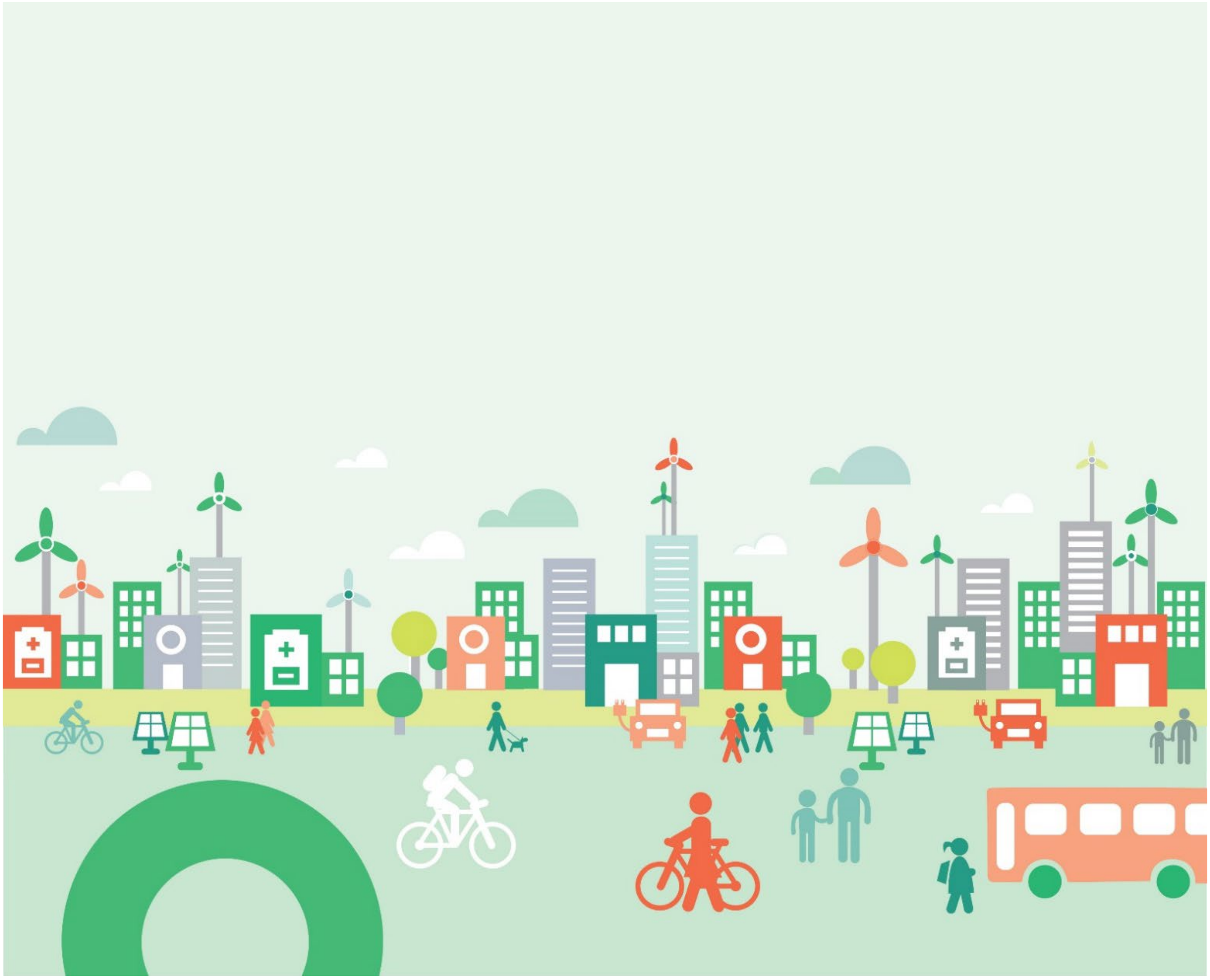
ENSURING AMBITIOUS GOALS

Barriers and good practices in the planning and building process

ZEN REPORT No. 54 – 2024



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Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

ZEN Report No. 54

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Ensuring ambitious goals: Barrier and good practices in the planning and building process

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Preface

Acknowledgements

This report has been written within the Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN). The authors gratefully acknowledge the support from the Research Council of Norway, the Norwegian University of Science and Technology (NTNU), SINTEF, the municipalities of Oslo, Bergen, Trondheim, Bodø, Bærum, Elverum and Steinkjer, Trøndelag county, Norwegian Directorate for Public Construction and Property Management, Norwegian Water Resources and Energy Directorate, Norwegian Building Authority, ByBo, Elverum Tomteselskap, TOBB, Snøhetta, AFRY, Asplan Viak, Multiconsult, Civitas, FutureBuilt, Heidelberg Materials, Skanska, GK, NTE, Smart Grid Services Cluster, Statkraft Varme, Fornybar Norge and Norsk Fjernvarme.

The Research Centre on Zero Emission Neighbourhoods (ZEN) in Smart Cities

The ZEN Research Centre develops solutions for future buildings and neighbourhoods with no greenhouse gas emissions and thereby contributes to a low-carbon society.

Researchers, municipalities, industry and governmental organizations work together in the ZEN Research Centre to plan, develop and run neighbourhoods with net zero greenhouse gas emissions over their lifetime. The ZEN Centre has nine pilot projects spread over all of Norway that encompass an area of more than 1 million m2 and more than 30,000 inhabitants in total.

