not deformed or heavily corroded Easy to cut, resize and reuse	9 798,80 sek/m	1,587,400 sek
Stainless steel tube rod (Ramp railing verticalsupport)		**Purpose :** Ramp railing vertical support **Properties :** Performs well in outdoor environments and has strong resistance to corrosion.	**Source** : Can be recovered from demolished buildings, old bridges or refurbished public spaces. **Availability** : Stena steel AB **Longevity** : Lasts 30 to 50 years	Required quantity = 61 pcs	High reuse potential Stainless steel is fully recyclable without significant loss of quality	124,90 sek/m	22,856sek
Stainless steel tube rod (Ramp top handtrail)		**Purpose :** Ramp top handrail **Properties :** Performs well in outdoor environments and has strong resistance to corrosion.	**Source** : Can be recovered from demolished buildings, old bridges or refurbished public spaces. **Availability** : Stena steel AB **Longevity** : Lasts 30 to 50 years	Required length = 148m Required quantity = 25 pcs	High reuse potential Stainless steel is fully recyclable without significant loss of quality	124,90 sek/m	18,735 sek

Material	Image of the material	Purpose / Properties	Source / Availability / Longevity	Quantity and units	Reuse / Recycle potential	Listed price SEK	Estimated cost
Aluminium chequered plate (Bridge+deck+ramp)		**Purpose :** Used in the ramps and as deck plates as a steady surface to aid the movement. **Properties :** Durable and light in weight, strong resistance to corrosion, especially in outdoor and coastal environments.	**Source** : Can be recovered from decommissioned infrastructure, warehouses or transport equipment. **Availability** : Stena steel AB **Longevity** : Lasts 25 to 40 years	39 pcs (4m x 2m)	High reuse potential Easy to cut, resize and refix	115,70 sek/kg	541,500 sek
EPDM rubber sheet		**Purpose :** To treat the walking surface by minimizing its vibration. **Properties :** Suitable for outdoor usage inspite of extreme temperature and climatic conditions. Permeable surface and waterproof	**Source** : Recycled rubber from industrial waste or tyres **Availability** : Stena recycling AB **Longevity** : Lasts 15 to 25 years	Total surface (Bridge + Ramp) 478 sq.m	Low to moderate Recyclability is high	Approx 250 sek/ssq.m	119,500 sek
Perforated sheet (railing)		**Purpose :** Ramp railing / fall protection **Properties :** Allows air, light and visibility through the railing. Contributes to the industrial aesthetic of the bridge.	**Source** : Can be sourced from industrial walkways, stair guards, façade panels. **Availability** : Stena steel AB **Longevity** : Lasting life span with proper maintenance.	68 pcs (Ramp + deck)	Moderate to high reuse potential if panels are not heavily bent or damaged. Very high recyclability	2 607,80 sek/m	177,300 sek
Concrete footing (Foundation)		**Purpose :** Transfers loads from columns to the ground. **Properties :** High compressive strength and typically cast in place pad footing.	**Source** : Usually newly cast on site. In this case reclaimed concrete aggregates can be used **Availability** : Swerock AB **Longevity** : Lasts 50 to 100 years	Required quantity = Approx 109.26 sq.m	Low reuse potential. Can be crushed and recycled as aggregate. High durability but limited direct reuse.	Approx 300 sek/sq.m	32,700 sek
Base plate (column to foundation connection)		**Purpose :** Steel plate that connects column to concrete foundation. Distributes load and anchors column using bolts.	**Availability** : Stena steel AB **Longevity** : Lasts 30 to 50 years	28 plates	Moderate reuse potential if not deformed. Very high recyclability.	27.70 sek/kg	30,400 sek

Material	Image of the material	Purpose / Properties	Source / Availability / Longevity	Quantity and units	Reuse / Recycle potential	Listed price SEK	Estimated cost
Anchor bolts and connections		**Purpose :** Fixes column base plate to foundation and connects structural members. Transfers tension and shear forces. **Properties :** High strength steel bolts.	**Source** : Widely used new. Rarely reused due to safety and certification. **Longevity** : Long lifespan if protected from corrosion.	Approx 108	Low reuse potential High recyclability	250 sek	227,000 sek
Bicycle parking		**Purpose :** The site observation conveyed a need for bicycle parking since the bridge is connecting a residential neighbourhood with the recreational neighbourhood.	**Availability** : Stena recycling AB **Longevity** : Lasts 15 to 30 years	2 pcs (one pc - 6 cycles on each landing)	High reuse potential Can be recycled (Melted and reprocessed into new products)	1875 sek/pc	3750 sek
Light fixtures		**Purpose :** For proper illumination and spatial legibility **Properties :** LED (yellow)	**Source** : Procured from Industrial sites **Availability** : Återbruksbyrån **Longevity** : Lasts 20 to 30 years	Required quantity = 63 pcs (bridge + ramp + stairs)	Moderate reuse potential if in working condition. Certain parts can be recycled.	625 sek/pc	39,375 sek
Reclaimed wood planter box		**Purpose :** Aesthetics for the view deck	**Source** : Sourced from reclaimed timber **Availability** : Återbruksbyrån **Longevity** : Lasts 10 to 20 years	Required quantity 4 pcs	High reuse potential if timber remains structurally sound and untreated.	523 sek/pc	2092 sek
Reclaimed wood single seater		**Purpose :** Seating Arrangements	**Source** : Sourced from reclaimed timber **Availability** : Återbruksbyrån **Longevity** : Lasts 10 to 20 years	Required quantity 2 pcs	High reuse potential if timber remains structurally sound and untreated.	900 sek/pc	1800 sek

