CHALMERS
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Techno – Economic Analysis of Scenarios for The Future of HSB Living Lab: Repurposing vs Relocation

Master's thesis in Architecture and Civil Engineering

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DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING

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ABSTRACT

This thesis evaluates future scenarios for the HSB Living Lab through a techno-economic assessment comparing repurposing and relocation scenarios. The study aims to identify the most feasible future use of the modular building after its current operational period while contributing to circular construction practices. A mixed-methods case study approach was adopted, combining semi-structured interviews, questionnaires, building documentation analysis, supplier price data collection, and cost estimation. Two scenarios were analyzed: repurposing the building into educational facilities and relocating the building to another site with the same function as residential building. The evaluation integrated Techno-Economic Assessment (TEA) with the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) of multi criteria decision making method (MCDM). The findings indicate that repurposing provides the most preferable overall techno-economic criteria and better result on TOPSIS, due to lower implementation complexity, reduced uncertainty, lower risks and lower Capital Expenditure (CAPEX) compared to relocation scenario. The results also shows that while relocation technically feasible because of the building was a modular building that able to disassemble and reassemble, the scenario have higher risks due to the logistical work, mechanical and electrical system adaptation, reconstruction uncertainty and transportation risks that makes relocation produce more CAPEX. On the other hand, Operational Expenditures (OPEX) shows different result. Repurposing generates more OPEX since the educational function needs a high frequency maintenance, while relocation keep the original function as residential building that needs lower maintenance and able to generate direct income from the rent. This thesis contributes to the discussion on circular construction by developing a techno-economic and decision-making methodology for evaluating future scenarios of modular buildings and also supports stakeholder's understanding in the technical consideration and economical implication of the future scenario of HSB Living Lab building.

Key words: Techno-economic assessment, HSB Living Lab, TOPSIS, modular building, adaptive reuse.

Tekno-ekonomisk analys av scenarier för framtiden för HSB Living Lab: återanvändning kontra flyttning

Masteruppsats inom mastersprogrammet Design and Construction Project Management

Alam Medina Muhammad
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SAMMANFATTNING

Denna avhandling utvärderar framtidsscenarier för HSB Living Lab genom en teknisk-ekonomisk bedömning som jämför återanvändning och flyttning av byggnaden. Studien syftar till att identifiera det mest genomförbara framtida användningsalternativet för den modulära byggnaden efter dess nuvarande driftsperiod och att bidra till cirkulära byggmetoder. En mixed methods-forskningsansats användes, där semistrukturerade intervjuer, frågeformulär, analys av byggdokumentation, leverantörsprisdata och kostnadsuppskattning samlades in. Två scenarier analyserades: återanvändning av byggnaden i nuvarande anläggning samt flyttning av byggnaden till en annan plats, med hjälp av etablerad bygglitteratur. Den ekonomiska bedömningen (TEA) med hjälp av Tekniken Order Preference by Similarity to Ideal Solution (TOPSIS) inom en multikriterieanalys (MCDM) visade indirekta kostnadsuppskattningar för de flesta föredragna scenariot, återanvändning. Resultaten visade att TOPSIS, på grund av lägre implementeringskomplexitet, osäkerhet, lägre risker och lägre CAPEX, föredrog återanvändning framför flyttning. Resultaten visade också att även om flyttning tekniskt sett är möjlig på grund av byggnadens modulära uppbyggnad, medför det betydande risker, eftersom scenariot kräver högre kostnader på grund av logistiskt arbete, mekanisk och elektrisk systemanpassning, ombyggnadsosäkerhet och transportkostnader som gör flyttning mer kapitalkrävande. Å andra sidan visade OPEX-driftskostnaderna (OPEX) högre effektivitet för återanvändning. Återanvändning innebär nya OPEX eftersom den redan befintliga platsen använder och inte kräver underhåll, medan flyttning behåller den ursprungliga funktionen som studentboende och därför kräver underhåll samt kan användas för direktinkomst från hyra. Denna avhandling bidrar till diskussionen om cirkulär byggnation genom att utveckla ett teknik-ekonomiskt och beslutsbaserat ramverk för att utvärdera framtidsscenarier för modulära byggnader och stödja intressenters förståelse för de tekniska övervägandena och de ekonomiska konsekvenserna av framtidsscenariot för HSB Living Lab-byggnaden.

Nyckelord: teknik-ekonomisk bedömning, HSB Living Lab, TOPSIS, modulärt byggande, adaptiv återanvändning

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Preface

This thesis was developed from our interest in the project management aspects of construction projects, particularly in relation to economic performance and decision-making processes during early project phases. This interest led us to the opportunity to analyze the HSB Living Lab case study from our supervisor, Elena Malakhatka from Chalmers Next Labs, which made the entire research process both engaging and meaningful from the beginning until the completion of this thesis report. We felt grateful throughout this study, because we are able to strengthen our analytical, communication, and academic writing skills, while also improving our ability to think critically in addressing decision-making challenges within construction project.

We would like to express our gratitude to our Examiner and Supervisor in DCPM, Dimosthenis Kifokeris. Thank you for providing support and guidance throughout the process of this Master's Thesis, we obtained so much new knowledge and insight from you during the whole process of this thesis from the ideation of the study aim to the finalization of the thesis report. We would also like to thank our supervisor from Chalmers Next Lab, Elena Malakhatka, for giving us a chance to analyze and write this project. Thank you to Alexandra Bäckström for providing us a technical insight and so much initial data for this project and being willing to help us understand the case thoroughly. Also thank you to Alam's family, Rosa, Lailana and Altan who provided continuous support during his studies at Chalmers. Lastly, we would like to thank our opponent, Odai Alhossin, Khaled Hesso and José Luis for providing the valuable feedback needed to finalize this report.

Göteborg June 2026
Alam Medina Muhammad
Muhammad Zeeshan Munir

Notations

This section provides the main abbreviations, technical terms and equation symbol used throughout the thesis. These notations are used to improve readability and maintain consistency of technical term within the document.

Abbreviation

TEA	: Techno-economic assessment
MCDM:	: Multi Criteria Decision Making
TOPSIS	: Technique for Order Preference by Similarity to Ideal Solution

Equation Symbol

x_{ij}	: performance value of alternative $i$with respect to criterion j
r_{ij}	: normalized value of alternative $i$under criterion j
v_{ij}	: weighted normalized value of alternative $i$under criterion j
v_j^*	: positive ideal value for criterion j
v_j^-	: negative ideal value for criterion j
A^*	: positive ideal solution
A^-	: negative ideal solution
D_i^*	: separation distance of alternative $i$from the positive ideal solution
D_i^-	: separation distance of alternative $i$from the negative ideal solution
m	: number of alternatives
n	: number of criteria
i	: index of alternatives
j	: index of criteria
I'	: set of benefit criteria
I''	: set of cost criteria
$\max(v_{ij})$	: maximum value of criterion $j$among alternatives
$\min(v_{ij})$	: minimum value of criterion $j$among alternatives

1 Introduction and Research Scope

This chapter contains the foundation of the study. It presents the background of the research to explain the context and relevance of the topic, followed by the aim of the study, which outlines the overall purpose of the research. This chapter also presents the research questions that guide the entire research and define the scope of the study, clarifying the boundaries and limitations of the research.

1.1 Background

The construction industry has a significant role in global economic development, yet it also has significant environmental impacts. According to the Global Status Report for Buildings and Construction by the United Nations Environment Program, the building sector is responsible for approximately 37% of global energy-related CO2 emissions and around 34% of global final energy consumption (UNEP, 2024). In addition, the construction sector is one of the largest consumers of raw materials worldwide for 40% of global raw materials (WBSC, n.d.).

Sustainability can be explained with the triple bottom line framework, that consist of three dimensions: environmental, social, and economic sustainability (Elkington, 1998). Environmental sustainability has focus on reducing negative impacts such as greenhouse gas emissions, consumption of energy and resource optimalization on the building life cycle. Social sustainability addresses issues related to human well-being, health, housing quality, and community development. Economic sustainability refers to the long-term financial viability of projects and the efficient allocation of resources over their lifecycle. In the construction sector, economic sustainability plays a critical role in investment decisions, and financial feasibility influences whether sustainable solutions can be implemented in practice (Moshood et al., 2025).

Within this context, circularity is a fundamental principle in the built environment. Circular construction emphasizes maintaining buildings, components, and materials in use for as long as possible through adaptive reuse, refurbishment, design for disassembly and material recovery rather than demolition and replacement (Eberhardt et al., 2022). An example of such an initiative is NEST building in Switzerland, where materials, system and technology are tested in this modular building (Empa, 2026). Another example in Sweden is the HSB Living Lab, located at the campus of Chalmers

University of Technology in Gothenburg, Sweden. The building was constructed using modular building technology and granted a temporary building permit, meaning that the building was designed to be dismantled and potentially relocated after a limited operational period (HSB, 2025). The HSB Living Lab is a residential research facility consisting of 29 Apartments where students and researchers live while experiments on sustainable housing technologies are conducted (Sasic Kalagasidis et al., 2017).

Therefore, repurposing the building into a new function, or relocating the building are a circular strategy that supports sustainability in construction. The techno-economic assessment were conducted in this thesis to analyze how the technicalities and economic consideration contributes to the discussion of circularity in the construction industry by evaluating whether repurposing and relocating the building is a preferable option for the future use of HSB Living Lab building technically and economically (Mahmud et al., 2021).

1.2 Aim and Research Questions

The primary aim of this master's thesis is to contribute to the analysis of scenarios beyond the end of life of the HSB living lab. The thesis performs a *techno-economic assessment* of alternative future scenarios for the HSB Living Lab (HLL) to determine the most feasible and sustainable pathway for its continued use after the current operational period.

The study is guided by this research question (RQ):

RQ1: Which future scenario offers the best techno-economic outcome for the HSB living lab when evaluated technically and financially?

To have a detail result on both technicalities and economic, the study also guided by the following sub questions:

RQ2: What technical challenges and risks are associated with each scenario?

RQ3: What is the comparative economic performance of repurposing versus relocation of the HSB living lab?

1.3 Scope

This thesis focuses on a case study of the future use of the HSB Living Lab building. The scenario is developed through the ongoing discussion between stakeholders of

HSB Living Lab on how the future of the building is going to be. The analysis contains two scenarios of future use, which are:

1. **Building adaptation – (from residential to learning facility):** Conversion of the entire building into Chalmers learning environments (classrooms, laboratories, offices).
2. **Relocation – Entire Building:** Complete disassembly, transport, and reassembly of the modular building at a new site for continued use as a Living Lab or alternative program.

The evaluation of both scenarios is conducted through the assessment of strategic alternatives. The study delimitation is not aimed at establishing a detail design, it focuses on preliminary design concept and conceptual cost estimations. Also, this study does not consider the full-building reuse or recycling scenarios as part of the primary analysis. However, the reuse potential of individual building components is carried out where relevant, particularly in cases where clear evidence was obtained from the expert interviews regarding which components can realistically be reused.

1.4 Circular Construction

This study contributes to circular construction efforts in the built environment by supporting the reuse and redevelopment of existing buildings. Rather than focusing on demolition and new construction, the research explores alternative strategies that may reduce new material consumption, construction waste and environmental impact. The outcome of this research is to support decision-making process for the future use of HSB Living Lab. By evaluating the options such as repurposing and relocation scenario, this study applied sustainable principle to extend building life cycle.

The study also considers the sustainability in economic consideration through techno-economic assessment. The analysis of cost and technical complexities supports more economically sustainable assessment in building project. The research aligns with broader sustainability principles within the construction industry including resource efficiency, circular economy thinking and the maximizing use of existing infrastructure.

1.5 Ethical Consideration

This study was conducted with research ethical principles, including integrity, transparency, confidentiality and responsible data handling. The research involved interviews and stakeholder engagement, ethical consideration also explained and applied to the respondents during the process of data collection and analysis process.

All participants were informed about the purpose of the study and their voluntary participation before the interviews were conducted. All the data obtained from the stakeholders are confirmed to be able to use on the analysis chapter of the study and all the collected data were used solely for academic purposes. Any personal information obtained during interviews such as names was handled confidentially. The data were only accessible to the researchers and was not shared with unauthorized parties.

2 Methodology

This study adopts a mixed-methods approach that integrates qualitative and quantitative methods within a case study strategy to evaluate alternatives for the future use of HSB Living Lab. Mixed-methods research is combines the depth of qualitative investigation with the reliability of quantitative measurement, allowing for more comprehensive collecting and analysis of information gathered from different stakeholders and for developing a deeper understanding of perspectives that could affect the process (Green et al., 2015). The qualitative component is conducted through semi-structured interviews with experts and key stakeholders. In addition, the case study approach supports an in-depth investigation of HSB Living-Lab as a real-life project context, where technical, economic, and functional aspects of the future scenarios can be examined systematically and within their practical context (Hyett et al., 2014).

The quantitative methodology is applied with questionnaire and cost estimation analysis to support the techno-economic comparison of both scenarios. The questionnaire is used to know stakeholder priorities and knowledge about the scenarios, while cost estimation is to calculate economic consideration for both scenarios. This study follows deductive research approach, where existing theories and frameworks related to adaptive reuse, techno-economic assessment, and construction decision-making are applied to a specific case project evaluation. Deductive approach is begun with built the concepts and theoretical ground, which are then tested through empirical investigation to assess their applicability in practice (Woiceshyn & Daellenbach, 2018). In this study, literature on techno-economic analysis, adaptive reuse, building relocation, and decision-making in construction are being the theoretical foundation, and then examined through interviews, questionnaires, and cost analysis to determine the most suitable scenario for HSB Living Lab.

2.1 Research Framework

This study adopts the Double Diamond model as a research framework to structure the investigation. The Double Diamond is a well-known framework that organizes problem-solving into four stages: Discover, Define, Develop, and Deliver. The model combines divergent and convergent thinking, allowing research to first expand the understanding of the problem space and then narrow down towards evidence-based solutions (Kochanowska et al., 2022).

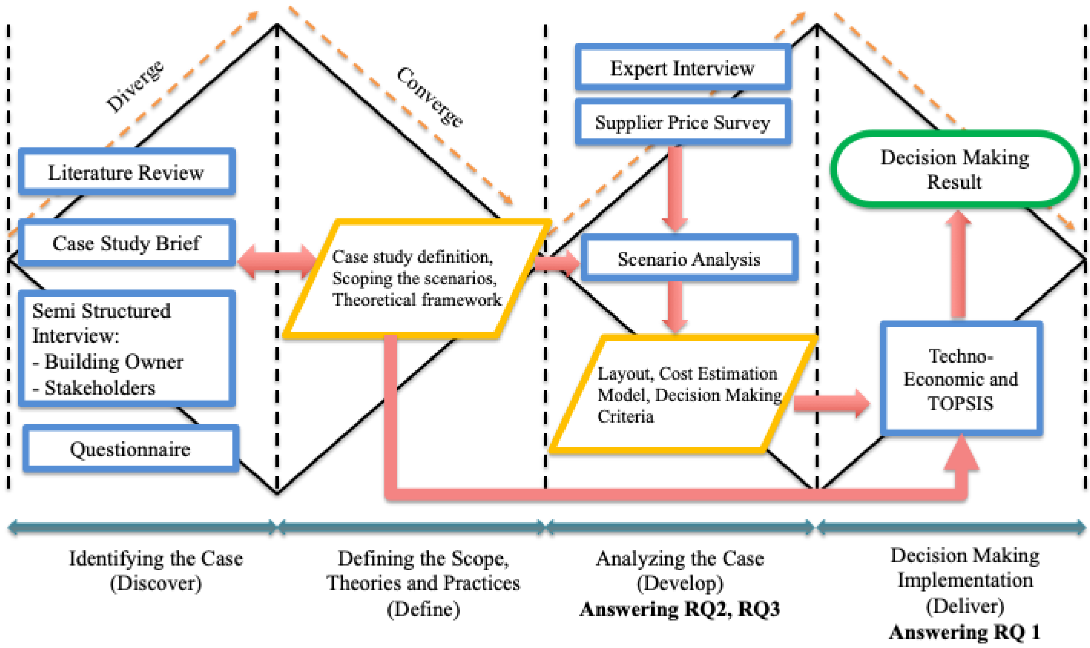

Figure 1 Research Framework

Table 1 Framework Shapes

Framework Shapes	Description
	Process
	Input/ Output
	End of the analysis
	Workflow

In the context of this thesis, the Double Diamond model is suitable because the research problem involves multiple stakeholders, uncertain future scenarios, and complex technicalities and economic factors. Previous studies highlight that the framework is effective for research that analyzing innovation, especially the study that need to structure the identifying problems to decision-making processes (Pandey et al., 2024).

The first stage of the Discover phase focuses on problem exploration through case study briefing, literature review, and semi-structured interviews with building owners and key stakeholders. This phase is to develop a deep understanding of the current condition of the HSB Living Lab, stakeholder expectations, institutional needs, and constraints related to repurposing and relocation of the building. According to the Double Diamond theory, this stage is taking a broad look of the case and is open to sources to discover the goals, needs, and motivations (Kochanowska et al., 2022).

The second stage is the Define phase, where the input from the discovery process is synthesized into a structured case study definition, scenario scope, and theoretical framework. The research problem is structured into clear definition and description, including the details of scenarios for the building's future use. This step shows the convergent logic of the Double Diamond model, in which the broad information collected in the first phase is analyzed into a focused research problem and analytical direction (Kochanowska et al., 2022).

The third stage is the Develop phase, where the possible solutions are assessed through scenario analysis, designing layout, cost estimation models, and decision criteria development. This phase includes expert interviews and supplier price surveys to support the techno-economic assessment. This phase in the Double Diamond process is the second divergent process, where multiple design and input from experts are explored before narrowing toward the most suitable option.

The final stage is the Deliver phase, where the scenarios are evaluated through a decision-making process to produce the final recommendation. This stage is making the output from the previous phase into a decision framework for stakeholders. As highlighted in design method literature, the delivery phase involves testing and comparing alternatives until an implementable solution is gained (Pandey et al., 2024).

The main contribution of this work is the development of a techno-economic evaluation method for evaluating a case study of the future use of a building. This proposed framework integrates stakeholders' insight, technical constraints, economic assessment, and structured decision criteria into a single decision support methodology. Researchers can adopt this method to analyze similar case in decision making, especially in a construction project that needs a deep understanding in technicality and economic performance of two or more options.

2.2 Literature Review

A literature review was carried out to establish the theoretical background for this study and to get insights into the previous studies on adaptive reuse, building relocation, techno-economic assessment, and decision-making in construction projects. The review primarily considered topics related to building transformation, modular construction, technical feasibility, economic evaluation, and construction decision-making, as the thesis will be based on comparing repurposing and relocation scenarios for the HSB Living Lab building. The review also contributed to the identification of the technical and economic factors that affect building transformation projects and to the development of the research methodology for this study (Snyder, 2019).

Several keywords were used in the literature search to ensure that both technical and economic aspects relevant to the research topic were included. The main keywords included techno-economic assessment, TEA, adaptive reuse, building adaptation, building relocation, modular buildings, economic criteria, construction costing, work breakdown structure, building services, building renovation, TOPSIS, multi-criteria decision-making, MCDM, questionnaire method, double diamond model, and decision-making in construction. In addition, specific searches related to HSB Living Lab and modular building systems were also carried out to better understand the characteristics and transformation potential of similar buildings (Tranfield et al., n.d.).

The literature was collected from academic databases, journals, books, conference papers, and institutional publications. Chalmers Library, ScienceDirect, Elsevier, Taylor & Francis and JSTOR were major sources used in this study. The theoretical framework was prioritized for peer-reviewed and recent studies that are relevant to adaptive reuse, modular construction, relocation, and techno-economic analysis, to ensure that the theoretical framework is up to date with current research and industry discussions. The literature review further confirmed the choice of technical and economic indicators, research methods, and the decision-making approach of TOPSIS in this thesis (Snyder, 2019).

2.3 Case study: HSB Living Lab

Figure 2 HSB Living Lab Building

The HSB Living Lab was chosen as the case study for this research because it is innovative in its modular construction, experimental, and has the potential to be transformed in the future. Table 2 provides the technical details of the HSB Living Lab, providing a clear overview of the building design and system setups. These are organized under three general headings: structural and material characteristics, mechanical, electrical, and control systems, and implications for integration, accessibility, and adaptability. This classification is an example of the way the building's modular design, building services integration, and accessible elements help to make it adaptable and efficient. The overview not only describes the physical and technical structure of the building but also serves as a foundation for the evaluation of the building's potential for future scenarios, including repurposing and relocation.(Sasic Kalagasidis et al., 2017).