To achieve its high ambitions, the Centre will, together with its partners:

- Develop neighbourhood design and planning instruments while integrating science-based knowledge on greenhouse gas emissions;
- Create new business models, roles, and services that address the lack of flexibility towards markets and catalyze the development of innovations for broader public use; This includes studies of political instruments and market design;
- Create cost-effective and resource and energy-efficient buildings by developing low-carbon technologies and construction systems based on lifecycle design strategies;
- Develop technologies and solutions for the design and operation of energy-flexible neighbourhoods;
- Develop a decision-support tool for optimizing local energy systems and their interaction with the larger system;
- Create and manage a series of neighbourhood-scale living labs, which will act as innovation hubs and a testing ground for the solutions developed in the ZEN Research Centre. The pilot projects are Furuset in Oslo, Fornebu in Bærum, Sluppen and Campus NTNU in Trondheim, Ydalir in Elverum, Campus Evenstad, Ny flypass Bodø, and Zero Village Bergen.

The ZEN Research Centre will last eight years (2017-2024), and the budget is approximately NOK 380 million, funded by the Research Council of Norway, the research partners NTNU and SINTEF, and the user partners from the private and public sectors. The Norwegian University of Science and Technology (NTNU) is the host and leads the Centre together with SINTEF.

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Summary

Barriers and good practices in ambitious projects

How can we ensure good processes before, during and after the realization of a zero-emission area? How can we ensure that buildings are realized as intended? Why do we struggle with good intentions being lost in the process from early planning to completed construction?

With this report, we want to collect key findings from the literature in terms of barriers, challenges, best practices, and drivers in pursuing ZEN-like projects. The focus is on building processes in the context of projects with ambitious energy and environmental targets.

Collaborative frameworks, stakeholders' engagement (including experts, suppliers, users, etc.), and new technical and management tools are needed to achieve ambitious project goals.

In the context of energy-efficient projects, hidden costs, split incentives, and inertia, are only a few of the constraints that ambitious projects must deal with, together with a lack of accountability of the actors after delivery, lack of knowledge and skills, poor communication and collaboration, lack of life cycle thinking, etc. They ultimately cause a **gap between ambitions and actual delivery**. Clear goals formulation, collaboration, closeness, involvement of stakeholders, and shared understanding/acceptance of the concept of Zero Emission Buildings by actors were some of the success factors in the pilots of the Research Centre on Zero Emission Buildings. However, the complexity rises significantly when we move to the district scale (like we do in the Research Centre on Zero Emission Neighbourhoods). Conceiving the development as a program of projects with a central coordinator seems a promising way forward to tackle the challenge of building carbon-neutral neighbourhoods. Many challenges persist, including uncertainties, interests mismatches, lack of knowledge of technical requirements and management processes.

The success of a project in terms of goal achievement is strictly related to a **successful process**. With the adoption of integrated design and Soft Landings strategies, the literature suggests the importance of collaboration, improvement of information flow, the rise of actors' accountability in the aftercare, and acknowledgement of the users' and Facility Manager's perspectives since the design stage. With commissioning, they have the potential to bridge the gap between design goals/ambitions and the operational status of a building, delivering actual benefits. Their maintenance might also require new actors in the urban panorama (i.e., urban Facility Managers).

Organizational, contractual, and cultural aspects should then be revised and improved to build the proper environment for a project's success, deploying new tools and methods. **Tools** to enhance projects' goals include quality assurance methods, early-stage simulation tools, information technologies, and extended reality technologies. With organizational strategies (e.g., Lean principles) and suitable contractual arrangements, they should support performance-based design and integrated project delivery, including integrated risk management, as a measure to ensure project success in terms of goal achievement.

In the fragmented and project-based Architecture, Engineering and Construction industry the adoption of tools is under its full potential because of technical, but also non-technical reasons. Most importantly, collaboration is still hindered, since diverse actors are coming together for a limited amount of time, with their own cultures, practices, and objectives. Lack of stakeholders' collaboration and commitment, insufficient organizational processes, and unsupportive development frameworks are reasons for failure in reaching energy master plan goals at the neighbourhood level more than lack of technologies. Thus, the literature suggests that to increase the opportunities for a project's success, the following actions/elements, among others, should be promoted:

- Exploration and implementation of collaborative frameworks and tools (including digital),
- Demanding and knowledgeable clients pursuing and following-up on ambitious goals under fair contract arrangements,
- Long-term relationships between actors to build trust and a 'no-blame' culture,
- Championing,
- Contracts as management tools,
- Early involvement of contractors and suppliers,
- Users' involvement,
- Increasing knowledge across industries,
- Sharing of knowledge, information, risks, and rewards,
- Life cycle thinking and performance assessment tools,
- Building and maintenance of a project culture,
- Improvement of experts' communication,
- Implementation of tools/practices to reduce conflicts.

Tools/recommendations are needed to untap the potential for integrated approaches in ZEN developments, and stakeholders' engagement must be guaranteed by carefully evaluating and managing goals, values, and risks.