SITE PLAN

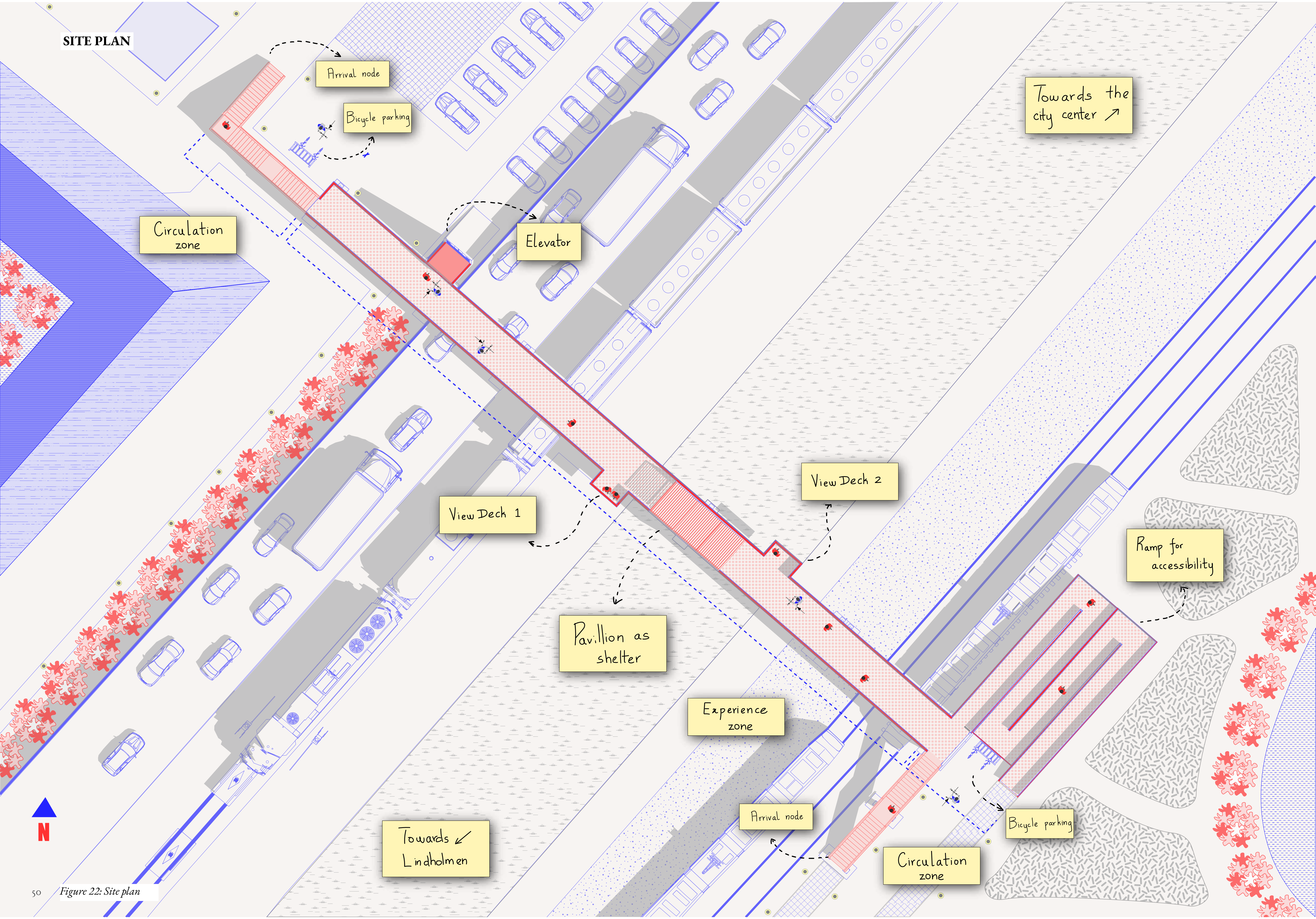
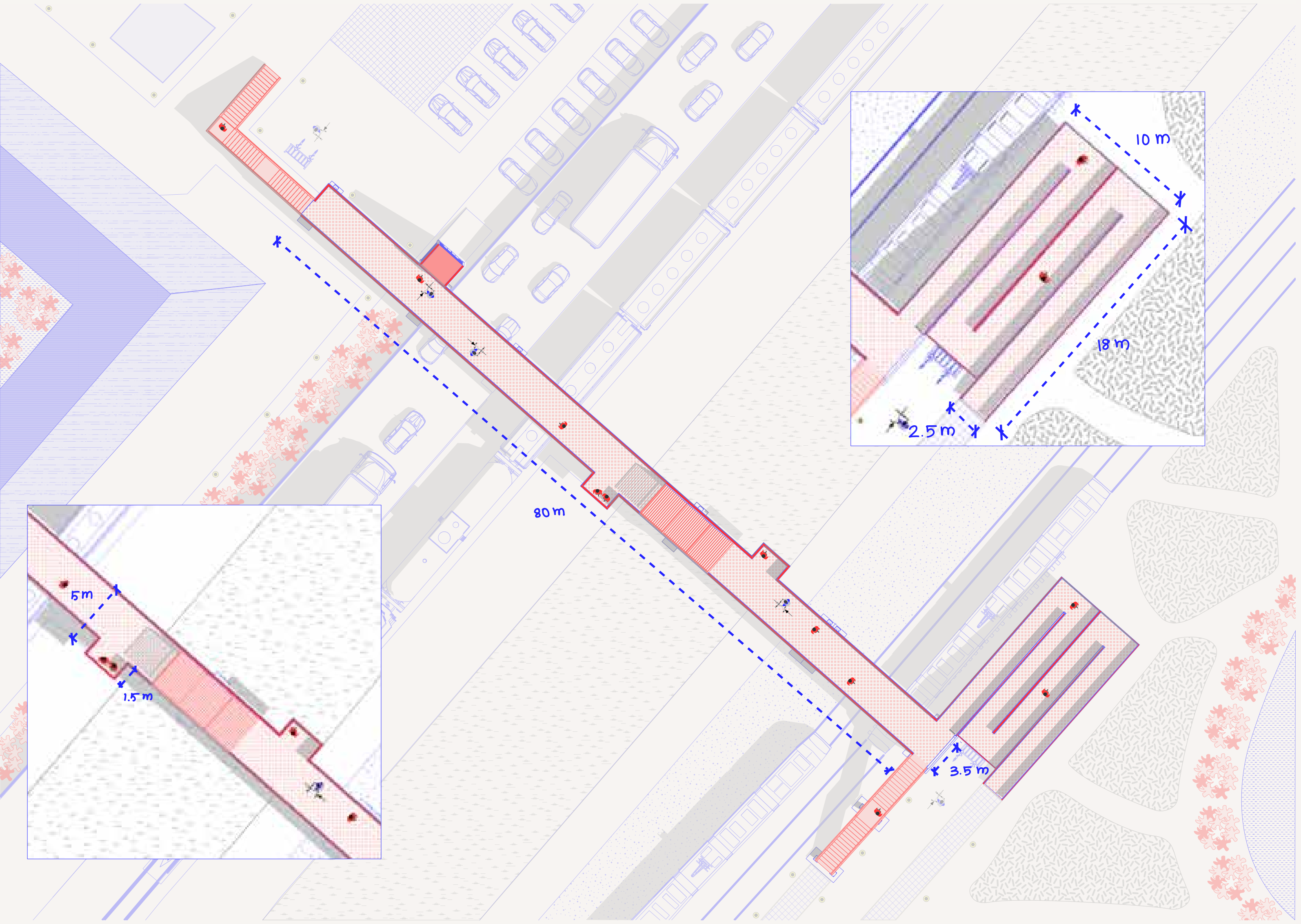
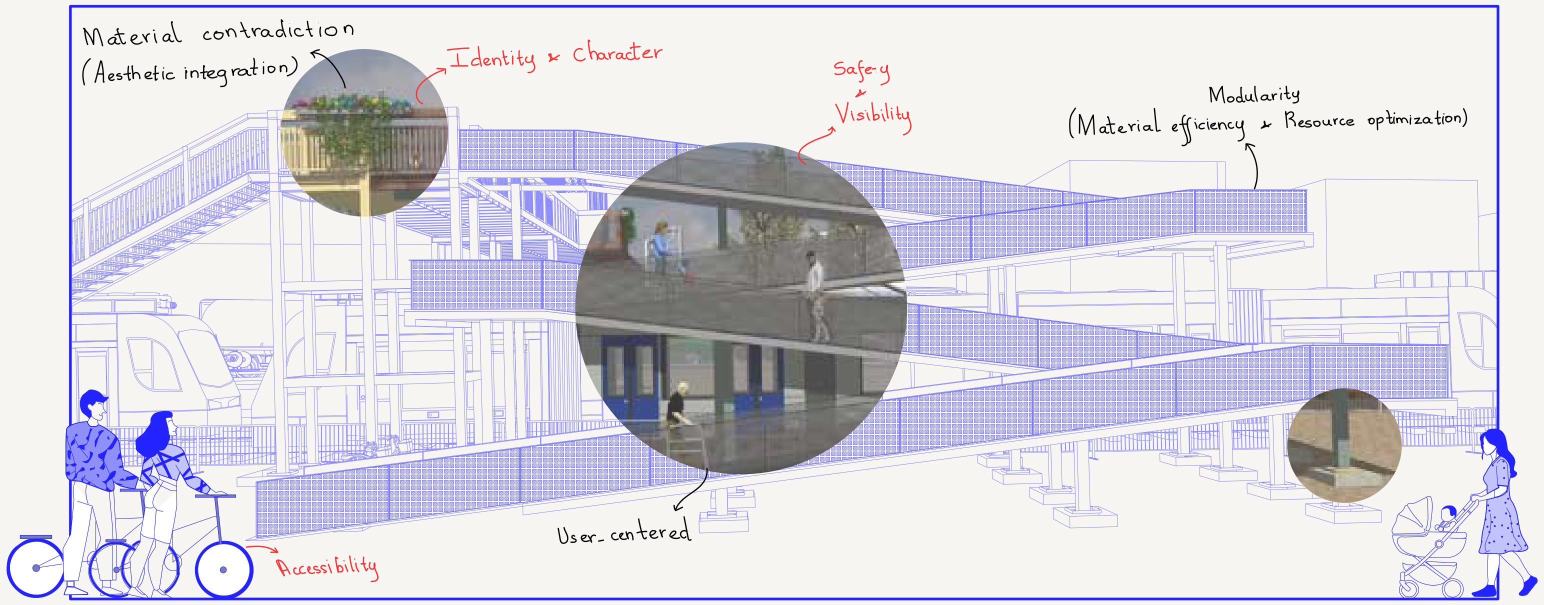