Table 2 Technical Characteristics

Technical aspect	Description
Structural and material characteristics	

Modular structural system	The building is composed of **44** prefabricated volumetric modules assembled on site across five levels. These modules act as individual structural units while also contributing to the overall load-bearing system through vertical and horizontal connections.
Steel frame and prefabrication	The modules are primarily based on a steel structural frame, which provides rigidity, dimensional precision, and stability for floor, wall, and roof assemblies. This supports efficient off-site manufacturing and accurate on-site installation.
Spatial organization	The modular grid directly shapes the internal layout. A central staircase and elevator core form the fixed structural and functional zone, while surrounding modules accommodate residential units, shared spaces, and service areas.
Building envelope	The building envelope consists of prefabricated wall and façade panels that follow the modular construction logic and contribute to enclosure, insulation, and overall building performance.
Integrated solar facade and replaceable sections	Parts of the facade incorporate solar cells directly into the cladding system, making the envelope multifunctional. Several wall and façade sections can also be removed and replaced, allowing changes in materials and insulation without altering the structural core.
Material visibility and access	Some structural and envelope elements are intentionally exposed or visible through panels and transparent sections, improving access for observation, maintenance, and future intervention.
Mechanical, electrical, and control systems	
Hybrid heating and distribution	The heating system combines district heating and air-to-water heat pumps, supported by heat exchangers that allow flexible operation. Heat is distributed through radiators, underfloor heating, and

	ventilation-based systems, with certain zones capable of separate regulation.
Ventilation and indoor climate	The building uses mechanical ventilation with heat recovery, with roof-mounted supply and extract units. Incoming air is preheated through a borehole-based system and adjusted in coordination with the heating system. Indoor sensors monitor temperature and carbon dioxide levels to support demand-responsive airflow.
Water and greywater systems	Water is supplied from the municipal network, heated within the building, and distributed through pipe systems that are partly visible in-service shafts. The system also includes greywater treatment, where wastewater from showers and sinks is treated and reused for applications such as toilet flushing. Some drainage lines are intentionally exposed, making system operation easier to inspect and understand.
Electrical and energy systems	The electrical system is closely integrated with the building's energy infrastructure. Façade-integrated solar panels generate electricity, which is managed through an energy hub that monitors production and consumption. Battery storage is used to store excess energy for later use or transfer to the grid.
Control systems	A central control platform monitors and manages major building functions, including heating, ventilation, electrical systems, and safety-related operations. At the same time, some subsystems retain local controls, allowing adjustment at different operational levels.
Integration, accessibility, and adaptability implications	
System integration	Structural, mechanical, electrical, and control systems are closely interconnected, meaning that the building operates as a unified technical system rather than as isolated components. This integration supports coordinated performance and efficient system management.

Accessibility	A defining technical characteristic of the building is that many structural and service elements are not fully concealed. Instead, they remain accessible through exposed routes, inspection panels, and transparent sections, allowing easier monitoring, repair, and replacement.
Adaptability	The modular structure, replaceable envelope sections, and accessible service systems make it possible to modify, upgrade, or reconfigure parts of the building with less disruption than in conventional buildings, where systems are usually embedded within walls and floors.
Future transformation	Taken together, the building demonstrates a technical structure that is both stable and flexible**.** It is designed not only for operation but also for observation, experimentation, adjustment, and future transformation, which is particularly relevant for assessing repurposing or relocation scenarios.

2.4 Empirical Data Collection

The empirical data collection in this research is used to support the techno-economic analysis of repurposing and relocation scenarios of the HSB Living Lab building. The research is of an exploratory nature and focused on a specific case, so a qualitative and quantitative approach is used to gather information from various stakeholders with expertise in the field. The data collection strategy involves the use of primary and secondary qualitative and quantitative data sources, such as semi-structured and previously recorded interviews, questionnaires, and building documentation. This method allows the integration of strategic, technical, and operational insights to get a comprehensive understanding of the factors that affect decision-making in building transformation (John W. Creswell, 2018).

2.4.1 Interviews

The research uses semi-structured interviews as the primary qualitative data collection approach. This method is chosen for its flexibility, allowing respondents to provide in-depth insights, while also focusing on themes related to research questions. Semi-structured interviews allow for both focused and open-ended questioning, which is ideal for discussing complex issues like building repurposing or relocation, technical considerations, and spatial needs (Mark Saunders, 2019).

The interviewees are selected based on their professional background, expertise, and their direct or indirect involvement in the HSB Living Lab, modular construction, campus development, and building operations. This includes a variety of stakeholders, including academic experts, campus planning, industry, and building operations. This approach guarantees that the data gathered represents different viewpoints, such as strategic, teaching, technical, and operational (Robert K. Yin, 2018).

Academically, interviews include experts from the fields of construction management and building services engineering. They provided information on teaching methods, space needs, and the link between teaching spaces and teaching and learning methods. Their insights are valuable in understanding the design of teaching spaces in the context of interactive and flexible learning (John W. Creswell, 2018).

Interviews involve the campus strategy and planning stakeholders from a campus development perspective. These interviewees offer their perspective on space needs, planning, and challenges of adapting to changing teaching needs in current facilities. This provides context for how the HSB Living Lab fits into the campus (Robert K. Yin, 2018).

We also have industry professionals to offer insight into the technical and practical difficulties of building transformation. This comprises a building services consultancy, a modular building expert, and a demolition and reuse expert. These stakeholders are able to offer insights into the complexity of the system, the flexibility of modular buildings, and reuse versus relocation. Their knowledge is crucial in assessing the technical and economic feasibility of the scenarios. The representatives' facility management representative connected to the HSB Living Lab is part of the group to offer operational perspectives on the building's performance, systems, and operational aspects. This input is used to relate the design to the functioning of the building.

The interview questions are based on the major research themes: spatial requirements for teaching, technical issues of the building, re-purposing and relocation opportunities, and challenges. Questions are intended to guide the conversation but are not intended to limit the interviewee's ability to describe and discuss their own experiences and perspectives, which may result in additional insights. In addition to primary interviews conducted as part of this study, secondary qualitative data is also used to enhance empirical evidence. This involves interviews with previous research projects on similar topics in the HSB Living Lab and other modular construction projects. This is done through interviews with an expert in modular construction, a project manager from a building services consultancy, and a demolition and reuse specialist. The interviews provide technical, cost, and practical information about building transformation(Mark Saunders, 2019; Robert K. Yin, 2018). Table 3 describes the general information about the interviews.

Table 3 List of Interviewees

No.	Name	Role	Organization / Context	Description
1	Interviewee 1	Head of Projects	Medic Solution Nordic AB	Modular construction expert and industry professional
2	Interviewee 2	Project Manager	Bengt Dahlgren	A project manager from a building services consultancy
3	Interviewee 3	CEO	Riv & Sanering	A demolition and reuse expert
4	Interviewee 4	Researcher	VTT Technical Research Centre of Finland	A researcher in circular construction
5	Interviewee 5	Facility Manager	HSB Living Lab	A facility management representative

6	Interviewee 6	Campus Strategist & Advisor	Chalmers University of Technology	A campus strategist at Chalmers
7	Interviewee 7	Professor (Construction Management)	Luleå University of Technology	A professor in construction management from another Swedish university
8	Interviewee 8	Professor (Building Services Engineering)	Chalmers University of Technology	A professor from the Architecture and Civil Engineering department at Chalmers
9	Interviewee 9	Campus Planning / Development	Chalmers University of Technology	A campus planning representative at Chalmers
10	Interviewee 10	Stakeholder / Representative	HSB Living Lab	A representative involved in the HSB Living Lab project

2.4.2 Questionnaire

The questionnaire is used as a supplementary data collection technique to collect data on the needs of teaching staff regarding spatial needs and learning environment in the university. The purpose of the questionnaire is to collect information that is user-oriented and reflects current teaching and space usage, as well as future expectations for learning environments, particularly in the context of re-purposing the HSB Living Lab (Mark Saunders, 2019).

The target audience is mainly academic staff from the Architecture and Civil Engineering department at Chalmers University of Technology. These include Professors, Researchers, Lecturers, and Examiners who are involved in teaching and course development. The respondents are selected purposively because they have experience in teaching spaces and can give valuable input on the requirements of space.

The survey consists of quantitative and qualitative data. The questionnaire contains closed questions to set trends in the teaching approaches, class sizes, importance of spatial and functional requirements, and the relevance of functional elements like furniture, digital technology, and indoor environmental quality. These questionnaires enable us to see the general trends of the participants' responses. Open-ended questions are also asked to allow participants to share their emotions, expectations, and concerns. It also inquiries about the significance of advanced building systems and problems encountered in retrofitting existing buildings for teaching (John W. Creswell, 2018).

The questionnaire provides a user's perspective to complement the expert perspectives collected from interviews. The interviews give strategic perspectives, and the questionnaire gives practical perspectives of teaching staff. The combined use of these two data sources helps to give a holistic view of the needs for building repurposing.

2.4.3 Building Documentation

The building documentation is the key part of the data used for the techno-economic assessment, as it provides the technical and quantitative information of the HSB Living Lab. These comprehensive building documentations allow for a systematic assessment of spatial and cost-related aspects, which are crucial for evaluating repurposing and relocation options (Volk et al., 2014).

The technical documentation includes the Autodesk Revit model of different disciplines and architectural plans of the building. These models offer detailed data on the spatial organization, size, and structure of the building. The Revit model is especially useful as it provides an overview of the building's modularity, spatial planning, and element distribution. Using these models and drawings, it is possible to understand the floor plans, determine the spatial potential, and assess the possibility of transforming residential units into classrooms. The presence of such digital building information facilitates spatial planning and allows us to design the proposed layout shown in the following sections (Succar, 2009).

Alongside the spatial and building information, an inventory list of building materials and components is also used. This list includes information about the types, conditions, and amounts of materials used in the building. This inventory information is crucial in assessing the reuse potential of building materials, which is a key factor in the reuse scenario. Through the identification of elements such as walls, doors, kitchen, and finishes that can be reused, the study can include strategies for reuse and adaptation instead of replacement. This helps to save budget and achieve sustainability by avoiding material waste and new material extraction. Furthermore, financial documentation is used to support the financial aspect of this research. This includes the financial reports and cost data related to the building. These reports include information about capital costs, operating costs, and maintenance costs. Having access to this information allows us to calculate the costs related to defined options, such as re-purposing and relocation (Mlote et al., 2024).

The combination of technical and financial documents enables us to perform a techno-economic assessment. The Revit model and drawings facilitate the technical analysis of spatial aspects, and further help to propose the new layout, while the inventory data supports decision-making on reusing materials and adapting components. Meanwhile, financial and operational cost data support the economic assessment, such as costing and scenario comparison (Robert K. Yin, 2018).

2.4.4 Supplier Price

The supplier price is used in this study as the primary basis for cost estimation by collecting unit prices directly from suppliers' published prices on the internet. This approach involves identifying the required building's working items, elements, service systems, and technical installations, followed by matching them with available supplier quotations from online catalogues or price lists. This method is suitable for this study because many interventions of components in both scenarios, such as selective removal, interior adaptation, HVAC replacement, furniture procurement and commissioning related work are dependent on market prices rather than historical cost databases. Cost estimations literature emphasizes that reliable estimates require actual market-based unit price rather than generalized assumptions, especially when project-specific scope definitions are sufficiently clear (El-Mohr et al., 2022). Recent studies also show that supplier price data and online marketplace information improve estimating transparency and support more accurate forecasting (Olowe et al., 2025).

In this study, supplier prices are specifically collected from the Swedish and broader European markets to ensure relevance for the HSB Living Lab case. An exception is made for the cost that doesn't list in Swedish or European market, such as the cost for feasibility study that derived from United States consultant. Swedish suppliers are prioritized for products related to interior works, furniture, mechanical and electrical systems, plumbing fixtures and educational space equipment. Where Swedish market data are limited or unavailable, prices from established European suppliers are used as secondary references, particularly for specialized learning technology systems and adaptive reuse components. Location-specific pricing improves estimate validity by accounting for local supply chain conditions and market fluctuations rather than relying on international average cost indices (Olowe et al., 2025).

2.5 Cost Estimation Method

The cost estimation in this study follows a preliminary estimating approach, which is considered relevant for projects that are still in the early decision-making phase and where detailed design information is not yet fully developed. At this stage, the objective of cost estimation is not to produce a firm tender price, but to establish a rough order of magnitude (ROM) budget that supports the techno-economic comparison of alternatives (Holm, 2019). Early-stage estimates are commonly referred to as budgets, schematic estimates or conceptual estimates, as they are developed based on limited project information and are expected to have lower accuracy compared to detailed estimates.

The first step of the estimation process involved the development of Work Breakdown Structure (WBS). A WBS is a breakdown of the total project scope into smaller and manageable work items, allowing costs to be allocated systematically to each project component (Cerezo-Narváez et al., 2020). The WBS is a fundamental framework for identifying all significant work items that have cost implications before detailed takeoffs and pricing are performed. Properly developed WBS improves cost transparency, enhances traceability of assumption (Holm, 2019).

For the HSB Living Lab case, the WBS was developed up to Level 3, which is considered sufficient for early-stage decision-making and feasibility assessment. The estimation is set using square meter unit price, assembly price or a percentage add-on for general work (Holm, 2019). As mentioned before, this study does not develop WBS to Level 4 or detailed work-package level. This limitation occurred where the case study still in the strategic decision-making phase, where detailed design drawings and technical specifications have not been finalized. Moreover, the limited research time limiting the possibility of conducting detailed quantity take-off.

The cost for each package is calculated by multiplying the intervention area by the unit cost taken from supplier price, benchmark data and published construction references (Olowe et al., 2025). For components that cannot be represented by floor area alone, such as electrical fixtures, doors, heating systems, and engineering consultation, the estimate is carried out with quantity take-off using unit counts or lump-sum values (Fazeli et al., 2021).

2.6 Decision Making Process

The decision-making process is the final synthesis stage of this study, where all findings and outputs from the previous research phase are systematically integrated to support the selection of the future use scenario for the HSB Living Lab building. As illustrated in the research framework, this phase is analyzed the outputs from literature review, case study definition, expert interviews, supplier price survey, cost estimation model and techno-economic assessment criteria into a structured support methodology.

The objective of this process is to identify which alternative scenario offers the most suitable solution based on techno-economic assessment. The decision is not based only on economic performance such as capital expenditure (CAPEX) and operational expenditure (OPEX), but also considering the technical, practical, and strategic factors from expert insight and theoretical findings (Mahmud et al., 2021).

The process is supported by the literature review and the theoretical framework established in earlier chapters, to ensure that the decision process is grounded with academic approaches. The main criteria that discussed on the decision making are mainly from techno-economic analysis (TEA), that ensure all the criteria is within the technicalities and economic scope for helping decision-making processes (Mahmud et al., 2021). In addition, TEA is combined with the adoption of Multi Criteria Decision Making (MDCM) framework, as the decision process involves multiple criteria with different characteristics from technical, economical, different objectives and units of measurement.

The use of MCDM is relevant in this study because several evaluation criteria are qualitative and cannot be directly compared through numerical analysis (Triantaphyllou, 2000). For example, criteria such as risk or constructability are often expressed through expert judgement rather than numerical values. MCDM methods enable these qualitative factors to be transformed into measurable scores, allowing them to be evaluated with the quantitative indicators.

This study used the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) from the MCDM method. TOPSIS was selected because it is suitable for ranking multiple alternatives based on their relative distance to an ideal solution (Hwang & Yoon, 1981). In the context of this study, the positive ideal solution is the scenario with the most favorable techno-economic performance across all criteria, while the negative ideal solution represents the least desirable outcomes.

Before applying the TOPSIS procedure, the evaluation criteria must be established and weighted. The criteria used in this study are obtained from two main sources: the literature review and the expert interviews. The literature review provides a theoretical basis and development of conditions in construction projects similar to this case study and shows relevant techno-economic indicators commonly used in adaptive reuse and relocation of a modular building. While the expert interviews contribute to the practical insights and case-specific priorities from industry professionals. The weighting process is informed by expert judgement or can be structured from the inputs from the interview. This is useful when the criteria are having a different level of importance, such as when economic criteria may be prioritized over structural indicators depending on stakeholders' objectives (Madanchian & Taherdoost, 2023).

Following the weighting stage, the TOPSIS method is carried out through a couple of systematic steps described on the literature review chapter. The scenarios of the HSB Living Lab which are repurposing and relocating that has highest closeness coefficient to ideal solution is considered the most preferable option and is therefore selected as the recommended decision-making outcome.

2.7 Validity and Reliability

The study was conducted systematically by following the methodological framework presented in this chapter, including the analytical sequence, data collection procedures, evaluation criteria, and assessment methods throughout the research process. The use of defined assumptions, documented calculation procedures, and structured decision-making process contributes to the consistency of the results. Therefore, the reliability of this study was actually carried out as planned from the method used (Mohamad et al., 2015)

Also, validity of the research is shown on how this study accurately addresses the research objectives and reflects the real conditions of the investigated case. The validity is ensured the collected data and research instrument accurately support the purpose of this study (Creswell, 2013). The techno-economic assessment and decision-making process were developed based on literature and expert interview inputs to ensure that the assessment of the scenarios is within a realistic and relevant condition. Assumptions and delimitations were explicitly stated to maintain transparency in the interpretation of results. Some estimations and assumptions were necessary due to the data availability; these assumptions were developed based on reasonable references and discussions with relevant interviewees.

2.8 Declaration of Artificial Intelligence Use

The preparation of this report was supported by the use of Generative AI, specifically ChatGPT from OpenAI. The tool was utilized to assist with language refinement, sentence clarity, and improvement of formatting consistency throughout the document. All analytical processes, interpretations, and conclusions presented in this report are solely the responsibility of the author.

3 Theoretical Framework

This chapter presents the theoretical framework used to evaluate future scenarios for HSB building, integrating both techno-economic analysis (TEA) and relevant theories on building adaptation and building relocation.

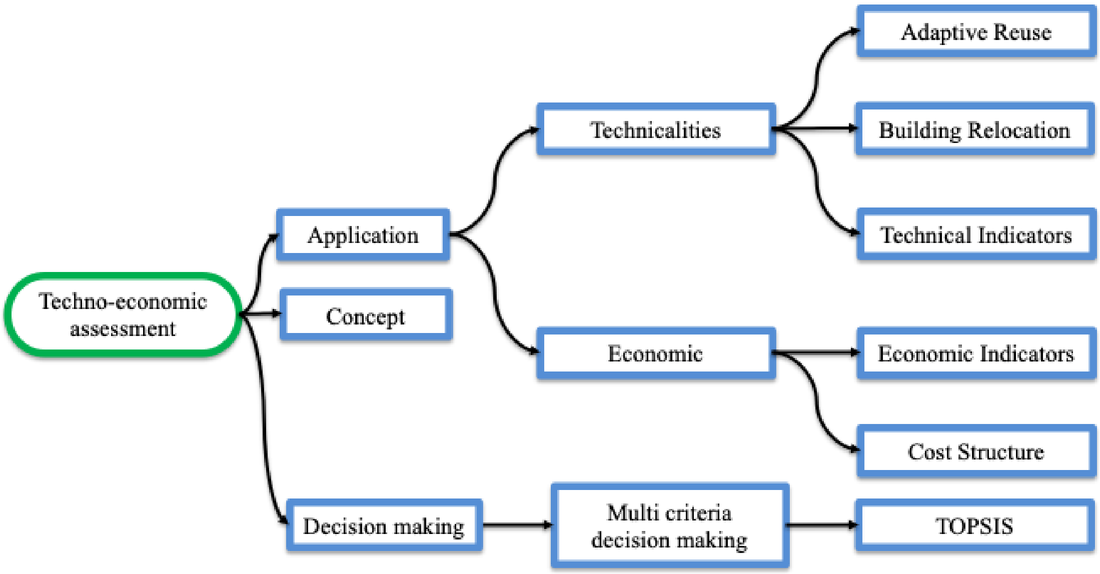

Figure 3 Literature Review Network

3.1 Techno - Economic Assessment

A building may technically support a new function but require extensive modifications that increase costs. Similarly, relocation may be technically possible but economically challenging due to transportation and reconstruction costs. Consequently, a systematic evaluation framework is necessary to compare these alternatives (Coskun et al., 2024; Pichlmeier & Lindner, 2024).

Techno-economic analysis (TEA) is a methodological approach to analyse technical and economic performance (Mahmud, Moni, High, & Dale, 2021). The approach allows decision-makers to assess whether a proposed solution is technically feasible and economically viable before implementation. TEA has been widely applied in engineering, energy systems, and infrastructure planning to evaluate alternative technologies and development pathways.

In this research, techno-economic analysis is used to evaluate potential future scenarios for the HSB Living Lab building. The framework compares two potential strategies: repurposing the building for a new function and relocating the building to another site.

By integrating technical and economic indicators, the techno-economic framework enables systematic comparison of these scenarios and supports evidence-based decision-making (Barahmand & Eikeland, 2022; Mahmud et al., 2021).

3.1.1 Concept of Techno-Economic Analysis

Techno-economic analysis is a methodological approach used to evaluate the technical performance and economic feasibility of a technology, system, or infrastructure project (Mahmud et al., 2021). The method combines engineering analysis with financial evaluation to determine whether a particular solution is viable. According to Mahmud et al. (2021), techno-economic analysis evaluates both technical performance and economic feasibility of technologies and is widely used to support decision-making during early stages of technology development.