List of acronyms

AEC – Architecture Engineering and Construction
AR – Augmented Reality
BAE – Building Architecture Engineering
BES – Building Energy Simulation
BIM – Building Information Modelling
BREEAM - Building Research Establishment Environmental Assessment Method
EPC – Energy Performance Contract
ID – Integrated Design
KPI – Key Performance Indicator
GHG – Greenhouse Gas
LCA – Life Cycle Assessment
LCC – Life Cycle Cost
LEED – Leadership in Energy and Environmental Design
MR – Mix Reality
RES – Renewable Energy Sources
SCI – Supply Chain Integration
SL – Soft Landings
TVD – Target Value Design
VR – Virtual Reality
ZEB – Zero Emission Building
ZEN – Zero Emission Neighborhood
XR – Extended Reality

Contents

1. Introduction

1.1. Context

How can we ensure good processes before, during and after the realization of a zero-emission area? How can we ensure that buildings are realized as intended? In many projects, something is lost from the early phase, when the project owner sets the ambitions until the building is completed. There are several stages involved from the start of the process until the building/area is finished. The standard "NS3467 Steps and deliverables in the building lifecycle" (merging the two phase-norms "Neste Steg" and "Steg for steg" initiated by Bygg21) aims at giving a common framework to the industry in terms of stages, deliverables, and perspectives to improve communication and timely decision-making across and within the projects (Knotten *et al.* 2016, SN 2023). However, when the ambitions are high and the solutions are partly unknown, as in the case of ZEN, additional guidance is needed to ensure that the project intentions are followed-up and the expected performance is delivered.

Why do we struggle with good intentions being lost in the process from early planning to completed construction? And how can we make sure that the project will deliver the expected benefits in operation? What is typically highlighted in the literature surrounding Building Architecture and Engineering (BAE) projects is weak goal formulation (Samset, 2010), optimization of project cost (investment cost) with little focus on lifetime cost, poor decision-making processes, time pressure, communication challenges between both phases and actors. These are known problems, which become more obvious when the complexity of the projects increases, such as in a ZEN project. Lack of clarity about the goals from the clients' side is only one aspect of the problem. Multiple elements can affect a project's success in terms of goal achievement, such as involving all the actors (project owner/client, main contractor, sub-contracts, users, facility managers), execution models, contracts, interaction models and distribution of responsibility.

1.2. Aim and scope

In this report, we focus on the planning and building process to learn more about the barriers, challenges, best practices, and drivers in pursuing and achieving ambitious goals in ZEN-like projects.

The topics of inquiry are the aspects that contribute to characterizing the building process in terms of involved actors/organizations, values, contracts, tools, and practices as causes for or measures against a gap between expectations and results. Indeed, given certain goals, the process to achieve them is in the hands of the project team, which is characterized by certain organizational, contractual, and cultural arrangements. To deliver, the project team will need to take timely decisions with the support of certain tools/methods/strategies, communicating with the client and keeping the goals in check. To do so, multiple tools are in place. They can be technical tools for performance assessment and/or for information exchange (Building Energy Simulation, BIM, …) or managerial strategies (Lean principles, set-based design, …) and related methods and tools (Target Value Design, BIM, …). Studying the process-related aspects mentioned here is important in moving from ZEN definition to ZEN realization, which is an important topic to cover at the current stage of the Centre when definitions are on the way to being finalized and experience from pilots has been collected.

The objective of this report is to shed light on the state-of-the-art of these elements in the context of ambitious projects by reviewing relevant scientific literature. Future works should complement the present report by providing empirical findings resulting from the observation of relevant case studies. The final objective is to contribute to providing recommendations for a successful planning and building process for ZEN.

2. Literature search

In the context described in the previous section, the literature has been inquired to understand which are the main challenges/barriers in delivering a successful project in terms of satisfaction of the initial goals (first round of literature search). Besides, drivers and good practices have been identified. The context is one of ambitious projects in terms of energy and environmental targets (also, but not only, in connection with certification schemes like BREEAM and LEED), and the focus is on the planning and building process rather than on the final performance. Some recurrent topics were inferred (i.e., collaboration, decision-making, engagement) and deepened in a new literature inquiry as a basis for discussing results (second round).
Before presenting and discussing the results (sections 3 and 4), more details on the review rounds are reported below.

First round: Different combinations of the following keywords have been used as queries in Scopus: building, ZEB, ZEN, district, energy, emission, building process, planning process, performance gap, energy gap, energy performance gap, industry, barrier, challenge, driver, best practice. The keywords have been selected and combined to target studies concerning the causes for or measures against a performance gap between design and delivery that are connected to the building/planning process. Indeed, the numerous works investigating the causes of a performance gap that are rooted in inaccurate modelling (during the design phase) and unexpected/variable interactions within the environment-building-occupants system (once the building is in operation) are outside the main scope of this review. By tuning the search query to match the targeted topic, only 13 papers were found in the end, and 8 were selected as strictly relevant. To them, 1 paper resulting from the same query in Google Scholar and 3 papers reporting the experience from the ZEB Research Centre and the Research Centre on Zero Emission Neighborhoods in Smart Cities (FME ZEN) have been added. All papers were read and classified in three groups depending on their focus – performance goals, processes measures, and support tools. Then, papers were read again and analysed to identify challenges/barriers and good practices mentioned throughout the texts. The main findings build up the results of this report (section 3).

Second round: More papers (10) were selected through new keywords and snowballing. This review round targeted topics that were found recurrent in the first round. They are described by the following keywords: collaboration, integrated design, integrated contract, partnership, partnering, alliance (or alliancing), relational contract, stakeholder analysis, and stakeholder engagement. Papers were read and key messages synthetized. The extracted knowledge was used as basis to further discuss the results (section 4).