Figure 22: Site plan

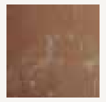


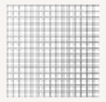
▶ Ramp

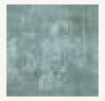
● Attained Frugal design principle ● Attained Architectural qualities



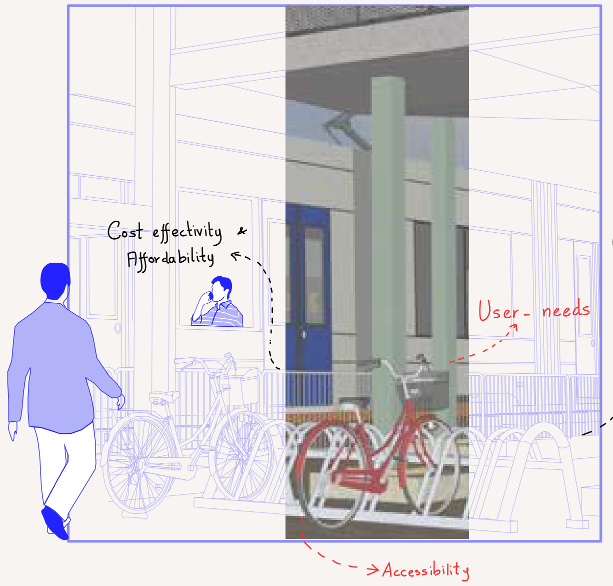
 Existing surface colour

 Reclaimed steel (Raw texture)

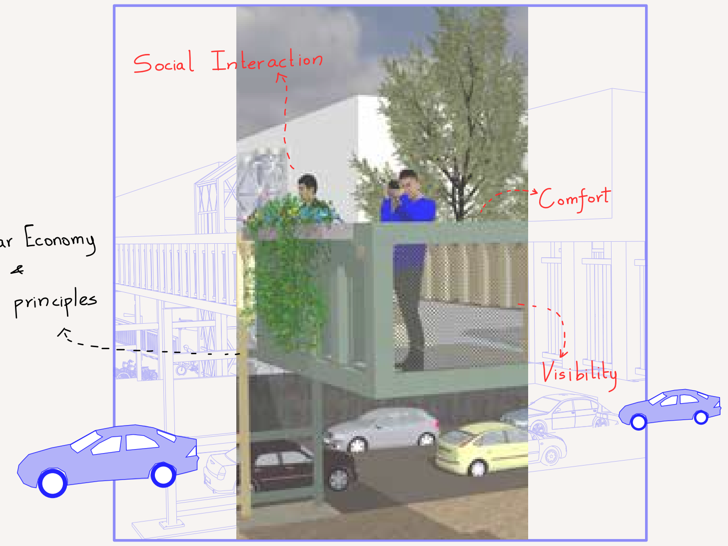
 Perforated sheet

 Reclaimed steel (Raw texture)