TEA integrates process design, system modelling, and cost estimation to assess the overall performance of a project. This integration allows researchers to understand how technical characteristics influence economic outcomes. Techno-economic analysis typically involves a series of analytical steps, including process modelling, equipment sizing, capital cost estimation, operating cost estimation, and financial analysis. These steps enable a comprehensive evaluation of project feasibility (Chai et al., 2022).

Another important aspect of TEA is its ability to evaluate the relationship between technological performance and economic outcomes. TEA is a method that combines engineering design with economic evaluation to assess the viability of technological systems. The method allows decision-makers to analyze how technological parameters influence project costs, profitability, and overall feasibility (Barahmand & Eikeland, 2022). Net present value (NPV), product selling price, capital expenditure (CAPEX), operating expenditure (OPEX), and payback period are typical outputs from techno-economic analysis (Mahmud et al., 2021)

3.1.2 Application of Techno-Economic Analysis in Building Projects

Several studies demonstrate the importance of techno-economic frameworks in building transformation projects. Choi and Kim (2023) developed a techno-economic feasibility framework for deep renovation of apartment buildings by integrating technical feasibility evaluation with cost-benefit analysis. Their study showed that renovation strategies must consider both engineering constraints and economic indicators to determine project feasibility.

Similarly, Ahmed and Asif (2020) conducted a techno-economic assessment of energy retrofitting strategies in residential buildings using building information modelling (BIM). Their study demonstrated that technical improvements in building systems must be evaluated alongside financial indicators such as payback period to determine economic viability.

Economic evaluation methods are particularly important in building transformation projects because financial feasibility is often the primary concern of stakeholders. Sharbaf and Schneider-Marin (2025) highlight that cost-benefit analysis remains one of the most important decision-support tools for evaluating sustainable upgrades in buildings because it compares the monetary value of benefits with project costs.

TEA has become a decision-making support framework for evaluating project alternatives. However, the literature indicates that its conceptual boundaries and methodological procedures remain insufficiently standardized (Chai et al., 2022). Several studies highlight that despite its broad application, TEA still lacks clear guidelines and comprehensive documentation regarding its features and evaluation scope resulting ambiguity in definition and implementation (Barahmand & Eikeland, 2022).

In this context, Mahmud et al. (2021) further identify technical feasibility as a core dimension of TEA, especially in construction projects where practical implementation could affect project outcomes. Within construction feasibility studies, technical feasibility can be analyzed through some criteria such as risk, construction time and constructability. Risk assessment is widely recognized as an essential component of construction feasibility to identify potential technical and execution uncertainties (Barahmand & Eikeland, 2022). Also, project time including schedule constraints is considered a critical technical parameter in evaluating construction alternatives (Khoulenjani et al., 2024). In addition, constructability that defined as the ease with which a design can be efficiently constructed and installed represents a crucial indicator of technical practicality and implementation (Wong et al., 2007).

3.2 Adaptive Reuse vs Relocation of Modular Buildings

Adaptive reuse, often referred to as repurposing, involves converting an existing building to serve a different function while maintaining much of its structural framework and physical identity (Lanz & Pendlebury, 2022; Shahi et al., 2020). Adaptive reuse has become an increasingly important strategy for extending the lifecycle of buildings and maximizing the value of existing infrastructure assets (Vafaie et al., 2023). Adaptive reuse allows stakeholders to retain structural components while modifying internal layouts and functional characteristics to support new uses (Douglas, 2006). This approach can reduce the need for new construction and minimize costs associated with demolition and reconstruction (Vafaie et al., 2023). However, the feasibility of repurposing depends largely on the adaptability of the building structure and the extent of modifications required (Tavakoli et al., 2026).

Research on adaptive reuse emphasizes the importance of evaluating both technical and economic factors when planning building transformations (Sanchez et al., 2020). Adaptive reuse implementation usually begins with identifying client requirements, defining alternative scenarios, and assessing the quality and availability of project-related data before evaluating technical and economic feasibility (Douglas, 2006). Such investigations generally include cost analysis, constructability considerations, and assessment of physical feasibility (Douglas, 2006). Economic analysis of adaptive reuse projects demonstrates that repurposing strategies can provide significant financial advantages compared with demolition and new construction (Sobieraj et al., 2025). Similarly, studies on adaptive reuse and circular construction indicate that retaining a greater share of an existing building can reduce material consumption and environmental impacts compared with complete demolition and reconstruction (Hu & Świerzawskib, 2024).

Adaptive reuse and relocation are two different, but related approaches used to increase the service life of buildings while decreasing the need for demolition and new construction (Shahi et al., 2020). Adaptive reuse is generally understood as the process of changing the function of an existing building while retaining a substantial part of its structure, materials, and physical identity (Lanz & Pendlebury, 2022). In contrast, relocation involves disassembling a building or its parts and reassembling them at another location, usually when the original site no longer supports its continued use

(Pichlmeier & Lindner, 2024). Adaptive reuse is broadly associated with building adaptation activities such as conversion, refurbishment, rehabilitation, and retrofitting to extend building life rather than replacing buildings entirely (Shahi et al., 2020; Vafaie et al., 2023). At the same time, relocation is commonly linked with modular construction systems because these systems are technically more capable of disassembly, transportation, and reassembly than conventional buildings (Coskun et al., 2024; Ostapska et al., 2024).

From a technical perspective, both approaches depend on the adaptability of the building itself; however, while adaptive reuse mainly focuses on in-situ transformation, relocation introduces additional challenges related to dismantling, transportation, logistics, and the recommissioning of building services such as MEP systems (Sanchez et al., 2020). For modular buildings specifically, relocation may be a feasible option because reversible connections, prefabrication, and controlled assembly methods increase the possibility of dismantling and relocating structures with less damage than conventional buildings (Coskun et al., 2024). The comparison between reuse and relocation depends less on selecting one strategy over another and more on the technical characteristics and feasibility of the building itself (Tavakoli et al., 2026). Buildings with high structural integrity, flexible layouts, reusable elements, and adaptable building services are more likely to support reuse potential, while buildings designed with modular assemblies and higher disassembly potential are more likely to support relocation if future site conditions require it (Vafaie et al., 2023). Therefore, adaptive reuse and relocation should not be considered unrelated strategies, but interconnected approaches within a broader framework of building adaptability and circular construction (Lanz & Pendlebury, 2022).

3.2.1 Technicality of Adaptive Reuse in the Built Environment

Adaptive reuse in the built environment refers to modifying the function of an existing building while maintaining a meaningful portion of the structural system, building materials, and physical shape of the building (Lanz & Pendlebury, 2022). This process is discussed using different terms such as renovation, conversion, retrofitting, rehabilitation, and refurbishment (Shahi et al., 2020). These terms are often used interchangeably, although different forms of adaptation require different levels of structural modification, building service replacement, and functional transformation of spaces (Shahi et al., 2020). Adaptive reuse is not only about extending the life of a building, but also about determining the extent to which the original asset can realistically contribute to the performance of the building under new functional demands (Tavakoli et al., 2026).

Studies on reuse success factors indicate that technical feasibility is strongly related to structural complexity, functional requirements, management issues, legal limitations, and environmental considerations (Vafaie et al., 2023). Therefore, adaptive reuse should be considered a multilevel technical process rather than a single design intervention (Vafaie et al., 2023). An important technical starting point in adaptive reuse is the condition of the existing structure (Vafaie et al., 2023). Before decisions regarding future use are made, it is necessary to determine whether the building can physically support a proposed function change without excessive intervention (Tavakoli et al., 2026). Structural integrity, material condition, lifespan, and flexibility of building components are repeatedly identified as key technical criteria in adaptive reuse studies (Vafaie et al., 2023). The ARP and AdaptSTAR approaches evaluate reuse potential based on factors such as adaptability, obsolescence, and characteristics that influence future conversion feasibility (Tavakoli et al., 2026).

Past studies on reuse assessment indicate that technical feasibility is not only dependent on whether a building can be preserved, but also on whether it can continue to provide value under changing functional requirements (Laefer et al., n.d.). This highlights the importance of early-stage technical assessment and understanding the residual performance of the structure before major intervention decisions are taken. Another important technical feature of adaptive reuse is the management of building elements and materials(Sanchez et al., 2020). Reuse-oriented approaches attempt to identify which building components can remain unchanged, which can be upgraded, and which can be selectively removed and reused. Research on selective disassembly demonstrates that this process can balance technical, environmental, and practical constraints while maximizing the recovery potential of valuable building elements (Sanchez et al., 2020).

Life cycle assessment studies further demonstrate that retaining a greater portion of an existing building can significantly reduce environmental carbon emissions compared with demolition and reconstruction (Hu & Świerzawskib, 2024). In this context, adaptive reuse is closely linked with the concept of buildings as resource banks, where embedded material and structural value are preserved alongside functional transformation (Sanchez et al., 2020). Design for Disassembly (DfD) adds another important layer to the technical discussion of adaptive reuse, particularly for modular and experimental buildings (Ostapska et al., 2024). Buildings designed with reversible connections and accessible assemblies can support easier removal, replacement, and reconfiguration of components with minimal damage (Ostapska et al., 2024). DfD enhances the long-term adaptability and transformability of buildings while supporting future interventions without requiring complete replacement (Coskun et al., 2024).

Building services such as HVAC, electrical, and plumbing systems also play a major role in the technical feasibility of adaptive reuse projects (Pichlmeier & Lindner, 2024). Even when the structural system remains suitable for new use, service systems may require significant modification or replacement to meet updated functional requirements Świerzawski. Therefore, technical feasibility assessment should consider the building as an integrated system rather than focusing only on visible structural components (Vafaie et al., 2023). Spatial flexibility is another important technical issue because buildings with flexible layouts can support new functions with fewer structural interventions (Hu & Świerzawskib, 2024). Research on the Swedish building stock indicates that reuse pathways are influenced by factors such as original building function, floor area, and ownership conditions, making some building types more adaptable than others (Iarkov et al., 2025). Buildings with regular geometry, usable spans, and less rigid layouts are therefore generally more suitable for adaptive reuse than highly specialized buildings with fixed spatial configurations (Tavakoli et al., 2026).

3.2.2 Building Relocation as an Alternative Strategy

Building relocation refers to the process of dismantling a building and moving its components to another location for reconstruction and reuse (Ostapska et al., 2024). Relocation has gained increasing attention in the context of modular and prefabricated construction systems because these systems are designed with standardized elements and demountable connections that support disassembly and reinstallation with limited structural damage (Coskun et al., 2024). Unlike adaptive reuse, which mainly focuses on modifying a building in its existing location, relocation introduces additional technical stages such as deconstruction, transportation, handling, and reassembly (Ostapska et al., 2024). The growing interest in circular construction has also increased attention toward relocation as a strategy for preserving building value when site conditions change, or existing locations become unsuitable for continued use (Pichlmeier & Lindner, 2024).

A major technical component of relocation is the disassembly process, which requires careful planning to avoid damage to both structural and non-structural components (Pichlmeier & Lindner, 2024). Research on building service reuse indicates that the potential for reusing systems such as HVAC, piping, and electrical installations is strongly influenced by how these systems are disconnected and handled during disassembly (Pichlmeier & Lindner, 2024). This demonstrates that relocation is not only a structural operation, but also a system-level intervention where building services and physical elements must be managed simultaneously. Design for Disassembly (DfD) strategies are particularly important in improving relocation feasibility because they allow building elements to be separated and reused more efficiently while minimizing performance loss and physical damage (Ostapska et al., 2024). Buildings designed according to DfD principles can generally be dismantled more effectively and with reduced material loss, increasing their future relocation and reuse potential (Coskun et al., 2024).

Transportation is another critical technical factor because it directly affects relocation feasibility and risk (Coskun et al., 2024). Building components must be transported safely between locations, creating limitations related to component size, weight, infrastructure conditions, route planning, and transportation regulations (Coskun et al., 2024). Improper handling during transportation may damage building components, reduce usability, and increase repair requirements after relocation (Rios et al., 2015). The reassembly stage also creates significant technical challenges, particularly in maintaining structural integrity and operational performance after relocation. Components must be accurately reconnected, while building services require recalibration and reintegration within the new environment (Pichlmeier & Lindner, 2024). Although modular systems facilitate this process through standardized connections and prefabrication logic, careful coordination is still necessary to ensure that the reconstructed building performs as intended (Coskun et al., 2024).

Another important aspect influencing relocation feasibility is the extent to which a building was originally designed for flexibility and disassembly (Ostapska et al., 2024). Buildings using modular design principles, reversible connections, and accessible assemblies are generally more suitable for relocation than conventional structures (Coskun et al., 2024). This indicates that relocation feasibility is not only determined during intervention stages, but is also strongly influenced by decisions taken during the original design phase (Ostapska et al., 2024).

3.3 Technical and Economic Indicators

Techno-economic assessment of building transformation projects requires the evaluation of both technical and economic aspects to support informed decision-making between alternative scenarios (Mahmud et al., 2021). In projects involving adaptive reuse and relocation, decision-making is not only influenced by financial feasibility but also by technical complexity, implementation challenges, uncertainty, and long-term operational performance (Barahmand & Eikeland, 2022). Therefore, technical and economic indicators are commonly used to evaluate the practicality, feasibility, and viability of different building transformation strategies more systematically and comparably (Khoulenjani et al., 2024).

3.3.1 Technical Indicators

Technical feasibility is considered one of the core dimensions of techno-economic analysis because practical implementation directly influences project performance and long-term viability (Mahmud et al., 2021). Several studies highlight that techno-economic assessment still lacks clear implementation guidelines and comprehensive evaluation frameworks, resulting in inconsistencies in practical application (Barahmand & Eikeland, 2022).

Technical indicators in building transformation projects commonly include constructability, implementation complexity, flexibility, risk, structural adaptability, and project duration (Barahmand & Eikeland, 2022). Risk assessment is widely recognized as an essential component of technical feasibility because it helps identify technical and operational uncertainties that may influence project implementation and future performance (Barahmand & Eikeland, 2022). Project schedule and construction time are also considered important technical indicators because they directly affect implementation feasibility and project coordination (Khoulenjani et al., 2024). In addition, constructability refers to the extent to which a design can be efficiently implemented and coordinated during construction activities (Wong et al., 2007).

In building transformation projects, technical indicators are also closely connected with structural flexibility, modularity, disassembly potential, and adaptability of building services because these factors strongly influence the feasibility of future modifications and operational continuity (Coskun et al., 2024; Ostapska et al., 2024).

3.3.2 Economic Indicators

Economic indicators are important in building transformation projects because they support comparison between alternative strategies based on financial feasibility, implementation cost, and long-term project viability (Mahmud et al., 2021). In projects involving adaptive reuse and relocation, economic evaluation is not limited to construction cost only, but also considers operational implications, implementation complexity, and uncertainty associated with different project scenarios (Barahmand & Eikeland, 2022).

Capital expenditure (CAPEX) and operational expenditure (OPEX) are commonly used economic indicators in construction decision-making because they provide an understanding of both initial investment requirements and future operational implications of a project (Geekiyanage et al., 2018). In building transformation projects, economic feasibility depends on factors such as modification requirements, transportation cost, dismantling complexity, reconstruction needs, material reuse potential, and future operational performance (Coskun et al., 2024; Pichlmeier & Lindner, 2024).

Cost-benefit analysis (CBA) is one of the most widely used approaches for evaluating whether a project alternative is economically justified. CBA compares project costs with expected benefits and supports comparison between multiple intervention scenarios based on economic outcomes (A. Sharbaf & Schneider-Marin, 2025). Financial indicators such as net present value (NPV), benefit-cost ratio (BCR), and payback period are also widely used in techno-economic studies because they help decision-makers evaluate the long-term financial performance and economic viability of alternative strategies (Bochare et al., 2024).

Economic evaluation in construction projects therefore relies on structured indicators that assess cost, performance, and implementation feasibility together rather than considering financial values independently (Mahmud et al., 2021). Techno-economic analysis integrates technical feasibility with financial assessment so that project alternatives can be evaluated more comprehensively under practical construction conditions (Barahmand & Eikeland, 2022). The reliability of economic evaluation methods is strongly influenced by uncertainty because variations in project parameters such as material cost, transportation requirements, implementation complexity, and future operational conditions can signifies (Barahmand & Eikeland, 2022). Therefore, sensitivity analysis and scenario-based evaluation are commonly used to support decision-making under uncertain project conditions and to improve the reliability of comparative assessment between alternative building transformation strategies (Khoulenjani et al., 2024).

3.4 Cost Structure Comparison: Reuse vs Relocation

The cost structure of adaptive reuse and relocation in construction projects is affected by uncertainty, the level of intervention, and the condition of existing assets. Economic evaluation is more complex than new construction projects(Barahmand & Eikeland, 2022) . Cost estimation in such cases requires a detailed understanding of building performance and needed modifications, as existing buildings are most likely not in line with current functional or regulatory needs (Choi & Kim, 2023). Variations in assumptions, such as energy costs and discount rates, can have a big impact, and this makes uncertainty an integral aspect of cost evaluation (Barahmand & Eikeland, 2022).

In the techno-economic analysis (TEA) method, the economic assessment is carried out by calculating both capital expenditure (CAPEX) and operational expenditure (OPEX), as these cost components are fundamental in determining the overall production cost and economic feasibility of the project (Henry et al., 2023). In CAPEX and OPEX calculations, gross floor area (GFA) and net floor area (NFA) are fundamental parameters because both capital and operating costs are commonly normalized on a per-square-meter basis to improve comparability across building alternatives (Geekiyanage et al., 2018). In addition, contingency allowances are essential CAPEX components, as they account for project uncertainty risk associated with design development and unforeseen construction works, it also used to avoid cost overruns in budgeting process

(Zhao et al., 2024). Contractor fees should be incorporated into CAPEX calculations as part of indirect costs and a profit margin into each project. Making the contractor fee a combination of home office overhead and anticipated profit, usually between 2.5–7.5% for commercial works and 10% or higher for civil and residential projects due to elevated direct labor risks. Since budget estimates are generally the least accurate form of cost estimation, they should also include significant contingency allowances, typically between 10–20%, to mitigate uncertainty and unforeseen costs (Holm, 2019).

3.4.1 Repurposing Cost Components

Repurposing scenario includes several components that associated with the process of transforming an existing building to a new function. Selective demolition, which is often required to remove non-functional components while preserving usable materials, is a more complex process than conventional demolition due to the requirements of precision and careful handling of components (Sanchez et al., 2020). Refurbishment and retrofitting costs is responsible for major part of the total investment, especially in case of upgrades, which involve systems such as HVAC equipment, extra insulation, and electrical equipment standards (W. Ahmed & Asif, 2020). Compliance with safety, accessibility, and energy regulations can add the project cost, particularly in older buildings where existing systems do not comply with modern requirements (A. Sharbaf & Schneider-Marin, 2025). Plumbing adjustment includes modifications to water supply systems, drainage, sanitary fixtures, and wastewater connections. Changes in occupancy type or space layout require significant plumbing reconfiguration, particularly where wet rooms, sanitary cores, or service zones are relocated (Douglas, 2006). In addition, information and communication technology is increasingly recognized as a dedicated cost component of construction projects, for example, data cabling, network systems, and smart building systems (Eliwa et al., 2022).

In the early phase of the project, project preparation is identified as a cost component in adaptive reuse projects, which includes feasibility studies, building condition assessments, design development, and project management activities (Douglas, 2006). Moreover, site preparation also includes temporary works, access arrangements, health and safety provisions, material storage, and waste segregation areas.

Besides building services, building envelopes and the interior of the building are also an important part of the adaptation. The building envelope works include façade upgrades, replacement or refurbishment of windows, insulation improvements, roof works, waterproofing, and entrance modifications. In addition, the interior comprises new partition walls, ceiling, systems, floor restructuring, access route, and space reconfiguration to accommodate the new building function (Douglas, 2006). Envelope and interior intervention are central to adaptive reuse because functional requirements frequently differ substantially from the original layout, and can reduce energy consumption (Gnaba et al., 2025).

The scope of intervention differs from one project to another, leading to a strong dependence on the cost outcome on the condition of the building and intended performance levels (Choi & Kim, 2023). Uncertain factors such as hidden defects or outdated systems can bring unexpected expenses during reconstruction, which makes cost prediction difficult in early project stages (Barahmand & Eikeland, 2022). Economic evaluation methods emphasize the need to account for such uncertainties to ensure a realistic decision-making process (A. Sharbaf & Schneider-Marin, 2025). For this reason, contingency allowances that are usually higher than other costs are made in adaptive reuse projects to address potential risks (Bochare et al., 2024).

Operational expenditure (OPEX) in the repurposing scenario refers to the recurring costs required to maintain the daily operation, functionality, and comfort of the HSB Living Lab building after renovation work is completed. Unlike capital expenditure (CAPEX), which focuses on one-time investment costs, OPEX is continuous expenses that occur throughout the building's operational life. In this study, the main OPEX components consist of energy and utilities, including district heating, electricity, water, and regular cleaning services. These components are important because they directly influence the long-term financial performance and sustainability of the repurposed building (SUHF, 2024).