Results from the first round are presented alone because the objective was to explore a very specific area and infer the relevant topics (section 3), whereas, with the second round, we improved our understanding of the most recurrent concepts to use them as lenses through which we discuss the previous findings (section 4).

3. Results

The works resulting from the first round of literature search can be divided into three groups, covering the following topics:

- Targeting ambitious (energy and environmental) performance goals
- Implementing process-related measures
- Tools to enhance ambitious goals.

They are all relevant when discussing barriers and best practices in achieving ambitious projects' goals; hence the findings are reported in the following, topic by topic.

3.1. Targeting ambitious (energy and environmental) performance goals

In the context of targeting ambitious environmental and energy goals, the experience of the pilot cases of the ZEB Research Centre is very relevant (Andresen *et al* 2019). Indeed, the pilots' objective was very ambitious – reaching the zero-emission target, meaning that the emissions caused by the building (including different stages of its life cycle depending on the pilot) must be outweighed by the energy production guaranteed by its Renewable Energy Sources (RES). The researchers reported **challenges** in delivering the planned performances concerning:

- the difficulty of keeping **the focus on embodied emissions**, when multiple criteria must contribute to the choice of building materials,
- the **disbelief of sub-contracts** towards functional demands and specifications from the design process, which they were not familiar with from the earlier stages,
- the **resistance** by sub-contractors to make order **changes** in the projects, even when strongly advised by engineers, because disincentivized by the contract type (i.e., turnkey contract).

On the other hand, the deployment of an **integrated design** approach was considered a best practice, allowing to have clear goals, collaboration and involvement of stakeholders, projects participants with a shared understanding and acceptance of ZEB, and 'closeness' between actors. The fact that the construction manager had enough time with the sub-contractors to connect and solve issues has been an advantage. However, a better connection between sub-contractors and the project management level (i.e., construction manager and contractor) was suggested to overcome their previously mentioned disbelief. Overall, the fact that everybody recognized the added value of participating in the project in terms of knowledge gain has been important. Thus, communicating the benefits in terms of skills and knowledge development can be an incentive to motivate sub-contractors to join more time-consuming contract arrangements in the future, like the ones associated with ambitious projects. Based on these lessons learnt, the use of a collaborative framework can be suggested as a best practice to achieve the goals, and an even higher collaboration level could be reached by including the sub-contractors in the process of identifying and sharing risks with the project owner and main contractors.

Thus, the recommendation to unfold a **collaborative** framework in the ZEN project seems an interesting way forward to make sure that ZEN's ambitious goals are met in future, and a supportive contract arrangement is crucial for that purpose.

However, when moving the attention from the single building level to the district one (which is the ambition of the ZEN Research Centre compared to the ZEB Research Centre), the complexity rises significantly. This is connected to the long timeframe that characterizes this type of development and the variety of actors involved. Indeed, the latter are engaged in non-simple interactions and driven by different interests. The presence of very ambitious requirements for the project brings additional complexity, which can hinder the success in terms of the achievement of the expected performance goals. A good example of such complexity is the ZEN pilot case Ydalir, in Elverum, Norway. It concerns the development of various infrastructure and building projects (school, kindergarten, and housing) involving multiple actors, both public and private, in a diversified land ownership scenario (80% public, 20% private) (Hamdan *et al* 2021a). In Ydalir, besides energy and environmental goals, particular attention was also devoted to creating social value in terms of sharing solutions. They were identified with the involvement of the community through co-creation. The project is still under development, but several publications already give insights into success factors and barriers (Hamdan *et al* 2021a), (Baer and Haase 2020), (Baer and Lindkvist 2022). The premise is that the development is understood as a program of related projects, according to a model proposed within ZEN (Hamdan *et al* 2021a) that is still not common but that looks promising. This implies that an overarching program, in the form of masterplan requirements, is collaboratively developed before building-level developments, and hopefully accepted by the individual developers, who must collaborate under the coordination and management of an intermediator party. The latter is accountable for goal alignment, systems integration, and contractual agreements. The **challenges** in ambitious district-level developments, based on the Ydalir pilot case, are related to the following factors:

- **Diversity** of stakeholders. They are, e.g., future users, suppliers, developers, and owners, which can differ in terms of approaches, business models and interests, also within the same category. In the Ydalir case, the owners' panorama was quite diverse - a semi-public development agency, a local real estate developer, and a large real estate developer with a longer value-chain. Diversity of stakeholders characterizes all projects, regardless of the level of ambition. However, in ambitious ones, more numerous and specialized actors are typically involved, and, when an ambitious program is set at the masterplan level, additional elements of disagreement can emerge. Actors might have different background, time perspectives, and potentially conflicting interests (i.e., developers must share district-level ambitions, but they are still competitors on the market for future selling), which make the collaboration more complex (Hamdan *et al* 2021a).
  In principle, these circumstances can be a reason for the **rejection** of the masterplan idea by some developers. Indeed, literature (Baer and Haase 2020) says that master planning at the neighbourhood level with energy ambitions can fail in reaching goals not for lack of technological solutions, but for lack of stakeholders' collaboration and commitment. In the case of Ydalir, one developer rejected the masterplan developed with ZEN ambitions. The rejection was based on cost justifications and incompatible design concepts (Hamdan *et al* 2021a). Also, the infrastructures were developed before the approval of the ZEN masterplan, missing some opportunities for optimization.
- Lack of **procurement practices** at the neighbourhood level. Insufficient organizational processes and unsupportive development frameworks are other issues that accompany the lack of stakeholders' commitment to ambitious energy masterplans (Baer and Haase 2020). In this sense, Ydalir is a pilot case because of the combination of different procurement practices experimented within the same neighbourhood. This was possible because multiple owners were involved and the development was decomposed into projects, which have different needs and are run in different stages (Hamdan *et al* 2021a).
- Need for **development work** before construction. It should preferably happen through engagement and collaboration of the owners if there is more than one. Since it is an unusual