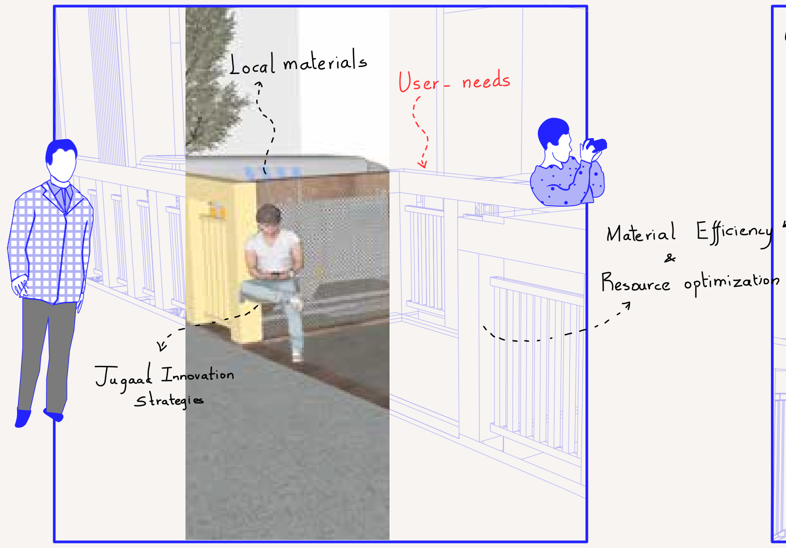
▶ Bicycle parking



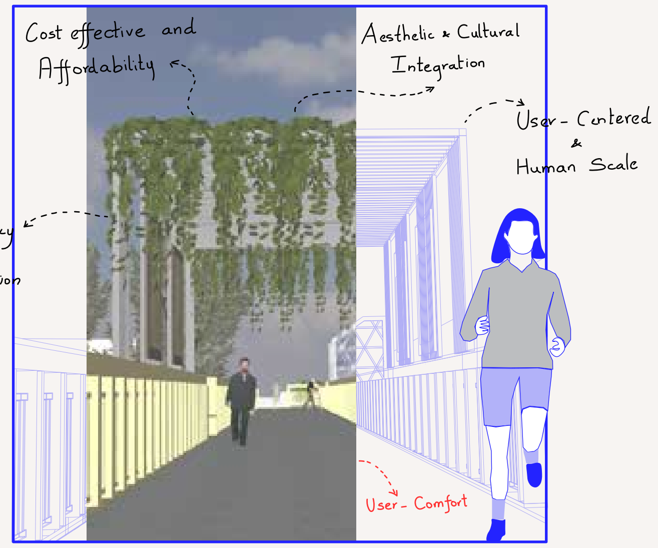
▶ View deck



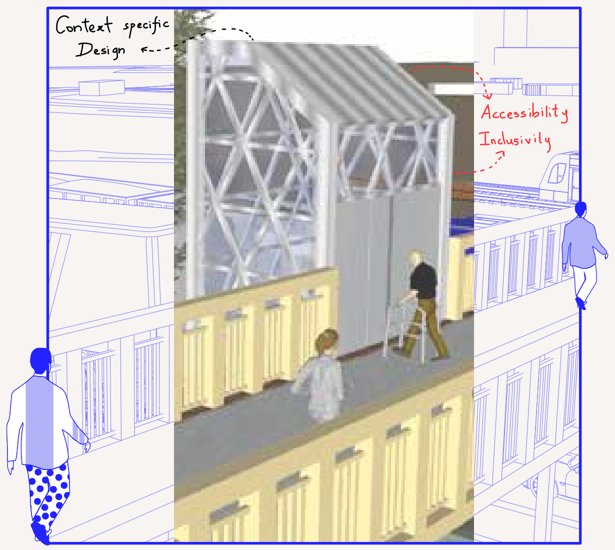
▶ Seating facility



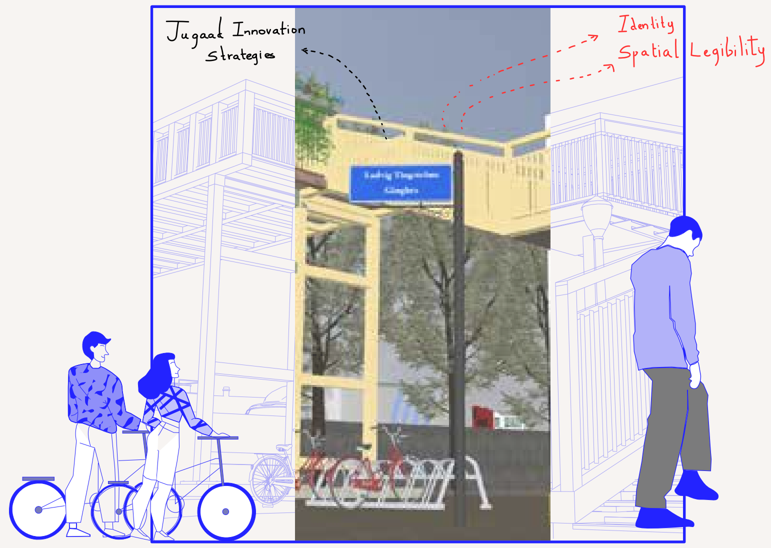
▶ Pavillion



▶ Elevator



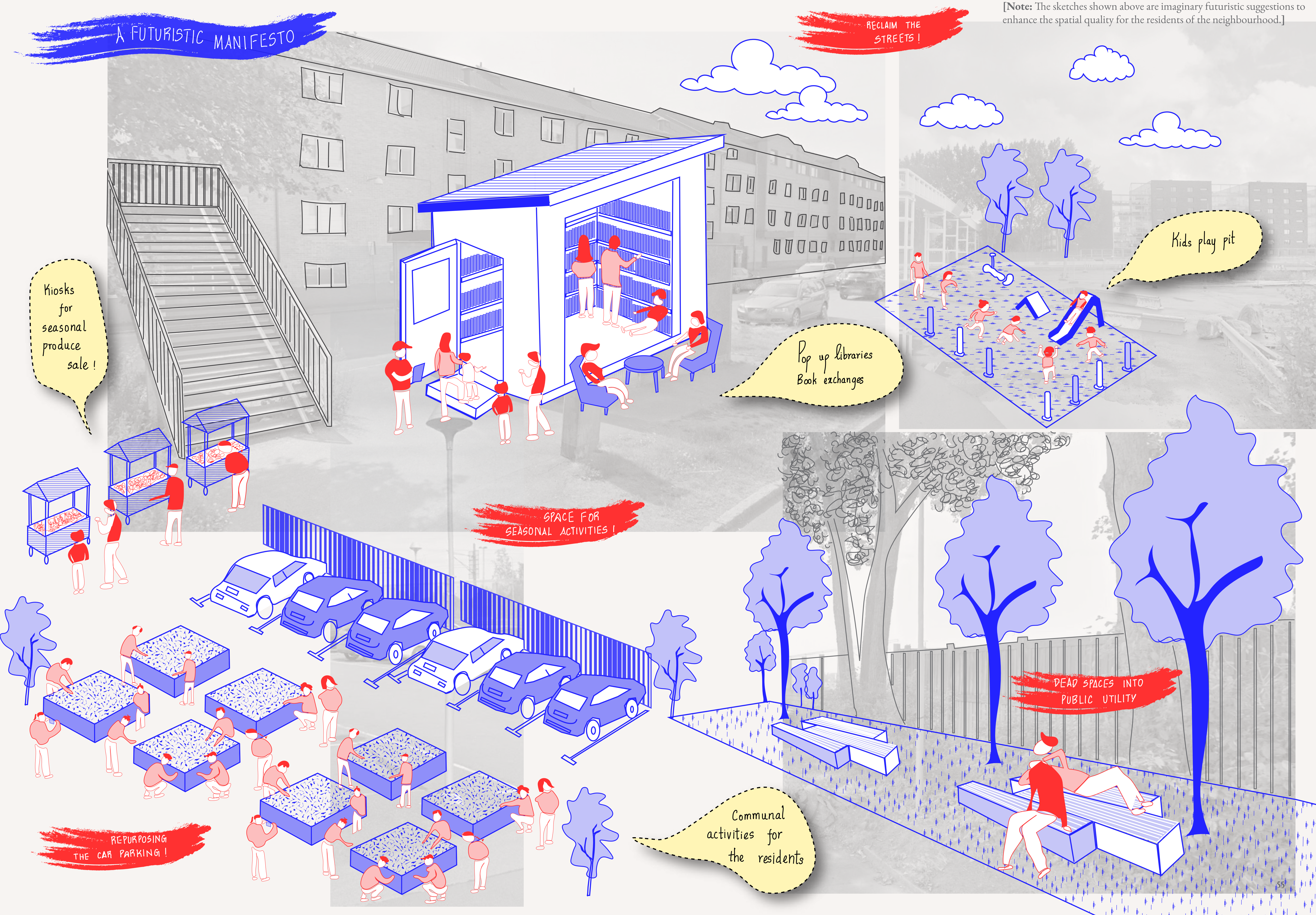
▶ Name pole



● Attained Frugal design principle ● Attained Architectural qualities

Figure 23: Design decisions

[**Note:** The sketches shown above are imaginary futuristic suggestions to enhance the spatial quality for the residents of the neighbourhood.]