3.4.2 Relocation Cost Components

Relocation carries extra layers of costs that are not part of adaptive reuse, such as disassembly, transportation, and reassembly. The disassembly stage requires careful removal of components to avoid damage, which adds to extra labor compared to standard demolition processes (Ostapska et al., 2024). The level of complexity in this stage varies depending on many factors, such as connection types, such as screws or welded connections, and material properties, which affect the ease with which the parts are separated and reused (Ostapska et al., 2024).

Transportation is an important and costly aspect, since it varies with the distance, the size of the component, and logistic constraints such as restrictions of route and regulations that require extra safety during transportation of buildings (Coskun et al., 2024). The modular construction systems provide easier handling and transport compared to conventional construction; however, there are still practical challenges affecting feasibility and cost that also depend on the dimensions of the components (Coskun et al., 2024). Movement of the components also brings the risk of damage, which can decrease the reuse potential or require additional repair work after relocation (Pichlmeier & Lindner, 2024).

Reassembly involves the precise installation of components to ensure the structural stability and performance of systems (Coskun et al., 2024). Building services may require adjustment as per the new site, which adds to the technical complexity and additional cost (Pichlmeier & Lindner, 2024). New site preparation is also required, which involves the construction of foundations and infrastructure, leading to additional costs that are not necessary in adaptive reuse projects (Coskun et al., 2024).

3.5 Decision Making in the Construction Industry

Decision-making in the construction industry is characterized as a complicated, difficult, and multi-dimensional process due to the involvement of multiple task and requirements, uncertainty, and conflicting objectives (Zhu et al., 2021). Construction projects typically have many elements that cannot be valued equally. This issue requires systematic and structured decision-making approaches to ensure project success and assist the client in decision-making process (M. N. Ahmed et al., 2024). The decision-making process in construction generally follows a structured sequence consisting of problem identification, identifying decision criteria, generation of alternative solutions, assigning weights to criteria, evaluating alternative solutions, and selection of the optimal solution (Szafranko & Harasymiuk, 2022).

The complexity of construction decision-making arises from the need to consider multiple objectives, including cost, time, quality, and sustainability, which are often conflicting (Zavadskas et al., 2014). In practice, decision-making is iterative and requires both quantitative data and qualitative judgement due to uncertainty and incomplete information (Taherdoost & Madanchian, 2024). As a result, decision makers in construction rely on both analytical tools and expert judgement to achieve optimal outcomes (Zhu et al., 2021).

Owner requirements are central to construction decision-making, as they define project goals (M. N. Ahmed et al., 2024). These requirements typically include cost efficiency, schedule controlling, quality standards and long-term operational performance (Nejatyan et al., 2023). Additionally, owners increasingly consider sustainability and environmental impact as key decision criteria in modern construction projects (Sivasubramanian & Lee, 2022). Therefore, decision-making frameworks must align technical solutions with owner expectations and project goals (Zhu et al., 2021).

Stakeholder expectations further complicate construction decision-making due to the diversity of interest involved in projects (Park, et al., 2025). Construction stakeholders including contractors, consultants, regulators, and end-users, often have conflicting priorities that must be adapted during decision-making (Senarath et al., 2026). Combining both expert and user perspectives has been shown to improve the effectiveness and acceptance of decisions in construction project (Park, et al., 2025). Consequently, decision-making tools must be capable of integrating multiple objectives into a unified evaluation framework (Zhu et al., 2021).

Construction projects involve various types of decisions across different phases of the project lifecycle. Strategic decisions, such as project feasibility and delivery method selection are made in the early stages and have long-term impacts on project performance (Mohammed et al., 2019). To address the complexity of construction decision-making, various tools and methodologies have been developed (Taherdoost & Madanchian, 2024). Traditional tools such as risk identification or risk assessment are still used but often insufficient for handling multiple conflicting criteria. As a result, a method particularly Multi-Criteria Decision Making (MCDM) has gained widespread adoption in construction (Zhu et al., 2021).

3.5.1 MCDM in Construction Industry

Multi-Criteria Decision Making (MDCM) is a structured methodological framework used to evaluate and prioritize alternatives based on multiple criteria. Unlike traditional decision-making approaches that rely on a single objective such as cost optimization, MCDM acknowledges decision making to choose between alternatives that are supposed to be screened, prioritize and eventually ranked (Triantaphylou, 2000).

MCDM is established in operations research and decision theory and has been widely applied in construction project management, where decision-makers must evaluate complex decisions among technical, financial and environmental considerations (Zavadskas et al., 2014). Different alternatives on MCDM could have different criteria, where criteria represent different dimensions from which the alternative can be viewed. The challenges might appear within this model when different criteria may conflict with each other, such as cost and profit. Also, different units of measure will apply in different criteria, where MCDM naturally can solve and consider all these challenges (Triantaphylou, 2000).

The use of MCDM methods in the construction industry has increased significantly due to the growing complexity of decision problems (Zavadskas et al., 2014). MCDM provides systematic approach for evaluating alternatives based on multiple criteria, enabling decision makers to make more informed and balanced decisions (Zhu et al., 2021). This method is particularly useful in construction because it allows decision makers to assign weights to criteria and evaluate trade-offs between competing objectives. This capability is important in construction projects, where decisions often considering balancing economic, technical and environmental factors (Balasbaneh et al., 2025).

The application of MCDM in construction occurs in various types of projects and objectives. Common applications include environmental management, material selection, economic viability, technical performance and sustainability assessment (Mlybari, 2025). The practice of MCDM in construction has evolved to include hybrid approaches that combine multiple methods to improve accuracy and robustness (Zavadskas et al., 2014). For example, using Life Cycle Assessment (LCA) and MCDM or Analytics Hierarchy Process (AHP) with Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) (Mlybari, 2025). These hybrid approaches influence the strengths of different methods and provide more reliable decision outcomes.

Among the various methods developed within MCDM framework that classified according to the type of data that been used such as deterministic, stochastic and fuzzy, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is recognized as one of the most applied for ranking alternatives in complex decision environments (Triantaphylou, 2000). While MCDM provides generals structure for decomposing decision problems, defining criteria and incorporating stakeholder preferences, individual methods differ in how they synthesize and evaluate alternative performances. TOPSIS differ itself through evaluation of each alternative based on its quantitative distance from both ideal (best) and a negative ideal (worst) solution (Hwang & Yoon, 1981).

3.5.2 TOPSIS in Construction Industry

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is one of the most widely used MCDM methods in the construction industry due to its simplicity and effectiveness (Taherdoost & Madanchian, 2024). TOPSIS is based on the concept that the best alternative should have the shortest distance from the ideal solution and the greatest distance from the negative ideal solution (Hwang & Yoon, 1981). The TOPSIS method enables decision-makers to evaluate and rank multiple alternatives based on a set of criteria (Taherdoost & Madanchian, 2024). By comparing alternative, TOPSIS give a structured and transparent process to choose the most preferable option.

TOPSIS enables a clear and rational ranking process, particularly in cases involving conflicting criteria, which are typical in construction and project management context (Zavadskas et al., 2014). Furthermore, compared to other MCDM such as AHP and ELECTRE, TOPSIS offers efficiency without requiring extensive pairwise comparisons, making it suitable for practical applications with large datasets (Behzadian et al., 2012).

TOPSIS method has simple processes to program and use, and it is also efficient technique with widespread application (Madanchian & Taherdoost, 2023). Shih et al. (2007) discussed some advantages of TOPSIS in decision making:

a. The method can represent the rationale of human choice.
b. Scaler value of TOPSIS can account simultaneously for the best as well as worst alternatives.
c. It has a simple computation process that makes programming on a spreadsheet possible.

d. As discussed before, the number of attributes does not affect the number of TOPSIS process steps.

However, TOPSIS also faces different disadvantages in the following issues, such as weighing the criteria is a difficult and uncertain process. Also, it sometimes cannot determine uncertain data precisely due to the possibility of vague human judgments when the information is not sufficient (Madanchian & Taherdoost, 2023).

The process of choosing the best alternative using TOPSIS can be done in six main steps that shown in Figure 4 (Madanchian & Taherdoost, 2023).

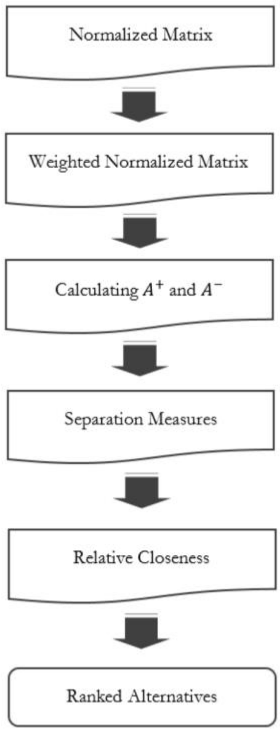

Figure 4 TOPSIS Process

In MCDM problems, criteria often shown in different units, making direct comparison difficult. To enable comparison, the first step of TOPSIS is to make these criteria transformed into dimensionless values through normalization process. Vector normalization is commonly applied, where each element x_{ij} in the decision matrix is converted into normalized value (Shih et al., 2007).

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} {x_{ij}}^2}}$$

The second step is to calculate the weighted normalized matrix (*V*)

$$V = (v_{ij})_{nxm}$$

Where $v_{ij} = w_j r_{ij}$

The third step is to determine the positive ideal and negative ideal solutions. Positive ideal solution is Zenith ($A*$) and negative ideal solution is Nadir or anti ideal (A^-). These can be determined as the absolute form of positive and negative ideal as:

$$A^* = \{1,1,1,\ldots,1\}$$
$$A^- = \{0,0,0,\ldots,0\}$$

To obtain the negative and positive ideal solutions, the following equation can be used.

$$A^* = \{v_1^*, v_2^*, \ldots, v_n^*\} = \{({}^{max}{}_j v_{ij} \mid i \in I'), ({}^{min}{}_j v_{ij} \mid i \in I'')\}$$
$$A^- = \{v_1^-, v_2^-, \ldots, v_n^-\} = \{({}^{min}{}_j v_{ij} \mid i \in I'), ({}^{max}{}_j v_{ij} \mid i \in I'')\}$$

The fourth step of TOPSIS is to calculate the distance of alternatives with $A*$ and A^-. Euclidian Distance equation is used in this step:

$$D_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2}$$
$$D_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2}$$

The fifth step is to calculate the relative closeness. The range of the relative closeness factor is between 0 and 1, it is calculated using the following equation:

$$C_i^* = \frac{D_i^-}{D_i^+ + D_i^-}$$

The final step of TOPSIS is to rank the alternatives from the best with biggest C_i^* to the worst alternative with the lowest C_i^*. The alternative which has the biggest C_i^* is the solution of the decision-making process (Madanchian & Taherdoost, 2023).

In the context of sustainable economic evaluation within construction projects, key criteria commonly considered include initial construction cost, operational and maintenance costs, as well as the time required for design and construction activities (Kamali et al., 2025). These criteria are important because they show both the short-term capital investment and the long-term lifecycle implications of the project. To ensure comparability between alternatives, cost-related criteria are often expressed to a functional unit, allowing for standardized assessment across options of different scales. In construction projects, this is commonly represented as cost per square meter (cost/m^2), using floor area as the functional unit, which provides a consistent basis for evaluating a construction project (Holm, 2019).

Construction projects are dynamic and operate with uncertainty and multiple risks. In this context, risk management becomes a critical criterion in decision-making processes, and it will determine the project success as it able to identify and mitigate a potential threat (Zhu et al., 2021). In addition to risk considerations, technical aspects such as constructability or ease of installation also essential evaluation criteria in construction decision-making, particularly when comparing alternative design or delivery options (Villalba et al., 2024).

A major challenge in applying MCDM methods, including TOPSIS is when the decision variables cannot be expressed in a measurable quantitative value (Triantaphylou, 2000). This is common in construction projects, where several criteria such as technicality and risks are qualitative criteria. As a result, the decision-making process often relies on subjective judgements from expert assessments, professional experience or stakeholders' preferences. To enable systematic analysis within MCDM framework, these qualitative judgements must be translated into numerical scales or scores that allow comparison across alternatives (Zhu et al., 2021).

4 Empirical Results and Analysis

This chapter outlines the empirical results from the interviews and questionnaire of the study, and their analysis in terms of the developed scenarios. The findings are organized to include both qualitative expert feedback and user-focused feedback, offering a holistic view of the technical, spatial, and functional factors affecting the reconversion of the HSB Living Lab. The results are presented according to the scenarios, with each section combining empirical insights and analysis to support the techno-economic assessment.

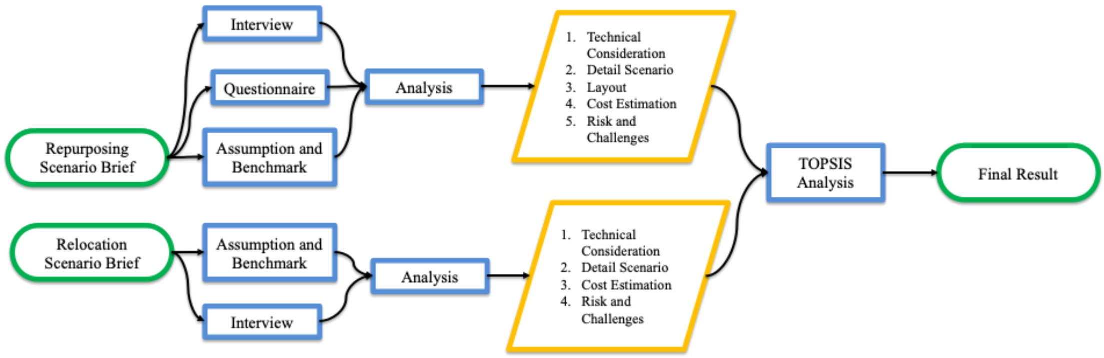

Figure 5 Analysis Flow

4.1 Scenario 1: Repurposing

In the present case study, the focus is on how the HSB Living Lab can be adapted to become an academic learning environment at Chalmers University of Technology, which is currently used as a residence and research facility. This emphasis is on redefining the utilization of the available spaces to fit in teaching activities, without changing the basic structural design of the building.

The change of use from individual and small group residential to collective and activity-based academic use. This transformation demands areas that can accommodate lectures, seminars, and group learning where interaction and flexibility will be important functional demands. The building is redefined as a communal space, which will encourage learning and interaction among students instead of individual living units. The strategy used in this case is internal restructuring as opposed to structural adjustment. The existing spaces are repurposed for new functions, and the building can be utilized to provide educational opportunities with the existing space. This avoids the need for major construction interventions and enables a functional change in line with academic needs.

In this scenario, the approach taken is one of internal reorganization rather than structural change. Spaces are designed to accommodate various teaching styles, such as bigger spaces to conduct group instruction and smaller rooms to conduct discussions and focused work. This diversity allows the building to be flexible in meeting the needs of various users and teaching methods. No changes are made to the main circulation system, and access and movement remain throughout the building. The adjacent areas are reconfigured for greater functionality and increased use for academic purposes. This facilitates free flow and clarity in space arrangement.

The situation, in general, offers a plan where the building is modified by means of functional reallocation and reorganization of space. The emphasis is on how to make use of the space available for education activities, and this is the basis for the comprehensive layout and design decisions made in the following sections.

4.1.1 Interview Insights

Interview insights offer a qualitative assessment of the key factors affecting the potential of reusing the HSB Living Lab. Their insights from experts in academia, campus planning, industry, and building facility management emphasize the strategic, technical, and operational aspects of converting the building. The findings are organized thematically to illustrate different themes and perspectives, which further support the spatial and functional analysis.

4.1.1.1 Demand and Pedagogical Requirements on Campus.

The interview outcomes show that there is a multi-layered and consistent impression of the increasing pressure on teaching space in the university context. Strategically, a campus strategist at Chalmers pointed out that the learning environment demand is changing in line with the overall institutional changes such as campus densification and redistribution of student activities across different locations. This change is not only increasing the number of users on campus, but also the demand for space that can be used for a wider range of teaching methods.

This opinion is also supported by a campus planning representative who observed that although the current spaces are being utilized using scheduling and optimization strategies, their efficiency is minimal, as the spatial arrangement is not in tandem with the teaching needs. The issue, however, does not just lie in the availability of space, but the appropriateness of the available spaces to the modern teaching practices. In most cases, the facilities used for traditional lecture teaching are not suitable for more interactive and flexible teaching, resulting in poor use of the teaching facilities available.

This is further discussed from an academic point of view. The teaching methods have undergone a dramatic transformation in the last few years, one of the professors in the Architecture and Civil Engineering department said. Courses are increasingly based on group discussions, workshops, and collaborative activities, rather than lectures, requiring different spatial arrangements. This view was also reinforced by another professor from the University of Sweden in the field of construction management, who emphasized the need for spaces that are functional and flexible to facilitate interactive teaching. All these insights point to the conclusion that the need to acquire learning spaces should be perceived not merely in quantitative terms but also in qualitative ones. It is not only the need to have more classrooms, but for spaces that are aligned with the way teaching is currently delivered. This difference is essential when one speaks about the reuse of an already existing building because the emphasis is no longer on the increase of capacity but rather on the functional change.

In addition, it was observed that teaching activities are usually carried out in small to medium-sized groups. This observation suggests that the provision of many medium-sized spaces may be more effective than focusing on large lecture halls. Combined, the results of the interview create a definite correlation between spatial demand and pedagogical change. The change in teaching practices is also directly affecting the kind of environments needed, and the significance of adaptability, usability, and diversity in spatial design.

4.1.1.2 Repurposing Technical and Operational considerations.

The technical aspects of the building and its limitations are closely connected with the possibility of repurposing the building. In terms of engineering, one of the project managers of a building services consultancy explained that the building had a much greater degree of system integration than a traditional building. The overcrowding of mechanical and electrical installations indicates its original intent as a research and experimental facility, in which systems were to be monitored, modified and tested.

Although this degree of complexity offers the chance to experiment, it may not always be in line with the needs of a teaching setting. One of the facility management representatives related to the building pointed out that a significant part of the existing systems is not needed in daily functioning and could be changed or simplified to accommodate the new functionality. Specifically, the systems associated with the ventilation, electrical distribution, and control mechanisms were outlined as possible areas where adjustment can be required.

Operationally, the difference between structural and non-structural aspects are of specific interest. Several interviewees emphasized that the building structural system does not pose much of a restriction to repurpose. Rather, internal configurations and building services are the main problems. This implies that internal restructuring would be sufficient in bringing about transformation, and no dramatic intervention would be necessary.

The industry perspectives give additional information on the feasibility implications of repurposing. An expert of a construction industry, who spoke on the topic of modular buildings, has observed that modular buildings are a naturally flexible building type, because they can be internally modified without affecting the structural integrity of the building. But such flexibility is best utilized when only internal factors, including partitions and finishes, are concerned. Massive changes or relocation brings in more complexity and expense and cuts down the overall viability of such solutions.

On the same note, a demolition and reuse specialist noted that in many cases reuse activities can be more resource-intensive than traditional demolition, especially where they entail large-scale dismantling or re-using. This view strengthens the need to reduce the intervention and working within the existing configuration of the building. The most efficient strategy, which is based on reconfiguration rather than reconstruction.

On the cost consideration, an expert in construction management indicated that a large percentage of building costs is linked with mechanical systems and finishes. This fact has a direct implication regarding the impact of repurposing strategies since it implies that changes to these factors should be carefully considered. To keep economic viability, complex systems can be avoided in making unnecessary adjustments to reduce the systems yet aim at the intended functional change. Overall, the technical and operational observations show that the concept of repurposing is quite viable and realistic, if it is done in a strategic manner. The focus must be on internal space adaptation, simplification of technical systems when it is needed, as well as the reduction of interventions that add complexity and costs.

4.1.1.3 Building as a Potential Learning Environment.

The building has its own opportunities as a learning environment in addition to technical and spatial features. Some interviewees emphasized the importance of real-life buildings to be used as learning aids, especially in those subjects that are associated with architecture, construction and building services. One of the professors in the department mentioned that observing and engaging with real systems can help students better grasp theoretical ideas, giving them a more concrete linkage of design and performance.

Others have also agreed with this view and pointed out that experimental learning is a significant element of technical education. The visible systems, including mechanical installations and structural elements, enable students to have direct access to the physical dimension of the built environment. This may be very useful in courses that emphasize performance building, sustainability, and system integration.

Nevertheless, the applicability of this aspect is changed based on the teaching context. Whereas certain courses might greatly benefit by being in direct contact with building systems, others might not need this kind of interaction. A facility-related representative mentioned that not all the experimental features might be required in the new purpose of the building, especially when they are not directly related to teaching.

This implies that the use of the building as a learning tool must be viewed as a bonus and not a main goal. The emphasis of repurpose is to be on the development of functional teaching spaces, and learning opportunities linked to building systems can be incorporated selectively. Meanwhile, the availability of these features makes the building stand out of the traditional teaching space, which offers a distinctive learning environment. This feature can be used to improve the learning experience of the building when implemented properly, and it could be used to promote a more integrated approach to teaching and practice.

4.1.2 Questionnaire Insights

4.1.2.1 Practice and Space Demand Teaching.

The results of the questionnaires give a clear insight into the current way of teaching and the effect of the same on the spatial requirements. These responses show that the teaching practices are mainly interactive with a high focus on group work, seminars, and activities that involve discussions. The most common teaching method in particular, group work, is an indication of a movement towards collaborative learning.