practice for developers, who are normally buying land and starting construction (Hamdan *et al* 2021a), it can represent an obstacle because early risks increase. The need for this stage (i.e., development work) also implies that value creation is shifted in time, and early developers have higher risks.

- **Restrictions** imposed by public procurement regulations. Masterplan level requirements can be defined collaboratively (as it happened in Ydalir, with 5 workshops organized by the project owner (Baer and Haase 2020)), but a public actor cannot bind them to contracts or zoning plans if they are more restricting than national planning and building law. In Ydalir, a development agency owned by the municipality was established to overcome this obstacle. It is an intermediary party, also increasing the coordination capacity in the project. The agency was able to bind the ZEN masterplan to an agreement with one landowner and to the procurement contracts with the developers who bought the land from the municipality (Hamdan *et al* 2021a).
- **Uncertainty** about the ambitions to choose as part of the masterplan development. In Ydalir, a massive effort was needed in discussing which and how ZEN requirements could be included in the contracts. Also, once they are defined, the **translation** of masterplan ambitions into procurement requirements is not trivial because they can still be open for interpretation by the different developers. Another source of uncertainty is the market demand and how the evolution of other building zones might influence it (Hamdan *et al* 2021a).
- **Scope** of the planning tools. A masterplan is a long-term planning instrument that, in developing a strategy, might conflict with the current market circumstances in which the individual projects are produced. In Ydalir, the requirements on parking, designed based on the ZEN principle of reducing private cars, were changed to make the offer market-relevant for future owners, who did not want to buy a house without private parking lots or garages (Hamdan *et al* 2021a).
- **Lack of knowledge**. It refers not only to technological requirements for ambitious projects like ZEN but also to process management in the context of a collaborative holistic approach (Baer and Haase 2020), as the one required in ZEN-like developments.
- **Undefined long-term management strategies**. The role of the project owner will typically change after delivery, as it will happen in Ydalir. This leaves a gap in terms of responsibility for the operation of the neighbourhood, which has an important role in maintaining performance levels (Baer and Haase 2020).
- **Lack of tools**, built on Life Cycle Assessment (LCA), that can support the decisions in the early stages of planning and design (Baer and Haase 2020).

Based on this, the following **best practices** can be identified thanks to the Ydalir experience:

- **Collaborative** approach in the development of an overarching masterplan. In Ydalir, the project owner initiated several workshops with different topics to define the common goals for the area. This helped to give to all stakeholders a common understanding of the complexity of the project (Hamdan *et al* 2021a), developing knowledge and trust and a shared understanding of the vision (Baer and Haase 2020). The collaboration was perceived as positive to share infrastructure costs and to find innovative solutions (Hamdan *et al* 2021a).
- Presence of an overarching **program** with a **coordinator** responsible for goal alignment, system integration, and contractual agreements among the different projects and related actors. In Ydalir, the program was in the form of a masterplan that was bound to contracts, and the coordinator for that was an intermediary party that, being semi-public, could act outside the more rigid public schemes and structures. This actor also ensured that the project performance was followed-up, thanks to a checklist of KPIs (Hamdan *et al* 2021a).

- Deployment of **dialogue-based procurement** and **interaction-based contracts**. In some of the projects of the Ydalir development, a dialogue conference proceeded with the formal tendering to get input on the qualifications, award criteria, tender evaluation, and documentation requirements to be defined in the tendering documents. Incentives were given in connection to competences in the project organization. Interaction-based contracts, instead of simple design-build ones, allowed to think more holistically about the project solutions, resulting in a very successful and awarded project for the school and the kindergarten, which were delivered in time, on budget and in less time "than normal construction projects with sustainability goals" (Hamdan *et al* 2021a).
- **Exchange of knowledge** and **information** among the different procurements and projects. In Ydalir, this was made possible by two factors: the decomposition of the development in projects that are run at different times, and the adoption of different types of procurements, some replicated, and some adjusted based on the gained experience.
- Involvement of **experts and researchers**, enabling the development of scenario analyses in the stage of evaluation of alternative strategies. In Ydalir, different LCA studies were conducted in the planning stage by researchers from the ZEN Research Centre.

Despite the success factors, the selling process of the housing stock in Ydalir is slow. Price and location are among the causes for it. However, this issue must be avoided by making sure that ambitious projects can **create value** for all actors, including the final users, to play as positive examples and foster the spreading of such initiatives. This is ensured by clarifying the actual needs that the project must respond to. In Ydalir, this was done by working on social value creation, which was addressed by defining sharing services at the community level through co-creation activities (Baer and Lindkvist 2022). This investigation clarified even more that the operation phase of a project is a key element of success, which might require new structures and roles in the urban panorama (e.g., Urban Facility Management) to foster the creation and maintenance of community services.