ENVIRONMENTAL ASSESSMENT

The following environmental assessment presents indicative embodied carbon comparisons for selected materials used within the proposal. These calculations are conceptual and assumption based, intended only to illustrate the potential environmental impact of reused materials in comparison to conventional new construction materials. The values are derived from approximate emission factors and simplified quantity estimations rather than detailed Life Cycle Assessment methods. Therefore, the assessment should be understood as a comparative design tool rather than a technically verified carbon analysis.

Material	New Material CO_2e ($kgCO_2e$)	Reused Material CO_2e ($kgCO_2e$)
Primary steel beams	4,300	645
Secondary steel joists	2,960	520
Steel columns	18,500	3,200
Aluminium chequered plates	46,800	5,500
EPDM rubber sheets	7,200	2,400
Perforated metal sheets	3,900	780
Concrete footing	5,500	4,200
Stainless steel railing rods	2,800	950
Base plates	1,950	420

Table 1 : Environmental assessment

[**Note:** The embodied carbon values and emission factors used in this assessment are approximate reference values derived from publicly available industry databases, Environmental Product Declarations (EPDs) and standard embodied carbon estimation sources including ICE Database and One Click LCA. The calculations are intended solely for conceptual and comparative analysis within the scope of the thesis.]

The table presents a comparative embodied carbon assessment between conventionally manufactured materials and the reused materials proposed within the project.

The emission values for new materials are estimated using the formula:
Material Quantity × Embodied Carbon Factor ($kgCO_2e/kg$), where the carbon factors are derived from average industry references for common construction materials such as steel and aluminium. The reused material values are calculated using lower emission factors, as the materials avoid primary extraction, manufacturing and intensive processing stages.

Based on the selected sample materials, the reuse strategy demonstrates an approximate overall achieved reduction of 50 - 80 % in embodied carbon emissions, indicating the environmental potential of integrating reclaimed materials within infrastructure design.

ECONOMICAL ASSESSMENT

The cost comparison table demonstrates that the reuse based approach has the potential to significantly reduce overall material expenditure when compared to conventional construction methods relying entirely on newly manufactured products. The assessment indicates savings across almost all categories, particularly in structural steel elements, aluminium plates, public furnishings and surface materials. On average, the reuse strategy shows an approximate cost reduction of 35 to 40 percent compared to standard market prices for new materials. These reductions are achieved through the procurement of reclaimed materials, reuse of industrial components and adaptation of the existing bridge structure rather than complete replacement.

The findings suggest that frugal design strategies can contribute not only to environmental sustainability but also to economic efficiency by minimizing material procurement costs and extending the lifecycle of available resources. Retaining portions of the existing bridge further reduces demolition and reconstruction expenses, demonstrating how reuse based approaches can optimize both resource consumption and project expenditure while maintaining the required architectural and functional qualities.

Material	Conventional Market Price (SEK)	Reuse Based Estimated Price (SEK)	Approx. Savings
Primary steel beams	110,000	68,200	38% lower
Secondary steel joists	5,200	2,900	44% lower
Steel columns	2,150,000	1,587,400	26% lower
Aluminium chequered plates	820,000	541,500	34% lower
EPDM rubber sheets	240,000	119,500	50% lower
Perforated metal sheets	260,000	177,300	32% lower
Concrete footing	52,000	32,700	37% lower
Stainless steel railing rods	28,000	18,735	33% lower
Base plates	48,000	30,400	37% lower
Stainless steel railing supports	34,000	22,856	33% lower
Anchor bolts and connections	320,000	227,000	29% lower
Bicycle parking	7,500	3,750	50% lower
Industrial light fixtures	72,000	39,375	45% lower