This trend implies that learning environments should be conducive to interaction and flexibility to enable students to actively participate in the learning process. These activities do not fit well in traditional lecture-based settings, which have fixed seating and have limited flexibility. Instead, there is a need to have spaces that can be redesigned to suit various teaching formats.

In terms of class size, the results show that most teaching activities involve groups of 20 to 40 students. This range constitutes the most typical teaching situation, and less frequent ones reflecting the necessity of bigger spaces. Meanwhile, the significance of smaller spaces to work in groups and conduct discussions can also be observed, which emphasizes the necessity of having different sizes in room. The synthesis of these results shows that space design must be flexible and diverse but not centered on the one type of classroom. To meet the needs of users, it is important to provide various spaces that may be used in support of various teaching activities.

4.1.2.2 Functional Priorities within the Learning Environments.

The results of the questionnaire clearly show that the effectiveness of a teaching space depends on the functional features. Basic factors that respondents consistently cite as a successful learning environment include comfortable furniture, reliable digital equipment and environmental quality of the interior.

The open-ended questions reveal more details on these priorities, including the significance of such practical aspects as sound insulation, electrical points, the possibility to see presentation screens, and enough space to move around. These reactions emphasize that the most important consideration to the users is usability and not architectural or technical complexity.

This view is consistent with the interview results and further enhances the notion that teaching environments are supposed to be structured in such a manner that they can assist in everyday activities. It should instead focus on making it comfortable, practical and user friendly instead of making it highly feature-driven, which might not be used by many people.

4.1.2.3 Perceived Limitations and Challenges.

The questionnaire also points to some of the difficulties relating to the possible reuse of the building. The most common concerns raised are spatial restrictions, especially regarding the room size and structure. Respondents reported that the available spaces are not necessarily appropriate to conduct teaching activities, especially where the available areas are limited by residential designs. Other problems are cost, regulations and the general appropriateness of the building as a teaching facility. These responses are indicative of a larger understanding of the feasible limitations of modifying an existing structure, especially one that was not initially conceived as a learning facility.

Simultaneously, the respondents stated that the highly technical systems of the building are not a key teaching necessity. Although these features can be an added value in some situations, they are not deemed necessary in most courses. This supports the argument that the main functional requirements should be considered when designing teaching spaces.

4.1.3 Proposed Layout

The proposed layout incorporates the findings from the interviews and questionnaire into a new layout for the redevelopment of the HSB Living Lab. The design strategy aims to adapt the building's existing layout to align with academic needs while considering technical and resource limitations. The design is aimed at supporting varied teaching formats, efficient use of space, and addressing user needs identified through the empirical study. The following sections explain the spatial arrangement on each floor and how the design meets functional, technical, and pedagogical needs.

4.1.3.1 General Design and Spatial Plan.

The suggested design for the repurpose of the HSB Living Lab is designed following the joint analysis of the findings of the interviews and questionnaires. The transformation strategy is also interested in internal reconfiguration instead of structural modification of the building, enabling it to be adapted efficiently without altering the logic of its construction. The strategy aligns with the principles of technical feasibility and resource efficiency that were majorly found in the analysis.

The repetitive modular structure of the building gives it a systematic foundation of applying a similar design approach to several floors. Each upper level is configured identically, originally intended to be used as a home, as shown in the typical floor plan. This repetition can enable a standardized method of transformation, whereby the same spatial logic can be applied to all the floors but in a flexible way in a particular space.

The design does not imply the creation of new elements but the reuse of the old materials and components. Internal partitioning and wall systems are maintained and modified extensively to create new classroom spaces to minimize the use of more building materials. The strategy reduces the intervention to the minimum, which is also in line with the idea of the circular construction that does not harm the embodied value of existing parts.

4.1.3.2 Capacity and Long-Term Planning Considerations.

Based on information provided by a campus strategist at Chalmers, it is estimated that by 2029, the building will host about 400 students, especially those activities that will have been moved out of the Lindholmen campus. This projection gives a strong framework on how to measure the efficiency of the proposed layout.

The arrangement of the classrooms on various floors and the addition of the bigger teaching area on the ground floor enables the building to accommodate a high number of students around 420 without affecting the quality of space. The layout is made possible by multi-classrooms of medium size, which means that teaching activities can be distributed without causing congestion and enhancing the overall usability. The stepwise approach to campus development also means that the repurposing process can be properly implemented and improved in time. This will enable modification to take place in accordance with the demands over time, so that the building can be flexible in the long run.

4.1.3.3 Conformity to the Teaching Requirements and User Needs.

The layout offered is highly consistent with the teaching practices and user needs that will be determined during the analysis. The allocation of the classes throughout the building reflects the common sizes of the classes that were reported in the questionnaire, and the presence of a flexible space can be used in interactive teaching.

The difference between the general classrooms and flexible learning spaces enables the building to adapt to a variety of instructional formats without having to have special rooms to perform each activity. This increases the flexibility of the building, as the spaces will be effectively utilized in various courses and teaching styles. Moreover, the design emphasis on functional aspects like spatial clarity, circulation and usability. Through these factors, the layout has made the teaching spaces feasible and convenient, as it was found in the interviews and questionnaire responses to be a major necessity.

4.1.3.4 Response to Technical and Operational Constraints.

The proposed layout is based on a balanced reaction towards the technical and operational constraints recognized during the analysis. The design addresses the more challenging needs of complex interventions and enables simpler implementation solutions by concentrating on internal reconfiguration and reusing materials. Meanwhile, the layout permits the targeted adjustment of technical systems when needed, which guarantees that the building will be able to accommodate its new purpose. This practice is consistent with professional knowledge as streamlining systems and preventing needless changes were discovered as the most effective approaches to effectively repurpose.

4.1.3.5 Ground floor transformation: Main Learning and Interaction Centre.

The Existing layout of the ground floor (**Figure 6)** is suggested as a central point of learning and teaching area for students. The planning is to convert the existing office, meeting room, hallway, and administrative spaces, which are shown by blue cloud lines, into a larger classroom that can accommodate about 50 to 60 students, and a common sitting area for students. **Figure 7** showing the new layout of the ground floor, including a classroom, a sitting area, and a small café area for students.

This space will consider the issues in larger-capacity teaching settings that were noted in both interviews and questionnaire responses. Although most teaching activities are carried out in medium-sized groups, large spaces are needed to accommodate shared sessions, presentations, or lectures. The small classrooms on the upper floors are thus balanced by the ground floor classroom, which has a large space capacity.

The rest of the ground floor areas are also redesigned into common spaces, in addition to the main classroom. These zones are meant to accommodate unstructured tasks like waiting between classes, group discussions and independent study. This approach reflects the importance of providing flexible and accessible spaces that enhance the overall student experience.

These shared spaces allow them to help in building a holistic learning experience, where learning and informality are united. This correlates with the results of the interviews and questionnaire results, where flexibility and usability were considered as the requirements.

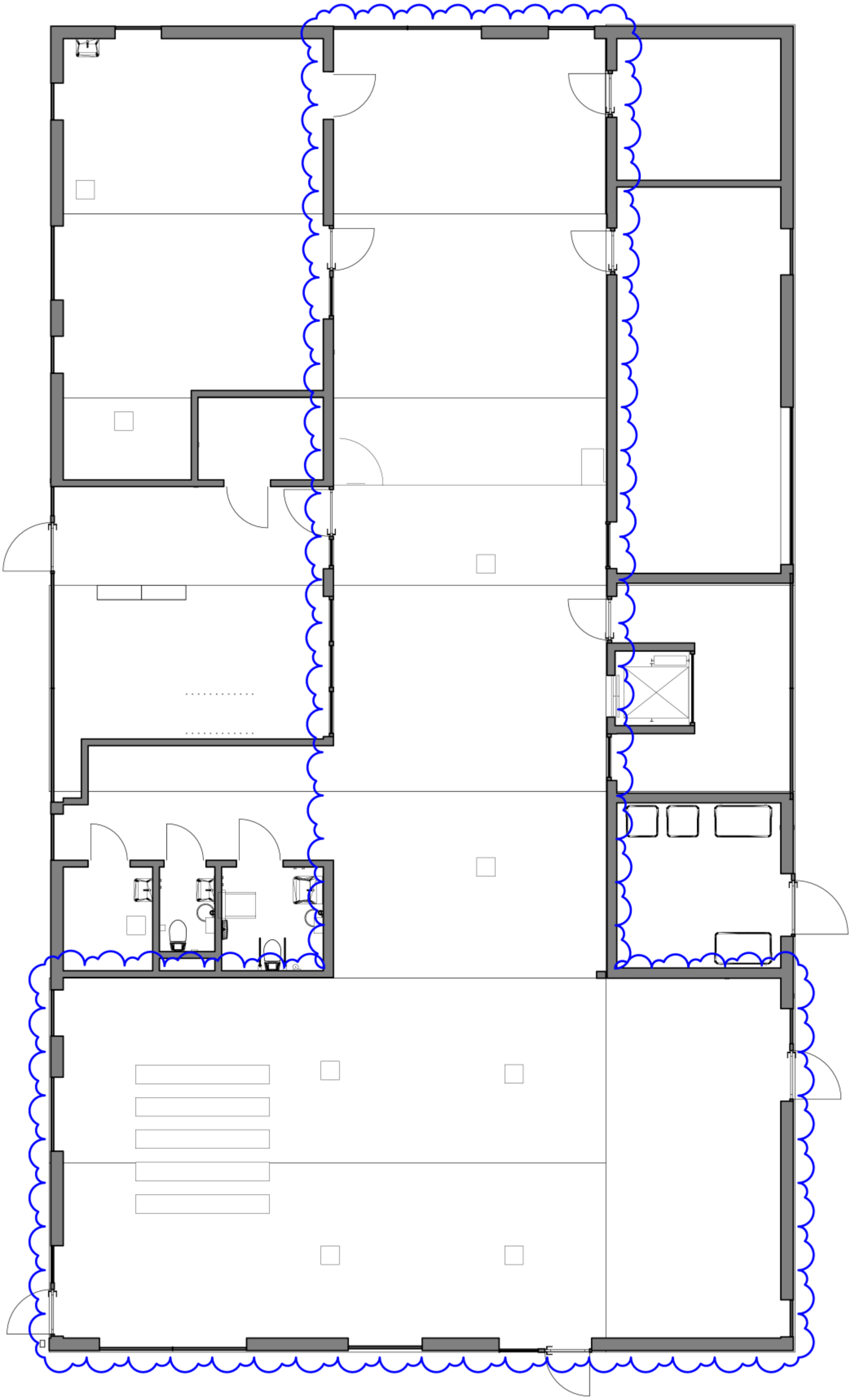

Figure 6 Existing Layout of Ground Floor HSB Living Lab

Figure 7 Purposed Layout of Ground Floor HSB Living Lab

4.1.3.6 Typical Floor Transformation and Classroom Distribution

The upper floors, which are of the same design, are restructured to create three main teaching areas and supportive features. **Figure 8** is showing the existing layout of the typical upper floors. The transformation is guided by the need to provide a balanced mix of teaching environments that reflect the diversity of pedagogical practices identified in the analysis.

The number of rooms per floor is two, which are to be used as general rooms that will be used to conduct lectures and teachings based on seminars. Such rooms are set up to house medium-sized groups, which usually fall within the 20-40 student range. This choice is directly related to the questionnaire results, as this range was determined as the most widespread in the questionnaire. These rooms are designed in such a way that it facilitates clear sightlines, efficient circulation, and ease of use to assist the instructors and students in their teaching activities.

The third classroom is to be a flexible learning environment, which will be used to conduct group work, discussions, and an interactive style of teaching. In contrast to the general classrooms, this space has flexible furniture layouts that can be rearranged based on the activity. It is a design based on both the results of interviews and questionnaires, in which interactive and collaborative instructional techniques were refined.

The current shared spaces of the existing residential pattern are re-conceived as informal learning spaces. These areas give students a chance to discuss, prepare, or do assignments without necessarily being in a classroom setting. The design allows a seamless learning process by incorporating these informal areas in the floor plan as opposed to isolating formal and informal functions. **Figure 9** is showing the new proposed layout of the typical upper floors, including three classrooms, new bathrooms, and a common sitting area for students.

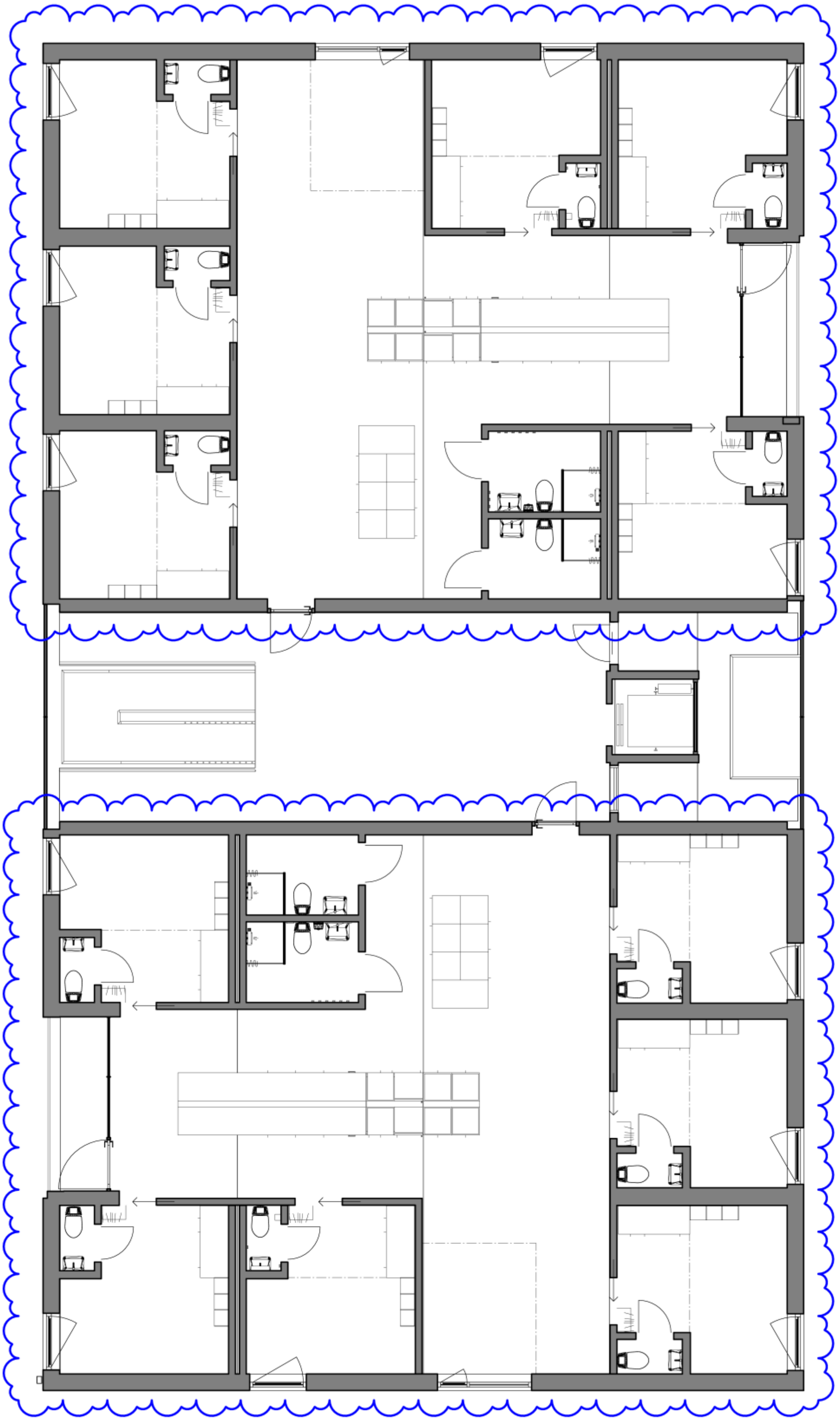

Figure 8 Existing Layout of Typical Floor HSB Living Lab

Figure 9 Proposed Layout of Typical Floor HSB Living Lab

4.1.3.7 Reuse of Material and Adaptation of Components.

One of the main features of the proposed layout is the focus on the reuse of materials and adapting the components. Instead of substituting the existing elements, the design focuses on the retention and reuse of materials wherever feasible. The reuse of internal walls and partitions is used to create new spatial configurations, which require minimum new construction and material waste is minimized.

Existing residential unit doors and openings such as the doors of rooms and bathrooms are modified to fit the functional needs of the new design. This can be done through the resizing, repositioning or alteration of door elements to enhance accessibility, movement and building standards. The design is continuation of the original structure as it does not replace the existing components but only changes them, thus enhancing functionality.

Equally, bathroom facilities are maintained but modified where required to meet the new usage habits and regulatory standards. These changes are maintained as minimally as possible to prevent the transformation of the plumbing systems on a large scale making the transformation both efficient and cost effective.

Moreover, the current kitchen features are not discarded but put in store to be used in other renovation projects. This approach reflects a broader commitment to resource efficiency, where materials are preserved and reused across different stages of development rather than being treated as waste.

4.1.4 Assumption and Benchmark

This study adopts a set of assumptions and benchmarking references to support the reliability of the CAPEX estimation for the repurposing scenario of HSB Living Lab. In accordance with (RICS, 2024) Benchmarking is used as a structured approach to compare project cost estimates against reference projects and professional data sources to validate whether the calculated costs are withing a reasonable range. The guideline emphasizes that benchmarking supports design development and cost planning by reducing the risk of underestimation or overestimation in the early project stages.

A key assumption in the cost estimation concerns the space requirement per student. Based on classroom planning layout, this study adopts a total net floor area (NFA) of

1.440 m^2, which is allocated for 10 classrooms, each designed to accommodate 40 students. This assumption results in a total capacity of 400 students withing the repurposed building. The assumed area of 3,6 m2/student includes desk space, circulation, teaching zone, furniture flexibility and supporting functional areas within each classroom.

To validate the estimated CAPEX, cost benchmarking was carried out using two independent benchmark sources obtained from expert interviews. The first benchmark was obtained from an expert interviewee with professional experience in modular construction and cost estimation, who developed a rough cost estimate of adaptive reuse project. The second benchmark was obtained from a company with prior experience in delivering a similar repurposing project involving the conversion of an existing building into a learning space. The closeness of both benchmark values to the calculated CAPEX in the following subchapter indicates that the estimation is neither significantly underestimated nor overestimated.

4.1.5 Cost Estimation for Repurposing

The Capital Expenditure (CAPEX) results for the repurpose of the HSB building represent the total initial investment required to convert the existing student housing into a learning facility. In the context of building adaptation, CAPEX includes all direct costs associated with physical modifications, technical upgrades, compliance works, and fit-out interventions necessary to meet the requirements of the new function.

Additionally, the building parameters provide important context for the CAPEX calculation. Based on the newly proposed layout in chapter 4.1.3, the repurposed HSB has a net floor area of 1.440 m^2 and a gross floor area of 1.835 m^2, distributed across four floors with 10 classrooms designed to accommodate 400 students. These figures indicate the scale of the conversion works, as the required investment is strongly influenced by usable areas. Moreover, the average capacity of 40 students per classroom affects costs related to interior fit-out, furniture, HVAC, and lighting.

The cost breakdown presented on **Error! Reference source not found.** indicates that the repurposing scenario is characterized by multiple cost components distributed across structural works architectural modifications, building services, and finishing elements. The base construction cost of the repurpose is SEK 23.171.724. The base construction cost was added by contractor’s fee for 6% and contingency allowance for

10% of the base construction cost, the sum of this number is SEK 26.879.200 (see Table 5) which being the total CAPEX of repurposing scenario. A major portion of the CAPEX is likely from interior reconfiguration and functional conversion works such as demolition of non-load bearing partitions, installation of new classroom layouts, acoustic treatments, ceiling works, flooring replacement and updated finishes.

Some works items also calculated based on the percentage of the base construction cost, some suppliers shows the cost of design and consultancy work such as architectural design (10% of the base construction cost), engineering design (5% of the base construction cost), project management and consultancy (7% of the base construction cost) and commissioning (1% of the base construction cost). These work items are differ compared to other items that are calculated based on the cost/m^2 or cost/unit.

Another significant CAPEX contributor is the mechanical, electrical and plumbing (MEP) adaptation. As mentioned by our interviewee, the main changeing for repurposing project is the MEP capacity to meet the new environment, layout, and the number of users inside the facility. For a building originally designed as student accommodation, the service systems may not fully meet the demands of classroom functions, especially regarding ventilation rates, lighting standards and HVAC performance.