When speaking about ambitious goals and district-level implementation programs, remaining in the Scandinavian context, the development of city districts in Sweden represents an interesting case study, which is discussed in Carlander and Thollander (2023). Through several interviews with relevant stakeholders, the authors defined the barriers encountered in adopting energy-efficient technologies in different stages (feasibility study, planning program, project planning, and production and follow-up). The authors refer to 4 categories of barriers: economic barrier, behavioural barrier, organizational barrier, and infrastructure limitations. Because of such barriers, when dealing with energy efficiency goals in building or district projects, it is often the case that a discrepancy between design and as-built is observed. The most common causes for this phenomenon are investigated in a recent rapid literature review (Eon *et al* 2020) including studies from different countries across the world. The authors mapped them throughout the building process (planning and design, procurement, construction, installation and commissioning, verification, occupancy and maintenance) into 4 categories of barriers: knowledge and skills, communication and collaboration, standards, and accountability. In both studies just mentioned (Carlander and Thollander 2023, Eon *et al* 2020) some recommendations to face the identified barriers are also suggested. Their findings in terms of barriers (***what***) and recommendations (***how***) per each stage (***when***) are systematized here in one single picture inspired by the NS3467:2023 (SN, 2023) framework in Tables 1-4 and discussed below. To do so, we harmonized the categories of barriers from the two studies as illustrated in Fig. 1. In Fig. 2 we illustrate how the building phases described in the above-mentioned studies match the ones of NS3467:2023, which is adopted here as a common framework.

In this report:	*Carlander and Thollander (2023)*	*Eon et al (2020)*
Economic barrier	Economic barrier	Accountability*
Behavioural barrier	Behavioural barrier	Knowledge and skills Communication and collaboration
Organizational barrier	Organizational barrier	…
Infrastructure limitations	Infrastructure limitations	…
Standard	…	Standard

* Classified as economic because it is often connected to the lack of an integrated delivery method and the related contracting framework.

Figure 1 Categories of barriers to implementing energy-efficiency projects.

<table>
<tr><td></td><td colspan="2">Needs & concept</td><td colspan="3">Pre-project</td><td colspan="3">Execution</td><td>Use</td><td>Liquidation</td></tr>
<tr><td>NS3467:2023:</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td></tr>
<tr><td>Carlander and Thollander (2023):</td><td>Feasibility study</td><td colspan="2">Planning program</td><td colspan="3">Project planning</td><td colspan="2">Production and follow-up</td><td colspan="2"></td></tr>
<tr><td>Eon et al (2020):</td><td colspan="5">Planning & design</td><td>Procurement</td><td>Construction + Installation& commissioning</td><td>Verification</td><td>Occupancy & maintenance</td><td></td></tr>
</table>

NB: 1 – identification of ideas and needs, 2 – project framing, 3 – programming and investigation, 4 – sketch design, 5 – pre-engineering, 6 – detailed engineering, 7 – production and delivery, 8 – hand-over and commissioning, 9 – use and operation, 10 – liquidation and reuse.

Figure 2 Building process stages in NS3467:2023 and two studies selected from the literature.

According to Carlander and Thollander 2023, and Eon *et al* 2020, the observed **economic** barriers hindering ambitions and the recommendations to overcome them (see Table 1-2) can be:

- **Hidden costs**.
  What. Investments in new technologies and future operation and maintenance costs are hard to calculate. Also, costs for re-working can occur because more energy-efficient technologies are presented too late in the process.
  When. This barrier typically occurs in the project planning phase when alternatives are normally assessed. However, it can be present already in the planning program stage, when believes probable higher costs for efficient technologies might affect the way ambitions are set.
  How. Promoting more sharing of costs and performance information from reference projects dealing with new technologies. Introducing subsidies and/or tax reductions to support late introductions. A more long-term perspective of the client to help boost the adoption of energy-efficiency technologies despite the hidden costs.

- **Access to capital**.
  What. The costs are always a constraint to the projects, and energy-efficient projects are perceived as more expensive. The work of project management is to control cost, time, and quality. However, often energy-efficient technologies were not budgeted at the beginning because they were proposed too late.
  When. This barrier can occur throughout the design process, from the concept to the detailed design.

How. The same recommendation mentioned for 'hidden costs' is applicable here too. Life Cycle Cost (LCC) calculations could be a tool to show that new technologies would lead to lower running costs.

- **Risk.**
  What. There is a (real or perceived) financial risk associated with the deployment of technologies that are typically more expensive than average. The fact that a big investment might not pay off is also a financial risk. Risks are also associated with not meeting compliance with regulations or with the expected performance because of a poor understanding of a technology that the suppliers did not work with before.
  When. Risks are associated with all the project phases - in budgeting and hiring contractors, before execution, and in construction and follow-up as well, in terms of poor installation and subsequent bad performances or the need to repeat works.
  How. Testing new technologies on a smaller scale. Promoting a daring and forgiving corporate culture to encourage people to take more risks and learn.

- **Split incentives.**
  What. The Architecture Engineering and Construction (AEC) industry is typically characterized by conflicts of interest between the parties involved in a project, like owners, design teams, contractors, consultants, sub-contractors, and users. For instance, the facility manager would aim to reduce the operation costs, while the contractor would be willing to minimize construction costs. Another example concerns control systems (e.g., Building Automation Systems) that are built as binding solutions from the suppliers, while the customer would like platform-free options to be able to integrate components to the best of his interests.
  When. This barrier occurs mostly during the project planning and the production and follow-up stages in the forms mentioned above. Multiple split incentives are common in the sector.
  How. Enabling an early detection of possible issues by promoting more co-working between stakeholders.