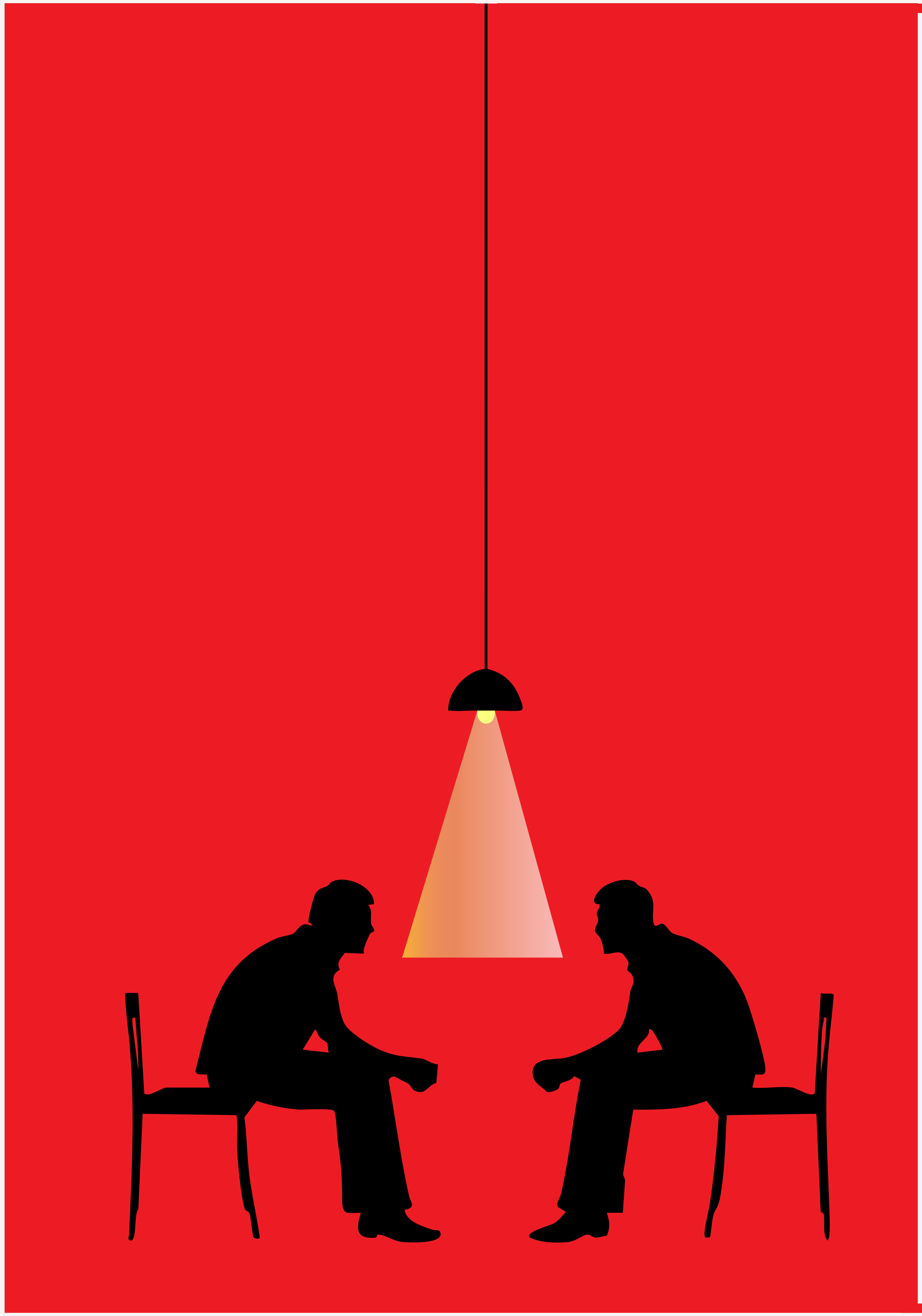
Table 2 : Economic assessment

OVERALL BUDGET ASSESSMENT

Category	Estimated Cost (SEK)
Material procurement	2,875,000
Transportation and logistics	180,000
Fabrication and welding	450,000
Labour and installation	850,000
Crane and machinery	300,000
Foundation and site work	420,000
Electrical and lighting installation	120,000
Outdoor elevator procurement	850,000
Elevator installation and shaft works	350,000
Engineering and consultancy	350,000
Permits, approvals and contingency	350,000
Estimated overall implementation budget	7.0 to 7.2 million SEK

Table 3 : Budget assessment

[**Note:** Note: The budget values are approximate conceptual estimates intended only for comparative values.]



06

- DISCUSSION AND REFLECTION
- REFERENCES
- LIST OF FIGURES

DISCUSSION AND REFLECTION

The origin of the thesis question depends on the project Ludvig Tingströms bridge which acts as the sole non-motorized link between Frihamnen and Kvillestan which is still in a functional state but underperforming in-terms architectural qualities and aesthetics. The structure represents a missed opportunity to act as a genuine urban connector rather than a mere crossing. Now the opportunity has risen as the City of Gothenburg has come forward to enhance the quality of the connection not just by replacing the old structure but by elevating its qualities by aligning with Gothenburg's sustainability goals. This sets the tone for the thesis where the bridge is opted for a redesign by reusing the recycled and reclaimed materials from other decommissioned structures within the city to strengthen the connection between the two neighborhoods across multiple dimensions like spatial, functional, experiential and symbolic.

Following the problem setting, a main concept like Frugal design is implemented at various stages throughout the thesis as it reflects precisely the direction of the thesis. Frugal design is often understood through its economic dimension of cost reduction, but it also comprises deep engagement with local context, active usage of available resources and addressing community needs. Frugality is used specifically to integrate reuse material culture, industrial heritage and sustainability values which are central to Gothenburg's urban identity.

Main Research Question :

How can a pedestrian bridge be adapted through frugal design to strengthen the spatial and symbolic connection between Frihamnen and Kvillestan?

The first step of the thesis is to understand the two neighborhoods to justify why this bridge is a vital infrastructure. Kvillestan presents as an established residential neighborhood characterized by apartment blocks housing diverse demographics including families with children, elderly residents who have lived in the area for decades, and younger professionals attracted by proximity to central Gothenburg and waterfront amenities.

The neighborhood includes essential community infrastructure such as schools, local shops and social services that generate consistent pedestrian traffic throughout the day with concentrations during morning and evening commute periods. For many elderly residents, the bridge represents not just an optional infrastructure but essential link to healthcare facilities, grocery stores and social connection. When I observe current usage patterns it becomes clear that the bridge functions as everyday necessity rather than an exceptional experience which means design decisions must prioritize reliability and accessibility over architectural spectacle (refer to *Figure 6*).

On the other hand, Frihamnen occupies a fundamentally different position, undergoing rapid transformation from its industrial harbor origins toward mixed-use urban development emphasizing residential, commercial and recreational facility. The Frihamnen area, including it's port facilities, warehouses and cranes is undergoing a transformation to coexist with cafés, creative workspaces and public amenities like Jubileumsparken. This transformation aligns with Gothenburg's wider Älvstaden development vision to convert underutilized harbor lands into vibrant urban districts while maintaining connection to industrial heritage that defined the city's identity and economic base for over a century.

What becomes clear from understanding both neighborhoods is that the bridge must mediate between distinct spatial characters, user populations and temporal rhythms while honoring each side's identity rather than imposing generic solutions that relate to neither. This is precisely where frugal design methodology offers advantages, because constraint-driven approaches require careful attention to local context, available resources and specific needs rather than applying predetermined architectural formulas.

The second step of the thesis was dissecting the proposal submitted by Mandaworks and Rundquist Architects in 2019 which was unimplemented for various reasons. One of the important reasons were budget constraints since they tried to accomplish an extravagant public space rather than considering the structure as just a connection. The proposal specified approximately 340 meters of total bridge length combining curved sections, multiple landing areas and elaborate ramp sequences (refer to *Figure 7*). While this length created opportunities for place-making and scenic experience, it fundamentally misunderstood pedestrian bridge spatial connection as requiring extensive journey rather than efficient crossing.

My critique of the proposal suggests that a Frugal alternative is possible to optimize the design on various levels. Some measures that were taken in the redesign is retaining the same length as of now which would achieve substantial material and cost savings while simultaneously improving spatial connection through more direct routing. Users crossing from Kvillestan to reach the planned tram stop at Lindholmsallén benefit from shorter walking distances that make multimodal trips combining cycling or walking with public transit more competitive against private vehicle use. Elderly residents appreciate reduced walking distances particularly during adverse weather when longer crossings become genuinely burdensome. The optimization demonstrates frugal principle that less can be more when the "less" eliminates unnecessary rather than essential elements.

Similarly with the width of the bridge which varied from 6 - 9 meters and up to 25 meters in the balcony area. As a frugal alternative the existing dimension of the bridge (1.75 m) is doubled (3.5 m) to provide a comfortable walking passage for the users despite their age and circumstances (refer to *Figure 16*). This optimized dimension strengthens spatial connection by eliminating conflicts, enabling comfortable speeds for different user types and creating clear spatial legibility. Material savings from width reduction translate to cost reductions enabling investment in other spatial connection priorities such as improved lighting for evening use or better surface materials providing slip resistance and smooth rolling for wheels.

While maintaining attention to dimensional efficiency and cost reduction, the primary objective of this thesis was to retain the architectural qualities achieved in the previous proposal. That proposal introduced five distinct spatial moments, each characterized by specific materials, vegetation and experiential qualities. However, this level of elaboration appeared to fragment the continuity of the bridge, creating a sequence of isolated architectural spaces rather than extension of the surrounding urban fabric. In response, this study tries to reinterpret those spatial qualities through the lens of frugal design principles, aiming to preserve the same spatial experience.