Table 4 Repurposing Base Construction Cost

No	General Work	Work Item	Unit	Quantity	Unit Cost	Total Cost
1	Project Preparation	1.1 Feasibility study	Contract	1	SEK 400.000	SEK 400.000
		1.2 Architectural design	Contract	1	SEK -	SEK 1.883.880
		1.3 Building permit and regulatory approval	Contract	1	SEK 37.000	SEK 37.000
		1.4 Engineering design (MEP)	Contract	1	SEK -	SEK 941.940
		1.5 Project management and consultancy	Contract	1	SEK -	SEK 1.318.716
					Subtotal	SEK 4.581.536
2	Site Preparation	2.1 Temporary site facilities	Unit	4	SEK 6.400	SEK 25.600
		2.3 Waste management setup	m^2	1835	SEK 200	SEK 367.000
					Subtotal	SEK 392.600
3	Selective Removal	3.1 Removal of existing furniture	m^2	1835	SEK 90	SEK 165.150
		3.2 Removal of internal partitions/ inner wall	m^2	5717	SEK 300	SEK 1.715.100
		3.3 Removal of kitchen units	Unit	9	SEK 7.000	SEK 63.000
		3.4 Removal of bathroom fixtures	Unit	38	SEK 16.000	SEK 608.000
		3.5 Removal of electrical system	m^2	1835	SEK 600	SEK 1.101.000
		3.6 Removal of plumbing system	m^2	1835	SEK 200	SEK 367.000
		3.7 Removal of existing residential HVAC system	m^2	1835	SEK 200	SEK 367.000
		3.8 Waste transportation and recycling	m^2	2009	SEK 200	SEK 401.800
					Subtotal	SEK 4.788.050
4	Building Envelope Adaptation	4.1 Window replacement or modification	Unit	70	SEK 12.000	SEK 840.000
		4.2 Door security system	Unit	10	SEK 11.000	SEK 110.000
					Subtotal	SEK 950.000
5	Interior Construction	5.1 New inner walls for classrooms	m^2	1350	SEK 640	SEK 864.000
		5.2 Suspended ceilings	m^2	1835	SEK 530	SEK 972.550
		5.3 Raised flooring or cable floor systems	m^2			SEK -
		5.4 New classroom door	Unit	10	SEK 5.400	SEK 54.000
		5.5 Doors installation (WC+classroom)	Unit	22	SEK 2.000	SEK 44.000
					Subtotal	SEK 1.934.550
6	Mechanical Systems (HVAC)	6.1 Installation of ventilation systems	m^2	1835	SEK 1.000	SEK 1.835.000
		6.2 Air handling unit	Unit	2	SEK 500.000	SEK 1.000.000
		6.3 HVAC control systems	Unit		SEK -	SEK -
		6.4 Indoor air quality monitoring systems	Unit		SEK -	SEK -
					Subtotal	SEK 2.835.000
7	Electrical Systems	7.1 Electrical infrastructure upgrade	m^2	1835	SEK 1.100	SEK 2.018.500
		7.2 Electrical panel	Unit			SEK -
		7.2 Lighting system for classrooms	m^2	1440	SEK 400	SEK 576.000
		7.3 Power outlets and floor boxes	Unit	400	SEK 1.000	SEK 400.000
					Subtotal	SEK 2.994.500
8	ICT and Learning Technology	8.2 Wi-Fi access points	Unit	10	SEK 1.300	SEK 13.000
		8.3 Visual systems	Unit	10	SEK 15.000	SEK 150.000
		8.4 Audio systems	Unit	20	SEK 4.300	SEK 86.000
					Subtotal	SEK 249.000
9	Plumbing Adjustments	9.1 Adjustment of water supply lines, drainage	m^2	1835	SEK 1.100	SEK 2.018.500
		9.2 Installation of restroom facilities	Unit	12	SEK 3.500	SEK 42.000
		9.3 Sink installation	Unit	21	SEK 7.000	SEK 147.000
					Subtotal	SEK 2.207.500
10	Interior Finishing	10.1 Flooring repair	m^2	1440	SEK 240	SEK 345.600
		10.2 Wall finishing and painting	m^2	1350	SEK 200	SEK 270.000
					Subtotal	SEK 615.600
11	Furniture and Learning Equipment	11.1 Classroom desks	Unit	200	SEK 2.100	SEK 420.000
		11.2 Lecturer podiums/desk	Unit	10	SEK 2.100	SEK 21.000
		11.3 Storage cabinets	Unit	10	SEK 3.400	SEK 34.000
		11.4 Classroom chairs	Unit	400	SEK 2.400	SEK 960.000
					Subtotal	SEK 1.435.000
12	Testing and Commissioning	12.1 HVAC testing	Contract	1	- SEK	SEK 188.388
		12.2 Electrical system testing	Contract			
		12.3 ICT system testing	Contract			
		12.4 Safety inspection	Contract			
13					TOTAL CONSTRUCTION COST	SEK 18.838.800
					TOTAL WITH CONSULTANCY	SEK 23.171.724

The total CAPEX of SEK 26.879.200 estimated for repurposing HSB can be considered within reasonable range when compared with two benchmark references identified for the total cost of repurposing the building. First, one of the expert interviewees, provided a cost estimation based on the net floor area and resulting in an approximate total

CAPEX of SEK 25.000.000, which is closely aligned with the estimate developed in this study. Additionally, the second source obtained from a company that previously delivered a comparable repurposing project for a study space reported a unit cost of SEK 17.000/m^2. When applied to the net floor area of the building, this resulting to a total CAPEX of approximately SEK 24.480.000. The close estimation of both benchmark values to the calculated CAPEX supports the validity and reliability of the cost estimation obtained in this research.

Table 5 Repurposing Total CAPEX

Metric	Cost		Notes
Base Construction Cost	SEK	23.171.724	
Contractor Fee Added	SEK	24.562.027	2.5% to 7.5%
Cost + Contingency	**SEK**	**26.879.200**	10% to 20%
Cost per m^2	SEK	18.666	
Cost per Classroom	SEK	2.687.920	
Cost per Student	SEK	67.198	

The operational expenditure (OPEX) for the repurposed HSB is estimated at SEK 790.800 per year (see Table 6). This is equal to SEK 549/m^2 annually based on the net floor area. This recurring cost reflects the annual expenses required to operate the building as classroom facilities after the repurpose works have been completed.

Table 6 Repurposing Total OPEX

No	General Work	Work Item	Unit	Quantity	Unit Cost		Total Cost	
1	Energy and Utilities	1.1 Ditrict Heating	kWh	1440	SEK	1,13	SEK	118.786
		1.2 Electricity	kWh	1440	SEK	0,60	SEK	65.664
		1.3 Water	SEK/m^3	400	SEK	30,00	SEK	116.520
2	Cleaning Service	Regular cleaning	SEK/year	1440	SEK	279,00	SEK	417.830
3	Corrective Maintenance	Broken interior, furniture etc	SEK/year	1440	SEK	50,00	SEK	72.000
4						TOTAL	SEK	790.800
						TOTAL/m^2	SEK	549

The results show that cleaning services is the largest contributor of OPEX, cost amount of SEK 417.830 per year, or approximately 53% of total operational costs. This high portion is considered to accommodates 10 classrooms and 400 students, which requires frequent and regular cleaning. The calculation is based on 260 cleaning days per year, with cleaning productivity from the supplier is 250 m^2 per hour and using SEK 1.607 per day.

The remaining SEK 72.000 per year is allocated to corrective maintenance, as our interviewee mentioned that the cost is to cover minor repairs as damaged interior finishes, classroom furniture and other items. The unit cost of SEK 50/m^2 is used from the benchmarking cost of a company that runs a newly adapted building project into a classroom.

4.1.6 Risks and Challenges

The findings from interview and interviews and questionnaire shows that the repurpose of HSB Living Lab into learning facilities faces several risks and challenges. These challenges associated with technical building services, spatial suitability, functional adaptation and economic feasibility.

One of the most frequently identified risks is about compatibility of the existing building systems with a new educational function. Several interviewees emphasized that the original building was designed as residential facility rather than as a teaching space. As a result, building service systems such as HVAC, electrical and fire safety systems was not suitable for classroom use. For example, one of the interviewees highlighted that *"ventilation might be an issue for repurposing, and that fire assessment would also be required before any change of use could be implemented"*. Similarly, the interview with a professor said that ventilation capacity would be a major constraint because classroom spaces accommodate a higher occupancy load than residential rooms, thereby increasing cooling and fresh air demands.

Another major challenge is the spatial configuration and room dimensions of the HSB Living Lab building. The open-ended answer from the questionnaire responses also discusses this issue, with respondents mentioning concerns such as *"room sizes", "small building",* and *"the building is too small for my classes*". These responses indicate that the existing residential layout may not support classroom requirements, especially for larger teaching groups. The interview with campus planning representatives further confirms this issue, stated that Chalmers increasingly requires larger classrooms capable of accommodating up to 60 students, making the current room sizes became a limitation.

The questionnaire responses also show concerns about user comfort and functionality, especially related to windows, visibility and environmental quality. Several respondents expecting larger windows and said some space may not be ideal learning environment. This aligns with the interview findings suggesting that although the building has good daylight potential, issues such as shading and thermal comfort must be carefully addressed if the building is converted into classrooms. These factors are critical because comfort conditions directly influence students and teacher concentration and learning performance.

Another challenge is in the removal or modification of residential specific components. The current building includes kitchens, bathrooms and apartment internal layouts that may not be necessary in a learning environment setting. According to the interview with the Chalmers academic staff, substantial refurbishment would be needed to remove these functions and free up usable learning space. This process increase both cost and design risks, as modification to plumbing, internal partitions, and service routing may increase Capital Expenditure requirements.

Economic risk also mentioned as an important result across the interviews. Campus planners mentioned that repurposing existing buildings often involves high cost to bring the building to a new functional standard, particularly when adapting technical systems and interior spaces. The uncertainty surrounding the extent of required refurbishment increases the risk of cost overruns, especially in the early planning stages when the exact scope of interventions is not yet fully known.

Overall, the findings suggest that the main risks and challenges or repurposing HSB Living Lab are not related to structural capacity, which several interviewees considered manageable, but rather to the technical adaptation of building systems, limitations in spatial layout, user comfort requirements and economic matters. These challenges must be carefully considered in the decision-making process in this study.

4.2 Scenario 2: Relocation

The relocation scenario considers the potential to disassemble the HSB Living Lab and reassemble it at a different site, while preserving its structural and functional characteristics. In contrast to repurposing, which is focused on internal reconfiguration within an existing building, relocation presents a different set of technical, logistical, and economic challenges. The building's modular design offers a starting point for relocation, with the volumetric units that make up the building theoretically capable of disassembly, transport, and re-installation. But this is not a technical process; it is a mix of planning, coordination, and decision-making in an uncertain environment.

The relocation approach involves a series of actions, including disassembly, transport to a new location, and reassembly and reconnection of structural and building services. Although the modular building is designed for this process, the challenges are related to the integration of systems and the conditions under which relocation occurs. Weather conditions, transportation logistics, and permits all play a part in this.

From a building's strategic point of view, relocation also alters the use of the building. The building can be used in different ways, depending on the needs of the new building owner or manager. However, this also brings uncertainty, as the building's performance, cost, and operation are site-specific. Thus, relocation should be considered not just a technical but also a multi-risk and multi-dependent scenario.

The relocation scenario is a technically possible but challenging option for extending the life of the HSB Living Lab. It is dependent on a multi-actor approach, stage-wise planning, and awareness of cost and risk factors. The following section provides interview insights, which identify some of the technical, operational, and strategic aspects of relocation.

4.2.1 Interview Insight

The insights from the interviews about relocation offer a comprehensive view of the technical, operational, and financial aspects of relocating the HSB Living Lab. The views expressed by industry experts, academics, and stakeholders capture the potential benefits of modular relocation, as well as the challenges of relocating it. These perspectives are grouped into different themes to reflect common themes and considerations.

4.2.1.1 Technical Feasibility and System Complexity

Technically, some interviewees pointed out that the modularity of the building allows relocation. A specialist in modular construction indicated that the building was built with prefabricated volumetric units, which can be dismantled and relocated. This feature enables the building to be considered as a series of modules rather than a permanent structure, so it can be relocated without having to be demolished.

Likewise, a project manager of a building services consultancy said the structural system does not present significant problems in relocation. The structural system can be dismantled and reconnected, considering that the process of disassembly is planned carefully. But the ability to relocate is highly dependent on the connections of building elements, especially mechanical and electrical connections. While the structure can be easily managed, integrated systems like air supply, pipes, and electricity need to be carefully disconnected and reconnected.

An academic specialist in construction management also noted that the structural system is only a major component of the building. The next significant part of this modular building that makes it more complex is the building services and finishes. This suggests that relocation is feasible, but the key in relocation is to control the non-structural elements.

4.2.1.2 Logistical and Economic Challenges

While relocation is technically possible, it is logistically challenging. One modular construction expert noted that relocating the building is a significant task involving several trucks to transport each module. The tasks of lifting, transporting, and placing the modules in the new location require equipment like cranes and multi-tasking crews.

A specialist in demolition and reuse also noted that dismantling the structure itself is an intensive process. In contrast to demolition, where efficiency is key, relocation involves dismantling to allow the reuse of parts. This increases the time, effort, labor, and clear coordination required. Often, different teams are involved in dismantling and transporting, with specialized skills and tasks. The weather also affects relocation. Rain and wind can impact the dismantling and lifting operations. These can cause uncertainties in planning and implementation and make this process more challenging than conventional construction work.

Moreover, one circular construction researcher noted that unforeseen circumstances can occur during disassembly, including concealed connections or challenges in separating modules. This can cause delays and cost overruns, complicating the relocation process. Economic factors related to relocation have been identified in several interviews. One insight from the industry experts is that transportation and lifting costs have a significant portion in the total cost of the relocation process. The deployment of cranes, trucks, and other equipment and labor is a high up-front cost.

An academic expert and facilitation manager also pointed out that the cost of relocating building services can be similar to the cost of new installation, especially if systems need to be re-configured or need to be adapted to the new site. This may limit the economic benefit of relocation, as the cost savings of reusing structural elements may be offset by the cost of system changes.

Additionally, a demolition expert pointed out that reuse-based processes can be more costly than traditional demolition, particularly when the process involves careful dismantling and handling of components. This indicates that relocation cannot be taken as an economic advantage, and it needs to be evaluated carefully.

A further point is that the cost variability also depends on the new location. One stakeholder involved in the building pointed out that elements such as energy solutions, rental income, and site characteristics can affect the post-relocation economic performance of the building. This adds a new level of uncertainty, given that financial performance is linked to other factors.

4.2.1.3 Risk, Uncertainty and Future Potential

Uncertainty is a common theme in interviews. Although the building can be relocated, the specific nature of the work, cost, and performance is uncertain. This is because of the complexity of the disassembly, uncertainty in site conditions, and reinstallation issues.

A circular construction researcher noted that disassembly may involve uncertainties, including the state of the connections and ease of disconnection. This can result in schedule and budget overruns. Likewise, the industry practitioners pointed out that contingency planning is essential as unexpected issues may be encountered during relocation. This may include damage to components, weather delays, and coordination challenges.

At a strategic level, one stakeholder related to the building highlighted that relocation is affected by the market, such as the presence of potential buyers and the timing of the project. Relocation is contingent not only on the technical aspects but also on finding a new use and location.

Despite the difficulties, relocation has reuse potential. The building's modularity means it can be repurposed for various uses, according to the preferences of the new owner.

One stakeholder said that the building could be reused for residential, educational, or mixed-use. This adaptability is enabled by the accessibility of the building systems and the modular design, which enables parts of the building to be combined in various ways. But this potential can only depend on the building's design, which could be adapted to the new context.

At the same time, interviewees highlighted the value of relocation in prolonging the life of the building, rather than creating a temporary structure. By reusing the building through relocation, it is possible to retain material and functional values and contribute to sustainability goals.

4.2.2 Assumption and Benchmark

Several assumptions were established to support the cost estimation and scenario comparison in this study, particularly where exact project data were unavailable. For the relocation scenario, a temporary consolidation center was assumed to manage logistics during dismantling, transportation and reassembly activities. The relocation destination was assumed to be in Lund city, based on discussions with interviewees regarding realistic future placement options. It was also assumed that 24% of the existing MEP system could be reused in the relocation scenario, based on interview findings related to technical feasibility. In addition, cleaning activities were assumed to occur 52 times per year (weekly basis) for the OPEX calculation.

Benchmarking was also used to support financial assumptions where direct project specific data were limited. The relocation scenario assumes a rental income of SEK 2.400.000 per year based on comparable building benchmarks. Contractor fees and contingency allowances were included in both scenarios; however, the relocation scenario was assigned higher values due to its greater technical complexity, uncertainty and coordination challenges compared to repurposing. The cost of acquiring new land was excluded from the analysis, as land ownership conditions were considered highly-case specific and outside the scope of this thesis.

4.2.3 Cost Estimation

This chapter presents the cost estimation results for the relocation scenario of the HSB Living Lab building. The analysis includes both capital expenditure (CAPEX) and operational expenditure (OPEX) to evaluate the financial implications of relocating the existing building to a new site. CAPEX represents the one-time investment required for disassembly, transportation, site preparation, reassembly, and recommissioning, while OPEX reflects the annual operational costs associated with building use after relocation.

The relocation scenario reflects the interview results' information that this building can be dismantled, transported and reinstalled while preserving a significant portion of the original building components. This approach aims to reduce embodied carbon and material waste while maintaining economic feasibility. The CAPEX estimation for the relocation scenario consists of seven major work packages: project preparation, disassembly of the modular building, transportation and logistics, new site preparation, reassembly and installation, building systems reconnection and testing and commissioning.

Table 7 Relocation Total CAPEX

Metric	Cost		Notes
Base Construction Cost	SEK	24.071.056	
Contractor Fee Added	SEK	25.876.385	2.5% to 7.5%
Cost + Contingency	SEK	**30.690.596**	20%
Cost per m^2	SEK	21.313	
Cost per Tenant	SEK	76.726	

The base construction cost for relocation was estimated at SEK 19.569.964, while the total cost including construction consultation and contractor fee reached SEK 24.071.056. After adding contractor fee for 7,5% and contingency allowance for 20%, the final estimated project cost increased to SEK 30.690.596. Compared to the repurposing contractor fee and contingency allowance, the number on relocation is assumed higher than repurpose due to the complexity of the relocation project. Moreover, the average relocation cost was calculated as SEK 21.313/m^2 and cost per tenant is SEK 76.726/tenant. These values provide an important benchmark for comparing relocation against adaptive reuse or repurposing alternative.

Table 8 Relocation Base Construction Cost

No	General Work	Work Item	Unit	Quantity	Unit Cost	Total Cost
1	**Project Preparation**	1.1 Feasibility study	Contract	1	SEK 400.000	SEK 400.000
		1.2 Design for the New Site	Contract	1	-	SEK 978.498
		1.3 Building permit and regulatory approval	Contract	3	SEK 37.000	SEK 111.000
		1.4 Project Management and Consultancy	Contract	1		SEK 1.369.897
		1.5 Insurance for relocation	Contract	1		SEK 587.099
		1.6 Engineering Design	Contract	1		SEK 1.369.897
					Subtotal	SEK 4.816.392
2	**Disassembly of Modular Building**	2.1 Furniture Removal	m^2	1835	SEK 90	SEK 165.150
		2.2 Removal of kitchen units	Unit	9	SEK 10.000	SEK 90.000
		2.3 Removal of bathroom fixtures	Unit	38	SEK 16.000	SEK 608.000
		2.4 Removal of electrical system	m^2	1835	SEK 600	SEK 1.101.000
		2.5 Removal of plumbing system	m^2	1835	SEK 200	SEK 367.000
		2.6 Removal of HVAC system	m^2	1835	SEK 200	SEK 367.000
		2.7 Non-structural Component Removal	m^2	1835	90	SEK 165.150
		2.8 Module lifting (Loading to transport)	Day	22	SEK 34.000	SEK 748.000
					Subtotal	SEK 3.611.300
3	**Transportation and Logistics**	5.1 Temporary Construction Consolidation Center (logistic)	m^2	1000	SEK 500	SEK 500.000
		5.2 Modular Transportation	Km	11440	SEK 39	SEK 446.160
		5.3 Module Unloading	Day	22	SEK 34.000	SEK 748.000
					Subtotal	SEK 1.694.160
4	**New Site Preparation**	6.1 Ground Works	m^2	436	SEK 8.500	SEK 3.706.000
		6.2 Foundation works	m^2	436	SEK 3.000	SEK 1.308.000
					Subtotal	SEK 5.014.000
5	**Reassembly and Installation**	5.1 Module installation	Day	22	SEK 34.000	SEK 748.000
		5.2 Façade reinstallation	m^2	798	SEK 496	SEK 395.808
		5.3 Roof installation	m^2	474	SEK 594	SEK 281.556
		5.4 Window Installation	Unit	47	SEK 12.000	SEK 564.000
		5.5 Door Installation	Unit	17	SEK 1.260	SEK 21.420
		5.6 Lift Installation	Unit	1	SEK 100.000	SEK 100.000
		5. 7 Kitchen Installation	Unit	9	SEK 27.000	SEK 243.000
		5.8 Bathroom Installation	Unit	38	SEK 3.500	SEK 133.000
		5.7 Stairs Installation	Unit	8	SEK 29.000	SEK 232.000
		5.8 Scaffolding	m^2	1170	SEK 190	SEK 222.300
					Subtotal	SEK 2.941.084
6	**Building Systems Reconnection**	6.1 HVAC	m^2	1835	SEK 1.000	SEK 1.835.000
		6.2 Electrical wiring	m	16000	SEK 200	SEK 3.200.000
		6.3 Lighting installation	m^2	1440	SEK 400	SEK 576.000
		6.4 Water system	m^2	1835	SEK 1.100	SEK 2.018.500
		6.5 Reuse Potential	%	30		SEK 1.831.080
					Subtotal	SEK 5.798.420
7	**Testing and Commissioning**	Commisioning	Contract	1		SEK 195.700
8					TOTAL	SEK 19.569.964
					TOTAL WITH CONSULTANCY	SEK 24.071.056

Project preparation accounted for SEK 4.816.392, representing one of the largest early-stage cost components. This general work includes feasibility studies, design for the new site, building permits and regulatory approvals, project management, insurance for relocation and engineering design. Among these items, engineering design and project management/consultancy contributed significantly to the cost, reflecting the complexity of relocating a modular building. Both cost is represented on percentage from the base construction cost, and both calculated as 7% of the base construction cost.