- **Imperfect information.**
  What. Information regarding energy-efficient technologies is hard to find and the suppliers can fail in conveying them to the customers.
  When. This barrier occurs when alternative technologies are supposed to be evaluated (project planning phase) but it also concerns the information related to the installation, with consequent defects (production phase).
  How. Promoting the sharing of results from past experiences. Having a dedicated person in the project with ambitions to look for the necessary information. We can also mention accurate documentation activity and open access data as measures to face the problem of imperfect information.

- **Lack of accountability for building energy performance.**
  What. The stakeholders' involvement in the project ends as long as their job is completed, and the actual performance is no one's responsibility[1].

[1] We defined it here as an economic barrier because it is often connected to the lack of an integrated delivery method and the related contracting framework for it.

When. The barrier affects the whole process pre-occupancy, and the consequences are often on the shoulders of the users alone.
How. Extending stakeholders' involvement past the delivery. Promoting real (post-occupancy) energy performance assessment. Energy Performance Contracts (EPCs) can be also mentioned as mechanisms to ensure the implementation of such principles since contractors' profit is based on the actual performance of the building in use.

Table 1 Economic barriers to the implementation of energy-efficiency goals.

NS3467:2023:	1	2	3	4	5	6	7	8	9	10
Carlander and Thollander (2023):	Feasibility study	Planning program		Project planning			Production and follow-up			
		Hidden costs		Hidden costs						
	Hidden costs *(horizontal)*									
		Access to capital								
	Risk									
				Split incentives						
				Imperfect information			Imperfect information			
Eon et al (2020):	Planning & design					Procurement	Construction + Installation& commissioning	Verification	Occupancy & maintenance	
	Lack of accountability									

NB: 'horizontal' in tables refers to a barrier that affects the whole industry beyond the individual project boundaries.

Table 2 Recommendation to tackle economic barriers.

NS3467:2023:	1	2	3	4	5	6	7	8	9	10
Carlander and Thollander (2023):	Feasibility study	Planning program		Project planning			Production and follow-up			
	Information sharing from reference projects; Subsidies and/or tax reductions to support late introduction of technologies; term-perspective of the client									
		LCC calculation								
	Testing of new technologies on a small scale; Daring and forgiving corporate culture									
				Co-working between stakeholders						
				Energy champion; Sharing of results from past projects						
Eon et al (2020):	Planning & design					Procurement	Construction + Installation& commissioning	Verification	Occupancy & maintenance	
	Stakeholders' involvement after delivery Energy efficiency assessment based on post-occupancy performance									
									Accessible energy performance data	

The identified **behavioural barriers** and related recommendations (see Table 3-4) can be:

- **Inertia.**
  What. It refers to the general attitude of the industry of choosing to rely on established practices and technologies rather than adopting new solutions. The construction sector is very conservative, where satisfactory solutions and budget and schedule still outweigh optimal but disruptive solutions. Also, since projects are very long, there is a tendency to postpone decisions. In the context of decisions, the focus is still on the investment's costs regardless of the well-

known fact that the construction is a small percentage of a building's life. Life-cycle financial methods are available (i.e., LCC), but they are still rarely deployed.
When. This barrier affects the whole building process, even beyond the boundary of the specific project.
How. Bonuses, subsidies, tax reductions, stricter requirements, and tougher clients' demands to facilitate a change in practices. Investing in persons with real ambitions in charge of following up on critical decisions. Promoting LCC calculation to encourage life-cycle thinking.

- **Lack of knowledge[2].**
What. There is a general acknowledgement of a lack of updated knowledge and time to gain it within one single project. Stakeholders can be narrow-minded, and this, on top of the lack of knowledge, is a cause for relying always on the same practices.
When. This barrier has a serious impact on the decision-making capability of the stakeholders; hence it occurs when solutions are assessed in the planning program, project planning, and production and follow-up phases.
How. Promoting capability-building activities, co-working, information sharing (since time and money constraints make it impossible to cover a gap in knowledge within the scope of a project), and certifications for professionals. Let national requirements and clients' demands put pressure on the offer.

- **Fear[3].**
What. A sense of fear due to uncertainties about the final performances can prevent contractors from adopting new technologies.
What. According to the literature, the barrier occurs in the project planning stage in connection with the evaluation of alternatives. However, it might also affect the planning program.
How. The barrier can be considered as connected to a lack of knowledge. Thus, the same recommendations reported above are applicable here.

- **Form of information.**
What. How an idea is presented influences the follow-ups. An idea poorly presented by a stakeholder that did not gain trust is not likely to be pursued.
When. The barrier occurs in the project planning production and follow-up stages, where solutions are normally proposed and assessed, and necessary information is collected.
How. Investing in persons who are trustworthy and have real ambitions on the project to collect the necessary information and to translate it for the project staff in an accessible way.