The first design challenge addressed was accessibility. Given the spatial constraints on the Kvillestan side, a compact vertical solution was needed (refer to *Figure 22*). An elevator was placed at this landing despite its higher cost, as it provides inclusive access for a wide range of users including individuals with reduced mobility, children, young parents with strollers and cyclists. This decision reflects the prioritisation of social inclusivity over strict cost minimisation. Additionally, a bicycle parking was integrated near the landing using reclaimed metal stands sourced from Återbruksbyrån, aligning with the project's emphasis on material reuse and local sourcing.

Structural performance and user comfort were addressed through consideration of vibration in the existing bridge structure. While long-term maintenance remains essential, the proposal introduces a supplementary surface strategy to improve immediate conditions. EPDM rubber sheets, derived from recycled tires, are proposed as a surface layer to reduce vibration and enhance walking and cycling comfort. This material choice also supports the project's bigger commitment to circular material use.

Identifying the bridge's potential as more than a transit corridor, the design incorporates spatial elements that encourage pause and social engagement. The existing views across the site embraces the placement of two viewing platforms positioned along the midsection of the bridge. These platforms create opportunities for users to stop, observe and interact with the surrounding landscape. Between these points, a semi-sheltered structure is introduced. This element serves both as environmental protection and as a space for cultural interpretation, offering information about the historical and urban context of Kvillestan and Frihamnen.

On the Frihamnen side, where more space is available, accessibility is addressed through a switchback ramp system that allows gradual landing while maintaining comfortable slope. This supports continuous movement for all user groups. Bicycle parking is also provided at this landing, ensuring that both ends of the bridge offer similar functional amenities (refer to *Figure 23*).

Through these interventions, the project demonstrates how frugal design principles can be applied to integrate architectural qualities without relying on excessive material or spatial elaboration. The result is a bridge that frugally strengthens accessibility, comfort and public engagement while maintaining spatial and symbolic coherence with its urban context.

Sub Questions :

What are frugal design principles?

Frugal design principles in architecture refer to an approach that seeks to achieve maximum functional performance with minimal use of resources. This approach prioritizes material efficiency, cost awareness and contextual responsiveness as key drivers of design. Rather than relying on abundance, it focuses on optimizing structural systems, reducing waste and selecting materials based on local availability. This often results in solutions that are closely aligned with regional construction practices and environmental conditions.

User centered considerations such as accessibility, safety and comfort are treated as fundamental requirements, ensuring that the design responds effectively to everyday use. In this sense, frugality is not understood as a reduction in quality, but as a strategic prioritization of what is necessary.

In addition, frugal design emphasizes adaptability and circularity, particularly through the reuse of existing materials and the capacity for future modification. Working with reclaimed components introduces variability, which in turn requires flexible design strategies and iterative decision making.

Cost is not treated solely as a constraint but as a guiding parameter that shapes spatial and material choices. The final appearance is often simple and clear, where the structure and materials themselves create the visual character instead of unnecessary decoration. Here Frugal design creates architecture that uses resources carefully and responds to the needs of people and place.

How can material inventories support frugal design?

Material inventories support frugal design by providing a structured understanding of available resources and their potential application within a project. Instead of selecting materials after the design is developed material inventories make materials an active part of the design process from the beginning. By documenting the type, dimensions, condition and availability of materials, I made informed decisions that align with material efficiency and local sourcing principles. This approach encourages the use of reclaimed materials and reduces the dependency on newly produced materials. This allows design decisions to develop from materials that are realistically available. Material inventories also connect the project to its local context and create a more resource aware design process.

Furthermore, material inventories helped in adaptability and iterative development, which are essential to frugal design. The variability inherent in reclaimed materials requires flexible thinking, where design solutions evolve in response to changing availability and constraints. Inventories also support cost awareness by making material quantities and procurement conditions explicit, allowing me to evaluate performance, affordability and sustainability. In addition, they contribute to transparency by linking material choices to their origins and lifecycle potential. Through this integration of data, context and design logic, material inventories function not only as technical tools but also as drivers of a more responsive and efficient architectural approach.

How do current/standard design approaches need to change to accommodate frugal design principles?

Current design approaches in architecture and infrastructure are largely based on a linear and specification driven process, where form, performance and aesthetics are defined early, followed by the selection of standardized materials to meet these requirements. This model assumes predictability in supply chains and prioritizes uniformity, precision and efficiency in execution. To accommodate frugal design principles, this process must shift toward a more iterative and resource informed framework. Material availability, particularly from reclaimed or locally sourced streams, needs to be integrated at the beginning of the design process and treated as a generative input. This requires flexibility in detailing, tolerance for variation and a willingness to adapt form and structure in response to material constraints. In addition, cost and environmental performance must be embedded as design drivers rather than post rational evaluations. Such a transition challenges the conventional hierarchy in which design intent precedes material logic, instead promoting a reciprocal relationship between the two. It also implies a change in authorship, where the designer operates less as a controller of form and more as a mediator between resources, users and context.

In the Swedish context, this shift is both timely and complex. The construction sector is characterized by high levels of industrialization, strong regulatory oversight and a reliance on standardized systems that ensure quality and safety. These conditions have created efficient and reliable construction practices but they often rely on new materials and standard materials which limits opportunities for reuse. However recent developments show a gradual shift toward circular practices. Municipal initiatives in Gothenburg especially within the Älvstaden development framework have started to include material reuse strategies in public projects.

Similarly, the ReTuna recycling mall in Eskilstuna demonstrates how reuse can be implemented within commercial and civic environments, while smaller scale pilot projects across Sweden experiment with reclaimed structural elements and adaptive reuse techniques. These examples show that although the current system values predictability there is a growing awareness of the need for flexibility and careful use of resources.

To fully accommodate frugal design principles, Swedish design practice would need to expand its working methods and cultural approaches. Procurement models must allow for uncertainty in material sourcing, enabling designers to work with available components rather than fixed specifications. Regulatory systems need clearer methods for approving reused materials while maintaining safety and supporting circular construction. In addition, collaboration between architects, engineers, contractors and material suppliers must become more integrated, as frugal design relies on shared knowledge of resources and constraints. Education and professional training also play an important role because designers need to learn how to work with changing material conditions and make decisions within limitations. In this context frugality does not oppose the precision and quality associated with Swedish construction. Instead it redefines them through careful use of resources and responsible design practices that are both technically strong and environmentally conscious.

Future opportunities :

The project demonstrates significant potential beyond its immediate role as a pedestrian and cycling connection. One of its primary contributions lies in its capacity to function as a demonstrative model for future infrastructure projects. Instead of replacing aging infrastructure completely the project proposes an alternative approach based on reuse adaptation and efficient use of resources. By integrating reclaimed materials into the structural and spatial design, it highlights the feasibility of circular construction at an urban scale. This approach can also influence the construction industry by reducing embodied carbon and minimizing material waste. If applied more widely such strategies could support local and national sustainability goals and help infrastructure contribute to environmental change beyond its functional role.