The disassembly phase required SEK 3.611.300. This included furniture removal, kitchen unit removal, bathroom fixture removal, electrical system removal, plumbing system removal, HVAC removal, and non-structural component removal. In addition, module lifting and loading to transport represented a critical cost due to crane operations and labor intensity. As mentioned by the interviewee, the relatively high cost of disassembly demonstrates that relocation requires careful arrangement to identify reusable components and minimize damage during dismantling.

Transportation and logistics were estimated at SEK 1.694.160, including temporary logistics consolidation and 44 modular transportations over 260 Km that calculated from the distance between Gothenburg city and Lund city. The results show that logistics costs are lower than the major cost such as systems reconnection and new site preparation, this indicates that technical reintegration at the new location creates greater financial impact than transport itself.

New site preparation required SEK 5.014.000, includes of ground works and foundation works. Foundation work represented a major share of this category, as the relocated building still requires new structural support systems that comply with the site conditions. This result shows that even when modules are reused, substantial investment is still needed for site infrastructure.

The reassembly and installation stage was estimated at SEK 2.941.084, including module installation, façade reinstallation, roof installation, window installation, door installation, lift installation, kitchen installation, bathroom installation, stair installation and scaffolding. Module installation and façade works were the dominant costs in this category, showing that restoring building performance after transport requires expert handles and precision.

Building system reconnection generated the highest technical cost at SEK 5.798.420, including HVAC, electrical wiring, lighting installation, water systems, and reuse potential adjustments. The reuse adjustment was based on the interviewee that stated HVAC system could be reused, it applied as a minus (-) item on the calculation, as the HVAC cost is around 24% of the total building system reconnection cost. Electrical wiring (SEK 3.200.000) and water system (SEK 2.018.500) were significant, these issues also arise on the interview and one of the interviewees was mentioned it is better to have new electrical wiring and water system if the building need to relocate, due to the complexity of the existing wiring and water system.

Testing and commissioning required SEK 195.700, ensuring that all reinstalled systems operate safely and efficiently before occupancy. The cost of testing and commissioning is derived from 1% of the base construction cost, although relatively small compared to other work components, commissioning is essential for operational readiness and long-term performance.

Table 9 Relocation Total OPEX

No	General Work	Work Item	Unit	Quantity	Unit Cost		Total Cost	
1	Energy and Utilities	1.1 Ditrict Heating	kWh	1835	SEK	1,13	SEK	151.369
		1.2 Electricity	kWh	1835	SEK	0,60	SEK	83.676
		1.3 Water	SEK/m3	40	SEK	30,00	SEK	11.652
2	Cleaning Service	Regular cleaning	SEK/year	1835	SEK	279,00	SEK	106.489
3	Corrective Maintenance	Broken interior, furniture etc	SEK/year	1835	SEK	50,00	SEK	91.750
4	Rental Income	Rental	Unit	29	SEK	-	SEK	2.400.000,00
5						TOTAL OPEX	SEK	444.936
						Net Profit	SEK	1.955.064
						TOTAL/m^2	SEK	309

The annual OPEX for the relocated HSB Living Lab was estimated based on energy consumption, utilities, cleaning services and corrective maintenance. These categories were selected based on common operational cost structures in residential building management and housing operation. Supplier price and benchmarking from similar building project is used to estimate utility and service cost based on Swedish market conditions, while rental income data were obtained from a benchmark rental cost.

Energy and utility costs include district heating, electricity and water consumption, which represent the fundamental operational cost of the building. District heating was estimated of SEK 151.369 annually. While electricity consumption estimated at SEK 83.676 annually. Water consumption was calculated at 40 m^3 with a unit cost of SEK 30/m^3, generating an annual cost of SEK 11.652. The total annual cost for energy and utilities reached SEK 246.697, equivalent to approximately 134 SEK/m^2.

Cleaning services were estimated based on regular facility cleaning requirements for student housing operations. The cleaning was assumed to occur 52 weeks per year, with an average cleaning productivity of 250 m^2/hour and an hourly cost of SEK 73,4/hour. This resulted in a cleaning cost of SEK 2.047,86 per cleaning cycle and an annual cleaning expenditure of SEK 106.488.

The relocation scenario assumes a rental income of SEK 2.400.000/year from 29 rental units. After deducting annual OPEX, the estimated net profit was SEK 1.955.064. this result suggests that although relocation requires a high initial capital investment, the operational performance remains financially positive due to the annual operating costs and stable rental income. Compared to the repurposing scenario, the repurposed building cannot generate income as the building is not generating direct product for the users, in this case are the students and teachers.

The results show that relocation is financially intensive at the investment stage but relatively efficient during operation. The most significant CAPEX drivers were building systems reconnection, new site preparation and project preparation, while district heating and cleaning services dominated OPEX. This suggest that decision-makers should consider on optimizing MEP reconnection strategies and foundation design to improve relocation feasibility.

4.2.4 Risk and Challenges

Relocating the HSB Living Lab presents several significant risks and challenges despite the building being originally designed as a modular and partially demountable structure. The interviews discover that the relocation process is not only moving modules from one site to another, but a complex operation that needs high logistical costs, uncertainty in dismantling, weather uncertainty, market risk, and coordination among multiple stakeholders.

One of the highest risks is the uncertainty of finding the new owner or destination for the building. According to the interviewee, the building must be removed due to the temporary land permit, which only allows the structure to remain until the end of the agreement period. The interviewee explained that HSB priority is to find a new owner who can take over the building, otherwise the solution is full deconstruction and material recovery. The interviewee also emphasize that deconstruction is considered plan B rather than the preferred option. This creates a major commercial risk because relocation can only proceed if a financially viable buyer and site are secured.

Another major challenge is the high relocation cost, particularly transportation and lifting operations. One of the expert interviewees highlighted that crane operations and transport are the major cost drivers in relocation, while permit costs are relatively small. The expert noted that relocation requires approximately 20-25 workers for dismantling, separate teams for transportation and multiple lifting operations, making labor intensity very high. Similarly other expert interviewee explain that the building consists of 44 modules, requiring one truck per module and a crane on-site for each lifting process. The interviewee emphasized that relocation is associated with substantial costs, especially transport and that identifying a suitable new location remains the key issue.

One of the managerial interviewees also stated that relocation within 50 km could cost approximately 40 million SEK and even suggested that building a new structure may be cheaper than moving and reassembling the existing one.

Technical uncertainty during dismantling and reassembly is another risk. Although the building was designed for modularity, several interviewees mentioned that dismantling always had unforeseen complications. One expert on modular building explained that even buildings planned for disassembly often contain unexpected solutions that differ from original drawings, requiring fast decisions and flexible execution. The expert emphasized *"you always get surprises along the way"*, and therefore additional time and resources must always be considered. This is supported by the other expert interviewee, who recommended high contingency allowances as well as additional warranty and leadership to manage such uncertainty.

Weather condition also being a huge challenge during relocation. Since dismantling and transport expose modules and structural elements to external conditions, rain and moisture can create risks for damage, delays and additional protection cost. The expert interviewee identified weather, especially rain, as challenge in relocating modules. This also supported by other expert that mentioned the weather must be considered both during dismantling and the at the temporary or final storage location, particularly in Nordic conditions where climate can affect construction operations.

The complexity of building services systems (MEP systems) also increases relocation risk. HSB Living Lab contains a large number of technical installations, many of which were designed for research purposes rather than standard residential use. Managerial expert interviewee explained that the building includes extensive cables, electrical meters, data models, batteries, and advanced technical systems that may be unnecessary for future users. The interviewee stated that electrical systems are difficult to reassemble and that new cabling may preferable rather than attempting full reuse, while HVAC and water systems are more feasible to dismantle and reinstall. One of expert interviewee in building services further noted that the building contains nearly double the number of installations compared to a typical residential building, which increases the complexity of relocation and adaptation.

Finally, project organization and decision-making flexibility are essential challenges. Expert in modular building interviewee emphasized that relocation projects require not only technical planning, but also a flexible organizational structure with trust between planners, dismantlers, contractors, and owners. Because unexpected conditions frequently arise during disassembly, decision-making authority must be decentralized enough to allow rapid adjustments without causing major delays. Without such flexibility, the relocation process can become significantly slower and more expensive.

Overall, the risks of relocating HSB Living Lab are dominated by economic uncertainty, logistical complexity, technical unpredictability, and coordination challenges. Although the modular design provides strong potential for relocation, successful implementation depends on planning, strong stakeholder coordination, contingency management, and making sure the relocation site for the building.

4.3 TOPSIS Implementation

To support final decision between repurposing and relocation scenario for HSB Living Lab, the TOPSIS method was applied. TOPSIS was selected because it allows the comparison of multiple alternatives based on several qualitative and quantitative criteria simultaneously, while considering the relative importance of each criterion. This is relevant for the HSB case, where the decision cannot be based only on cost, but also includes the technicalities complexity of the project.

The criteria used in the analysis were developed based on the interview findings and the economic analysis in the previous sections. Seven criteria were selected: CAPEX/m^2, OPEX/m^2, Risks, Ease of Implementation, Uncertainty, MEP Complexity, and Implementation Time. The weighting process began by ranked the criteria based on their importance to the decision-making process, where CAPEX/m^2 was considered the most important criterion and Implementation Time the least important. After ranking from 1 to 7, the weights were assigned proportionally using an even distribution method, resulting in a descending scale from the highest to the lowest priority criterion.

Table 10 Weighted Criteria

Criteria Weight							
Scenarios	**Capex/ m^2**	**Opex/ m^2**	**Risks**	**Ease of Implementation**	**Uncertainty**	**MEP Complexity**	**Implementation Time**
Ranking	1	2	3	4	5	6	7
Weight	0,25	0,214	0,179	0,143	0,107	0,071	0,036

CAPEX/m^2 received the highest weight (0,25), followed by OPEX/m^2 (0,214) and Risks (0,179), reflecting the strong importance of financial feasibility and risk mitigation in the decision-making process. Ease of Implementation (0,413) and

Uncertainty (0,107) were also considered important due to the practical challenges of executing both scenarios. MEP Complexity (0,071) and Implementation Time (0,036) were given lower weights as they were considered secondary compared to the economic and strategic factors. Ideally, the weighting of these criteria should be determined and validated by experts directly involved in the project, such as managers or decision-makers with deep knowledge of HSB Living Lab or building adaptation project. However, due to time constraints and limited availability of relevant experts during the thesis period, the weighting was established based on the researchers' own judgement that supported by insight from the interviews and literature review. While this introduces a degree of subjectivity, the weighting was designed to reflect the practical priorities, and strategic considerations identified throughout the study.

Table 11 Criteria Scoring

Score	Notes
1	very less
2	less
3	moderate
4	high
5	very high

A qualitative scoring system from 1 to 5 was used for non-financial criteria, where 1 represented "very low" and 5 represented "very high". For the repurpose scenario, the results showed lower CAPEX/m^2 (18.466 SEK/m^2), higher OPEX/m^2 (549 SEK/m^2), lower risk (score 2), moderate ease of implementation (score 3), lower uncertainty (score 2), higher MEP complexity (score 4), and the shortest implementation time (score 1). In contrast, the relocation scenario showed higher CAPEX/m^2 (21.313 SEK/m^2), lower OPEX/m^2 (309 SEK/m^2), higher risks (score 4), greater implementation difficulty (score 5), higher uncertainty (score 4), lower MEP complexity (score 3), and longer implementation time (score 3). The overall result displayed on the Table 12. Moreover, the overall step-by-step of the TOPSIS are shown on the table Table 13, Table 14, and Table 15.

Table 12 Scored Criteria

Scenarios	Capex/ m^2	Opex/ m^2	Risks	Ease of Implementation	Uncertainty	MEP Complexity	Implementation Time
Repurposing	18666	549	2	3	2	4	1
Relocation	21313	309	4	5	4	3	3

Table 13 Normalized Matrix

Scenarios	Capex/ m^2	Opex/ m^2	Risks	Ease of Implementation	Uncertainty	MEP Complexity	Implementation Time
Repurposing	0,66	0,87	0,45	0,51	0,45	0,80	0,32
Relocation	0,75	0,49	0,89	0,86	0,89	0,60	0,95

Table 14 Weighted Normalized Matrix

Scenarios	Capex/ m^2	Opex/ m^2	Risks	Ease of Implementation	Uncertainty	MEP Complexity	Implementation Time
Repurposing	0,16	0,19	0,08	0,07	0,05	0,06	0,01
Relocation	0,19	0,10	0,16	0,12	0,10	0,04	0,03

Table 15 Ideal Best and Ideal Worst Value

Scenarios	Capex/ m^2	Opex/ m^2	Risks	Ease of Implementation	Uncertainty	MEP Complexity	Implementation Time
Repurposing (A*)	0,16	0,10	0,08	0,07	0,05	0,04	0,01
Relocation (A$^-$)	0,19	0,19	0,16	0,12	0,10	0,06	0,03

After normalization and weighted normalization, the TOPSIS method identified the relative distance of each scenario from the ideal best ($\boldsymbol{D_i^*}$) and ideal worst ($\boldsymbol{D_i^-}$) solution. The repurposed scenario performed strongly in the most heavily weighted criteria, particularly CAPEX, risk level, uncertainty and implementation time. Although relocation showed better operational cost performance and slightly lower MEP complexity, its significantly higher capital cost, greater uncertainty and higher implementation risks reduced its overall results.

Table 16 Final Result of TOPSIS

Scenario	$\boldsymbol{D_i^*}$	$\boldsymbol{D_i^-}$	$\boldsymbol{C_i^*}$	Rank
Repurposing	0,08	0,11	0,57	**1**
Relocation	0,11	0,08	0,43	**2**

The result on the Table 16 indicates that repurposing scenario is the preferable option when evaluated through the TOPSIS framework. Its stronger performance in the high-priority criteria outweighs its disadvantages in operational expenditure and technical complexity. This suggests that, from a strategic perspective, repurposing provides a more feasible solution for the building. Therefore, based on the multi-criteria decision-making analysis, repurposing is considered the preferred alternative over relocation.

5 Discussion

This chapter critically discusses the main findings of the case study in terms of research questions and literature. The objective of this thesis was to assess the potential future uses of HSB Living Lab by applying repurposing and relocation scenarios by applying the techno-economic assessment approach. The results indicated that both scenarios are technically feasible but have very different levels of complexity and uncertainty in implementation and long-term feasibility. Overall, the repurposing scenario seemed to be more feasible in the current project scenario, whereas the relocation scenario reflects strong circular construction ambitions through preservation and reuse of the modular building system (Coskun et al., 2024; Lanz & Pendlebury, 2022; Vafaie et al., 2023).

The study found that future building decisions can't be made based on structural and economic considerations. During the analysis, it became apparent that there was a strong influence of operational continuity, stakeholder needs, practical implementation, and future user requirements make a higher impact on the assessment process. This was more clearly visible in the case of the relocation scenario. The modular structural system usually supports the technical capability of dismantling and reassembling the building, but the integrated systems within the building add complexity in the event of relocation (Coskun et al., 2024; Pichlmeier & Lindner, 2024).

The findings also pointed to the continuity of infrastructure in an adaptive reuse project. For the repurposing scenario, the majority of the existing structure and service systems would be able to be kept, minimizing the need for significant intervention. The proposed educational conversion was also in response to the increasing need for flexible learning environments in the university context. The relocation scenario added uncertainties of transportation, system recommissioning, coordination, and conditions at the future site (Ostapska et al., 2024).

Another key issue raised by the findings was how circular construction objectives can conflict with practical project conditions. Relocation perfectly matches the circular construction principles, as it aims to keep the building as a whole unit instead of the reuse of only selective materials (Eberhardt et al., 2022). However, the study did not include the full life cycle assessment (LCA) or detailed carbon analysis. Therefore, the environmental impact of both scenarios was not quantitatively compared, and the discussion of circularity was mainly based on materials preservation and building reuse perspectives. But the study indicated that there are many practical implementation issues that could affect the viability of such approaches. The current conditions meant that reusing the existing building was not a viable option, so repurposing was a more viable option to extend the use of HSB Living Lab, while still reusing the existing building materials (Pichlmeier & Lindner, 2024).

The methodological aspect of the thesis is also relevant to the use of techno-economic assessment in the construction industry. Most of the existing TEA studies are based on industrial or energy systems; however, fewer TEA studies are based on a combination of technical analysis, stakeholder perspectives, adaptive reuse, relocation assessment, and multi-criteria decision-making within a single framework for deciding the potential future ue of building scenarios. To fill this gap, this thesis combined the literature review, interviews, questionnaires, conceptual design, cost estimation, risk analysis, and TOPSIS evaluation into a single assessment framework (Barahmand & Eikeland, 2022; Chai et al., 2022).

The study also presents that quantitative analysis is not enough for the assessment of future building scenarios. The final assessment was shaped by the priorities of the stakeholders, the practical challenges of implementation, the need for operations, and uncertainties. In other words, the framework created in this research can be applied in other modular buildings, adaptive reuse, temporary buildings, and circular construction projects in which a balanced and practical approach is needed to evaluate different future scenarios.

5.1 Technicalities of HSB Scenarios

The technical feasibility of the HSB Living Lab scenarios highlighted that repurposing and relocation are two potential strategies for the future use of the building. The results, however, also showed significant differences between the two scenarios in terms of implementation, continuity of operations, uncertainty, and overall feasibility. Following the building characteristics, interviews, a wide range of responses from questionnaires, and technical analysis, it was evident that future building strategies can not only be evaluated through structural feasibility. However, the practicality of a future scenario is also heavily influenced by building services, operational systems, user requirements, and implementation conditions (Pichlmeier & Lindner, 2024; Vafaie et al., 2023).

The concept of HSB Living Lab started as an experimental building with volumetric modules that were prefabricated and joined together in a steel structure. Flexibility, adaptability, efficiency of prefabrication, and relocation possibilities are frequently mentioned as benefits of modular construction in the literature (Coskun et al., 2024; Ostapska et al., 2024). The same was observed in interviews that were carried out in this study. Several interviewees described the relocation of the structure as not being the primary problem, as the modules can be dismantled and reassembled. This is in line with the previous studies on modular construction, in which prefabricated systems are linked to future transformation potential and circular construction.

The results of this study indicated that relocation is not just a structural issue. The most significant findings of the study were the distinction between building structural and operational modularity. The building itself is designed in a modular structure, but the systems are highly interdependent. The HSB Living Lab is equipped with monitoring systems, sensors, HVAC networks, electrical systems, and research infrastructure, which are linked to experimental activities in the building. This would mean that relocation would be more than just moving structural modules from one place to another. It would also involve the disconnection, reinstallation, and reconfiguration of integrated systems to ensure that the building would continue to operate as designed after being reassembled (Pichlmeier & Lindner, 2024). Although the study identified the MEP system as a major complex challenge, the exact level of modification and recommissioning of all these systems may still be underestimated because a detailed level of assessment of all operational systems was out of the scope of this research.

The analysis of this study became more important as modular buildings are frequently referred to as moveable buildings, but in reality, the situation was more complex with the HSB Living Lab. The structural system itself was not defined as the main technical barrier. Instead, the complexity was in maintaining the configuration of the operational system, which is an extremely integrated experimental system. This means that future modular buildings for relocation should not only be designed with detachable buildings, but also with the separation of building services and operational systems, and an efficient and easy way to reconnect (Ostapska et al., 2024).

Uncertainties were another key element in the relocation scenario. The results showed that there are several technical and operational uncertainties associated with relocation that cannot be completely foreseen. This would impact on everything from transportation, temporary storage for modules, reassembly coordination, and adaptation to future site requirements. The future site of the building is not yet determined, so there are some technical uncertainties, such as new foundation design, new building permits and regulations, and surrounding infrastructure that cannot be clearly defined yet. This puts the relocation process at risk of delays, coordination issues, undetected damages, and disruption to all operations (Coskun et al., 2024).

The interviews also indicated that the complexity of relocation does not only occur at the dismantling phase, but it will be extended to several stages of the project. If the modules can be relocated, there will still be more work to be done to make sure that all systems are working after the relocation. For research buildings like HSB Living Lab, the building's operational performance is linked to building services and monitoring systems (Pichlmeier & Lindner, 2024; Vafaie et al., 2023). This means that the reconfiguration phase is now a crucial step in the relocation process that is totally different from a more traditional modular building that could have fewer interdependent systems.

The repurposing scenario seemed to be more technically feasible with the existing project conditions than relocation. The continuity of existing infrastructure was one of the main reasons for this. A large-scale dismantling and transportation of the building was not required, and the building could be used as it is today, with most parts of the building and the service system. This decreased the amount of technical uncertainty and the overall amount of intervention needed in implementation (Hu & Świerzawskib, 2024). This emphasized the use of existing spaces for new uses rather than rebuilding the structure on a new site.

The proposed educational layouts also indicated that the current building layout can accommodate the teaching and learning activities. The repetitive room layout and modular floor plan allowed for the transformation of residential spaces into classrooms, group learning areas, and flexible learning spaces. These observations are also frequently reported in adaptive reuse literature and are typically associated with buildings with repetitive layouts and modular structures that are easier to adapt for new uses. In the present case, the modular design minimizes the need for significant changes in the structure and allows simple and easy spatial adaptation (Iarkov et al., 2025; Tavakoli et al., 2026).

The questionnaire responses and interviews confirmed the appropriateness of the repurposing scenario. Several respondents emphasized the need for flexible educational areas in the university context. The proposed conversion was thus not only in keeping with the building's physical features but also with the institutional and user requirements. The practical and functional potential of a transformed building is also shaped by the needs and demands of users and by the operational needs (Lanz & Pendlebury, 2022).

One of the other interesting findings of the study was the educational value of the building itself. Some interviewees noted that the visible services and other components of the building, the technical display of different experiments, and the experimental nature of the HSB Living Lab could be beneficial for engineering and architectural education. In this way, the building also serves as a classroom as well as a part of an experimental learning environment that provides us with an extra benefit in the reuse scenario.

The findings also highlighted that the repurposing process cannot be considered an easy one. The building was designed for residential and research work, not for educational use or occupancy. Therefore, modifications for acoustics control, classroom function, accessibility, ventilation, and fire safety would still be required to upgrade certain standards to fulfil the requirements of obtaining a permit from the concerned authorities. Some interviewees also indicated that some experimental systems might not be needed in future educational applications and might need to be simplified or replaced. Even though the overall level of modification was still not as high as in the relocation scenario (Shahi et al., 2020; Tavakoli et al., 2026).

The two scenarios reflect different priorities between circularity and practical implementation. Relocation will maintain a greater extent of the original building system and will be in line with the principles of circular construction. Repurposing, on the other hand, involves less intervention, less uncertainty, and the ability to keep the existing infrastructure in use with fewer technical issues (Pichlmeier & Lindner, 2024; Vafaie et al., 2023). This is not to say that it is impossible to relocate technically. The results, however, indicate that relocation is much more difficult if the operational systems are well embedded in the building. The continuity of the repurposing scenario is beneficial because the building will be able to be integrated into its current setting and reworked for new uses. This helped to minimize the need for mass disruption to the system and support a smoother transition process.

The results are indicative that future evaluations of modular buildings should go beyond structural issues. Although structural flexibility is relevant, operational systems and implementation conditions can have a significant impact on the real potential for future transformation scenarios. For buildings that are smart and have experimental infrastructure, here, the operational modularity can be as significant as structural modularity. This was one of the key technical findings of the study and was a major factor in the overall assessment of the two scenarios. There is potential for HSB Living Lab to be repurposed and/or relocated. Relocation was seen as a more complex, yet very circular future option, and repurposing was more feasible and low risk technically under the current project conditions.

5.2 Economic Viabilities

The economic viability of the two repurpose and relocation scenarios was assessed through the comparison of capital expenditure (CAPEX), and operational expenditure (OPEX). This chapter particularly answers the third research question of this study about the result of comparative economic performance of repurposing versus relocation of the HSB is is living lab. In techno-economic analysis (TEA), economic feasibility is evaluated by integrating initial investment requirements with operational costs to determine whether a project is financially reasonable over its service life (Mahmud et al., 2021). As discussed in Chapter 3, CAPEX and OPEX are fundamental indicators in TEA because they directly reflect the economic burden and long-term sustainability of project alternatives (Henry et al., 2023). The findings of this study show that both scenarios had significantly different economic structures of CAPEX and OPEX.

As shown in the Figure 10 the repurposing scenario generated a total CAPEX of SEK 26.879.200, while the relocation scenario required a higher investment of SEK 30.690.596. This indicates that relocation demands approximately 14% more initial capital than repurpose. This result is consistent with previous studies which explain that relocation carries additional work items that are unavailable in repurposing, particularly disassembly, transportation, reassembly and new site preparation that makes the cost is relatively higher (Coskun et al., 2024). Repurposing the building generally avoids external logistics costs because the building remains on-site, allowing the investment to focus on internal transformation and building services adaptation (Douglas, 2006). This supports the argument of Sobieraj et al. (2025), who found that repurposing often provides greater economic advantages than demolition or relocation because it keeps the existing structural components while minimizing reconstruction requirements.

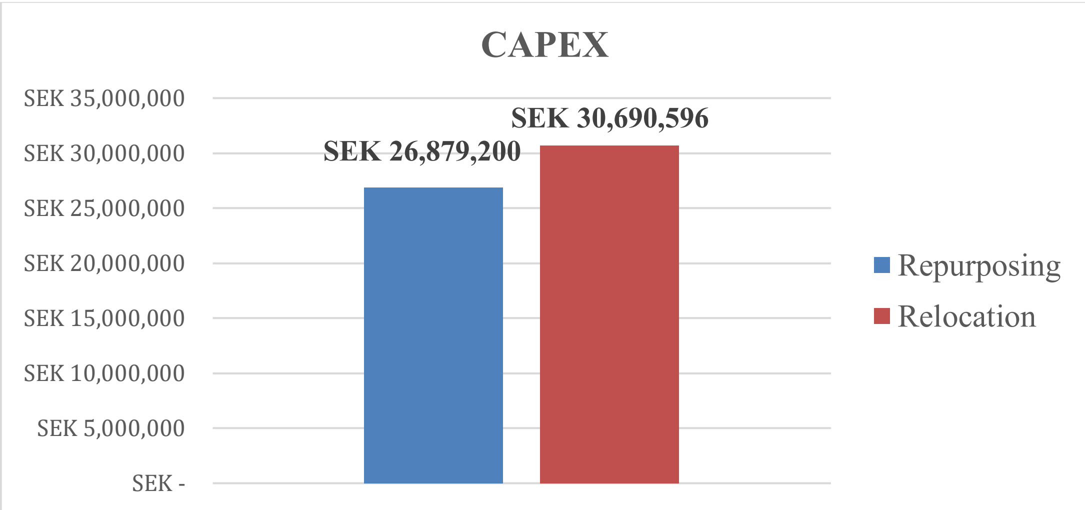

Figure 10 CAPEX Comparison

In the repurposing scenario, the largest cost drivers were interior reconfiguration and MEP adaptation. This aligns with Douglas (2006), who explains that building adaptation projects typically allocate most investment toward upgrading internal layouts, improving usability, and modifying service systems rather than constructing new structural elements. The interview findings also confirmed that structural interventions were not necessary, while ventilation, HVAC, electrical systems, and classroom functionality being the main financial expenses. W. Ahmed & Asif (2020) similarly found that service system retrofitting is often the dominant economic factor because technical systems originally designed for residential use rarely meet classroom performance requirements.

On the other hand, relocation produced higher CAPEX because of disassembly, transportation, reassembly, and building system reconnection. Building systems reconnection alone represented one of the highest categories, particularly electrical wiring and water systems. This finding strongly supports Pichlmeier & Lindner (2024), who state that MEP systems are often difficult and expensive elements to reuse during relocation because reconnection complexity can approach the cost of new installation. Several interviewees also emphasized that new electrical systems may be economically preferable to fully reuse because of the complexity of the original HSB Living Lab systems. This confirms that relocation does not necessarily save the cost simply because structural modules are reused, instead, the non-structural systems can overcome the financial benefit.

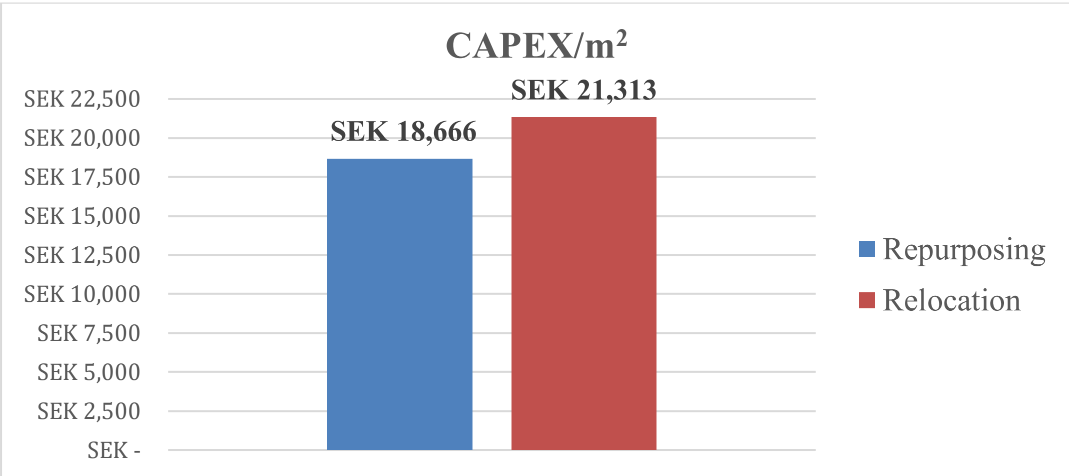

Figure 11 CAPEX Comparison (per m²)

OPEX of both scenarios shows an opposite result. Repurposing generated a higher annual OPEX of SEK 790.000 while relocation required SEK 444.936 annually. This difference is influenced by the building function, in the repurposing scenario, the building operates as an academic learning environment with intensive daily occupancy, frequent cleaning, and continuous energy demand from classrooms. Cleaning alone represented more than half of total OPEX, reflecting the operational intensity of educational facilities. This is consistent with SUHF (2024), which highlights that cleaning and utilities are major recurring costs in academic buildings due to high occupancy and continuous use.

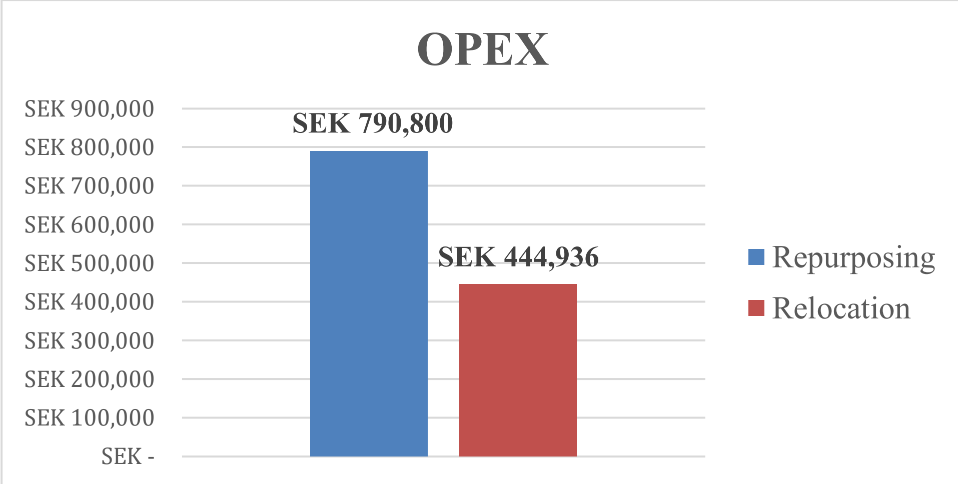

Figure 12 OPEX Comparison

In contrast, the relocation scenario assumes residential rental use, where cleaning frequency and energy demand are lower. OPEX is relatively low while the same function as student housing can generate profit of SEK 1.955.064 annually. This makes a difference in OPEX performance because relocation generate direct income, while repurposing as an educational building do not generate direct income. According to A. Sharbaf & Schneider-Marin (2025), the cost of a project must consider not only expenditure but also the monetary value of project benefits. From this perspective, relocation performs better than relocation because rental income gives a financial return despite higher initial investment.

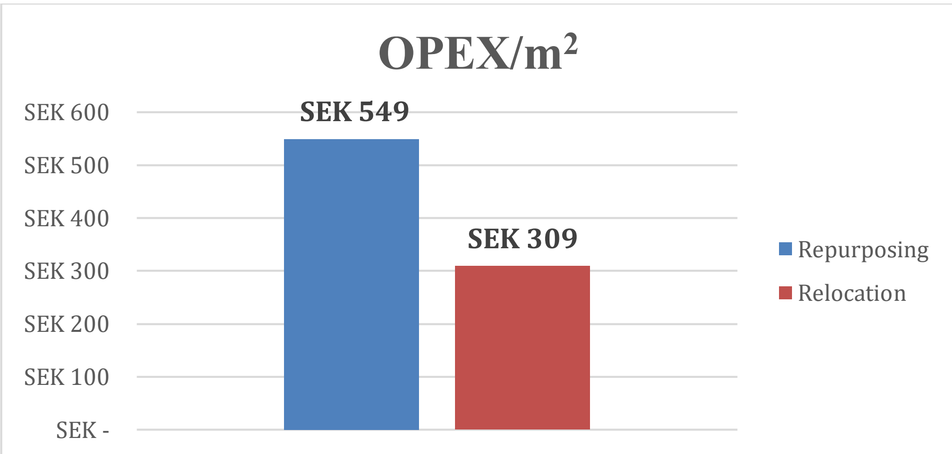

Figure 13 OPEX Comparison (per m^2)

However, economic viability should not be interpreted only through direct profitability. In university infrastructure projects, repurposing the building may create indirect value by solving campus capacity shortages, supporting learning development, and reducing the need for new educational buildings. Choi & Kim (2023) emphasize that in building transformation should consider strategic relevance functionality of the building, where in this study the repurposing supports approximately 400 students and addresses the increasing demand for learning spaces at Chalmers. Although it does not generate direct income, it may reduce future campus expansion. Therefore, its economic value partly includes in avoided future cost and functional performance rather than direct revenue.

Overall, the results indicate that repurposing offers stronger short-term economic efficiency due to lower CAPEX, lower implementation complexity and low financial uncertainty. While relocation requires greater investment and carries higher risk but offers stronger long-term operational profitability due to rental income and lower annual OPEX. This reflects the literature where adaptive reuse is often economically favorable when the objective is functionality and cost efficiency, while relocation becomes viable when future revenue is generated to cover initial capital expenditures.

5.3 Techno-Economic Assessment

The results shows that the repurposing scenario achieved a higher TOPSIS result compared to relocation, suggesting that it represents the most preferable option when technical and economic criteria are evaluated. In this study, the findings show that technical complexity has a strong relationship with economic consequences. According to Barahmand & Eikeland (2022), techno-economic assessment (TEA) enables decision makers to analyze how technical and economic criteria influence project cost and feasibility. The more complex the technical requirements for repurposing or relocating the building, the higher the uncertainties and risks involved during implementation. These uncertainties are reflected in higher contingency costs and contractor fees, since contractors need to account for unforeseen technical challenges and risks.

The findings also support the argument of Choi & Kim (2023), who state that building transformation must balance engineering with financial considerations. Although relocation theoretically provides opportunities for improved building performance and potentially lower operational costs, the scenario includes the process of dismantling, transportation, reconstruction, and adaptation. These processes increased technical uncertainty, implementation risks, and added a higher CAPEX that reduced the overall feasibility. This finding also highlights that lower OPEX alone is not enough to justify a project alternative if the technicalities are harder to achieve.

Another implication of the findings related to decision-making in circularity, although circularity objectives often encourage reuse and circular construction approaches, the results demonstrate that technical and economic assessment remain important to oversee project viability. A. Sharbaf & Schneider-Marin (2025) emphasize that cost-benefit considerations play an important role in circularity objectives, because stakeholders must balance sustainable agenda with financial consideration. In this study, repurposing appears to provide more balance between circularity objectives, economic investment, and practicality. However, direct financial benefit is identified only in the relocation scenario, because the relocation of the building will maintain its original housing function, which could generate direct income. The repurposed scenario into educational facilities does not produce direct commercial revenue, this finding suggests that technical and financial assessment need to be strengthened by another dimension such as social value and environmental benefits, since repurposing the building is intended for non-profit or public oriented functions. These additional dimensions will provide a more comprehensive evaluation framework for future decision-makers.

The different nature of building functions between repurposing and relocation of HSB Living Lab affected how the economic assessment in TEA is produced. According to Mahmud et al. (2021), net present value (NPV) and payback period are common outputs of techno-economic assessment. However, these indicators could not be obtained or compared in this study since the indicators are dependent on revenue generation, and one of the assessed scenarios is not profit-generating project. Aligned with the discussion above, adding another assessment could make the decision-making more comprehensive since it can assess other benefits of the scenario such as social benefits or environmental benefits that can add a value to the decision-making and TOPSIS processes.

The findings also reveal that the preferred scenario is dependent on the objectives of the future building owner. If the future owner is an academic institution, repurposing becomes the most suitable option because it provides both financial and technical advantages for educational purposes. The owner can focus on retrofitting and system adaptation rather than investing in a completely new site and building development process. Repurposing also makes the new owner optimize existing building while minimizing extra development cost. On the other hand, if the future owner is a housing company, the relocation scenario may become more attractive because the building keeps its original housing function and can generate direct income. If the relocation occurs with extensive reuse assessment and environmental evaluation, relocation project may provide long-term value for companies that prioritize circular construction practices.

6 Conclusion

This thesis investigated two scenarios of the future use of HSB Living Lab building that have been discussed previously with the stakeholders. The scenario is repurposing or relocating the building. The study aimed to evaluate which scenario provides a more feasible and suitable option through the application of techno-economic assessment (TEA) integrated with a multi-criteria decision-making (MCDM) approach. The assessment considered both technical and economic criteria gained from the literature review and interviews including capital expenditure (CAPEX), operational expenditure (OPEX), uncertainty, risks, ease of implementation, MEP complexity, and implementation time. Furthermore, the weighting of criteria was established based on expert judgment obtained through interviews and supported by findings from the literature review. The results showed that CAPEX was considered the most influential criterion in the decision-making process, followed by OPEX, risks, ease of implementation, uncertainty, MEP complexity and implementation time as the least important criterion.

The findings show that repurposing scenario provides lower CAPEX compared to the relocation scenario. Repurposing was also assessed to have lower risks, lower uncertainty and shorter implementation time because the building remains on the same site and does not require major disassemble, transportation and reassemble processes. However, repurposing requires higher MEP complexity due to the change of building function from residential use to educational purposes. On the other hand, the relocation scenario resulted in higher CAPEX because of the additional processes related to disassembly, transportation, reassembly and new site preparation. The relocation scenario also involved greater risks, uncertainty and implementation time. However, relocation showed lower OPEX and lower MEP complexity because the building function remains as housing, while the system configuration is assumed to use new systems and small quantity of reusable components.

The overall results of techno-economic assessment combined with TOPSIS analysis indicate that the repurposing scenario is the preferable option for the future adaptation of the building in this case study. The repurposing scenario achieved results closer to the ideal solution compared to relocation, indicating better overall performance based on the selected criteria and weighting system. The findings also show a strong relationship between technical complexity and economic criteria. More complex the technical implementation generally leads to higher CAPEX due to increased construction complexities, contingencies, and implementation requirements. On the other hand, OPEX shows different results, where changing the building function into an educational facility increases operational and maintenance requirements because the building is expected to accommodate intensive use by many users daily.

Finally, this study highlights how both scenarios contribute to the principles of circularity in the construction industry. The consideration of repurposing and relocation demonstrates the potential to reduce the consumption of new construction materials by maximizing the reuse potential of existing building components and structures. The study also highlights the importance of conducting thorough reuse assessments to optimize economic performance and reduce the construction costs.

6.1 Recommendation

This study recommends that future decision-makers involved in the HSB Living Lab prioritize adaptive reuse of the building to be an educational space rather than relocate the whole building into a new site with the same function. It shows from the results that when the technicalities and economic consideration are combined and analyzed, repurposing scenario is preferable option to be executed. Moreover, expanding the assessment for future research to discuss social benefits and environmental benefits such as Life Cycle Assessment (LCA) will strengthen the multi-criteria decision-making process since it will show different perspective from both scenarios and will affect the overall assessment on the decision-making processes.

The methodology that combines techno-economic analysis and multi-criteria decision-making process also provides a comprehensive analysis on how stakeholders in a construction project made a strategic decision on the planning phase. Based on the literature review, there is a gap in how techno-economic analysis was adapted on research in a construction industry topic, specifically on strategic decision-making. Therefore, the methodology that applied within this thesis can be used for future research in a similar case study with different objects.

7 References

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