The project also remains flexible in its implementation allowing changes based on institutional priorities and limitations. For instance, while the inclusion of an elevator strengthens accessibility, it remains a component that can be reconsidered depending on budget or maintenance concerns. In such cases, the design allows for alternative solutions, such as expanding available space on the Kvillestan side to accommodate a ramp system similar to the one proposed for Frihamnen. This flexibility ensures that the main goals of accessibility and inclusivity can still be achieved through different solutions making the project adaptable rather than fixed.

On the Frihamnen side, the project opens opportunities for expanding the bridge into a broader public space strategy. The availability of space near the landing, combined with proximity to the waterfront, allows for the development of a more activated and socially engaging environment. This could include the introduction of seating areas, informal gathering spaces and temporary or mobile programs such as food trucks and small-scale events. Such interventions would support the transformation of the landing from a purely transitional zone into a destination. Over time, this area could evolve into a vibrant public node that accommodates both everyday use and seasonal activities, contributing to the broader urban life of Frihamnen.

In addition, the bridge's elevated position and visual exposure present an opportunity to establish it as a viewing platform within the city. By framing views toward the harbor, skyline and surrounding landscapes, the bridge can attract not only daily users but also visitors and tourists. This dual role as infrastructure and viewpoint strengthens its symbolic presence within the city, reinforcing the connection between neighborhoods while also contributing to Gothenburg's public and cultural landscape. Together these possibilities show that the project goes beyond its basic functional role and demonstrates how small resource conscious interventions can create broader social environmental and urban impact.

Methodological Limitations :

The thesis adopts a design driven and material informed approach, which proved effective in linking spatial decisions with frugal principles. However, this approach also revealed several limitations during the process. One of the primary challenges was the reliance on material inventories as a generative tool. While the inventory helped ground the design in local resource availability, it remained speculative in terms of actual procurement. The variability of reclaimed materials including uncertainties in quantity dimensions and condition made it difficult to fully develop the structural system with complete confidence. As a result some design decisions were based on assumed material availability rather than verified supply which limited the accuracy of the proposal.

Another limitation emerged in balancing frugality with architectural intent. The attempt to retain the spatial qualities of the earlier proposal while reducing material use and cost was not always fully resolved. Certain elements, such as the inclusion of an elevator or expanded viewing areas, introduce tensions between affordability and inclusivity. While these decisions were justified with the design logic, they highlight the difficulty of maintaining all desired qualities within a strictly frugal framework. In some cases simplifying the design reduced the spatial quality showing that transforming an elaborate proposal into a frugal one requires more detailed exploration than the available timeframe allowed.

The process also revealed challenges in addressing technical and regulatory requirements. The design remained conceptual and the integration of reused materials within Swedish building standards was only partly explored. This limited the ability to understand how the proposal would perform within actual approval processes. In addition the lack of direct engagement with municipal authorities engineers and local users reduced the amount of feedback that could further inform the design.

Finally the iterative nature of the approach was not explored to its full potential. Although the process involved several adjustments based on material logic and spatial reasoning these iterations were limited by time and project scope. A longer process could have allowed deeper testing of alternative solutions especially in improving the relationship between structure material reuse and user experience. These limitations indicate that while the approach establishes a strong conceptual framework, further development is required to translate it into a fully resolved and implementable design.

Reflection of the Assessments:

The environmental and economical assessments demonstrate the potential of frugal and reuse based design strategies in reducing both material related carbon emissions and overall project expenditure. The environmental assessment indicates that the integration of reclaimed structural steel, reused aluminium elements and recycled surface materials can significantly reduce embodied carbon when compared to conventional construction methods relying entirely on new materials. Based on the selected sample calculations, the proposal achieves an approximate reduction of 88 percent in embodied carbon emissions across key material categories (refer to *Table 1*). This highlights the environmental value of extending material lifecycles, minimising waste generation and reducing dependence on energy intensive manufacturing processes.

Similarly, the economical assessment reveals substantial cost savings through the adaptation of the existing bridge structure and the procurement of reclaimed materials. The material comparison table indicates an average reduction of approximately 35 to 40 percent in procurement costs when compared to standard market prices for new construction materials. While certain elements such as the outdoor elevator, installation works and engineering processes continue to contribute significantly to the implementation budget, the overall project remains economically competitive. The estimated implementation cost of the proposed bridge is approximately 7 to 7.2 million SEK, including material procurement, transportation, labour, accessibility systems and construction related expenses (refer to *Table 2 and 3*).

In comparison, the earlier Mandaworks proposal was estimated at approximately 30 to 40 million SEK. The substantial difference in budget highlights the impact of adopting a frugal and adaptive reuse strategy. Instead of completely replacing the bridge and introducing large architectural interventions the proposal focuses on improving the existing infrastructure reducing material use and adding new components only where necessary.Despite the reduced budget, the project still attempts to retain essential architectural qualities such as accessibility, public interaction, viewing spaces and spatial identity. The comparison suggests that resource conscious infrastructure can achieve meaningful urban and social value while operating within significantly lower economic and environmental costs.

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APPENDIX

Reference Projects

Hangarbrua – An aluminium recycled bridge in Trondhein, Norway

The Norwegian Public Roads Administration (Statens vegvesen) opens a new pedestrian bridge in Trondheim, built by Leirvik in collaboration with Hydro and partners. It is the first aluminium bridge built in Norway since 1995 and with the deck surface made entirely from recycled aluminium sourced from the decommissioned Gyda oil platform.

Figure A : Hangarbrua going across the railroad tracks at Leangen station in Trondheim, Norway. (Photo credits: Vegard Thorvaldsen/Statens vegvesen)

The bridge deck was fabricated from re-melted aluminium scrap, demonstrating how industrial by-products can be transformed into durable infrastructure components, with assembly facilitated by the material's low weight and corrosion resistance (Hydro, 2025). A Life Cycle Assessment conducted by COWI indicates that using recycled aluminium reduces CO_2 emissions by approximately 70% compared to stainless steel alternatives, highlighting the environmental advantages of circular material use in bridge construction (Hydro, 2025).

The Hangarbrua project marks a milestone in circular construction, demonstrating how waste can be transformed into a durable and valuable building material. The bridge deck is made from 20 tonnes of aluminium sourced from the Gyda oil platform, which was in operation in the North Sea from 1990 to 2021. Following the platform's dismantling by Aker Solutions, the aluminium scrap was sorted by Stena Recycling before being delivered to Hydro.

The recycled concrete bridge in Switzerland

Figure B: The Re:Crete footbridge

The Re:Crete footbridge demonstrates the feasibility of reusing concrete elements extracted from an existing cast-in-place structure in a new load-bearing bridge (Freyssinet, 2023). In the project, 25 saw-cut concrete blocks from a demolished building were dimensioned, drilled, and assembled into a segmented post-tensioned arch, with internal tensioning cables and mortar ensuring structural continuity. The assembly method was designed to be fully reversible, allowing deconstruction and reassembly at a different location, which aligns directly with circular infrastructure principles. Re:Crete not only showcases concrete reuse as a sustainable construction technique that reduces the demand for new cement and lowers CO_2 emissions but also received recognition in the "Out of the Box" category at the Bâtiments Circulaires awards, highlighting its innovation in sustainable bridge design (Freyssinet, 2023).