- **Knowledge and skills.**
What. It is related to a more general lack of knowledge in the industry already mentioned. According to the review paper that has been analysed to prepare this report, several problems are found in the literature that are related to poor knowledge and skills. In the planning and design, they are related to energy illiteracy, lack of awareness about construction implications, and excessive focus of the members of the design team on their discipline. During procurement, the focus on costs outweighs the attention to having the proper skills on board. During the construction, the risk of a performance goal not being met can be related to the fact that poorly

[2] The inclusion of this item under the behavioural barrier category is a novel contribution by Carlander and Thollander (2023).
[3] The inclusion of this item under the behavioural barrier category is a novel contribution by Carlander and Thollander (2023).

informed changes are happening on-site. Other defects can be errors, omissions, or damages, and they can occur for lacking skills, management, communication, inspections, and attention to specifications. The latter can also lead to incorrect installation of technologies, which sometimes can also be incorrectly sized. The earlier these issues are detected, the cheaper it is to fix them. However, verification during the construction and at completion is not common enough, dragging problems into the operational phase, with consequences on the expected performances.
When. All stages before occupancy, in the forms just mentioned above.
How. Promoting training and upskilling of professionals.

- **Communication and collaboration.**
  What. Communication and collaboration are essential to guarantee the flow of necessary information across the process. However, different actors are still focusing on their expertise and poorly collaborating, and the projects are delivered for production with inadequate level of detail. During the procurement, change orders to save time or money can be supported by owners who are poorly informed about the implications on the performances. When these changings are happening on-site the design team is typically not informed, and no check of performance compliance is run. The 'broken' channels of communication and information are due to poor management and supervision of the process. A bad management can also be the cause of deficient scheduling of the installation activities, with negative consequences on the performance due to damages to the structures built before.
  When. All the stages before verification, in the forms just mentioned above.
  How. Improvement of the management process and deployment of tools to log data, share information and send feedback. Guarantee that the correct and necessary information is delivered timely and effectively as a core responsibility of management.

The identified **other barriers** and related recommendations (see Table 3-4) can be:

- **Organizational: Value and culture.**
  What. Individual values and corporate culture are organizational barriers hindering the achievement of ambitious project goals. It translates into a lack of mandates, more specifically of persons in charge of following up on ambitious ideas. We believe that this, together with the general inertia mentioned above, leads to the problem of suboptimization.
  When. The barrier occurs when options and ideas are proposed and assessed, in the design and production stages. However, we think it might also affect the definition of requirements earlier.
  How. Long-lasting processes to change individual and corporate culture. Ambitious persons can lead the way, but the lack of a shared culture valuing energy and environmental ambitions can hinder the individuals' initiative. Thus, this barrier can affect the whole industry, beyond the individual projects and process stages.

- **Infrastructure limitations.**
  What. Strategies on the infrastructures can be turned into postulates on the use of specific energy systems in new projects.
  When. Some technologies can be excluded in the feasibility study or later in the design stage because of external constraints.
  How. Promote cooperation among stakeholders, including those responsible for the energy infrastructures. Designing for optimum solutions in the presence of external constraints.

- **Standard.**
  What. The barrier does not necessarily relate to the lack of standards, but to the fact that their application for early verification process is uncommon and/or not rigorous. In some cases, verification is uncommon even at the completion stage. When verification is performed, problems can occur in terms of poor calibration of the tools or not rigorous observation of the protocols. Methods can vary among different practitioners, as well as results interpretation.
  When. This barrier is particularly present in the stage of handing over the building, which is the last occasion to perform verification of the actual performances.
  How. Verification mandates in the projects and development of new guidelines and standards.

Table 3 Behavioural and other barriers to the implementation of energy-efficiency goals.

<table>
<tr><td>NS3467:2023:</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td></tr>
<tr><td>Carlander and Thollander (2023):</td><td>Feasibility study</td><td colspan="2">Planning program</td><td colspan="3">Project planning</td><td colspan="2">Production and follow-up</td><td colspan="2"></td></tr>
<tr><td></td><td colspan="8">Inertia (horizontal)</td><td colspan="2"></td></tr>
<tr><td></td><td></td><td colspan="7">Lack of knowledge</td><td colspan="2"></td></tr>
<tr><td></td><td></td><td colspan="2"></td><td colspan="3">Fear</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td></td><td colspan="3">Form of information</td><td colspan="5">Form of information</td><td colspan="2"></td></tr>
<tr><td></td><td colspan="8">Form of information (horizontal)</td><td colspan="2"></td></tr>
<tr><td></td><td></td><td colspan="2"></td><td colspan="5">Value</td><td colspan="2"></td></tr>
<tr><td></td><td colspan="8">Value (at an individual level) and culture (at the corporate level) (horizontal)</td><td colspan="2"></td></tr>
<tr><td></td><td colspan="6">Infrastructure limitations</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Eon et al (2020):</td><td colspan="5">Planning & design</td><td>Procurement</td><td>Construction + Installation& commissioning</td><td>Verification</td><td>Occupancy & maintenance</td><td></td></tr>
<tr><td></td><td colspan="8">Knowledge and skills</td><td></td><td></td></tr>
<tr><td></td><td colspan="7">Collaboration and communication</td><td>Diversified and not rigorously applied methods and tools</td><td></td><td></td></tr>
</table>

NB: 'horizontal' in tables refers to a barrier that affects the whole industry beyond the individual project boundaries.

Table 4 Recommendation to tackle behavioural and other barriers.

<table>
<tr><td>NS3467:2023:</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td></tr>
<tr><td>Carlander and Thollander (2023):</td><td>Feasibility study</td><td colspan="2">Planning program</td><td colspan="3">Project planning</td><td colspan="2">Production and follow-up</td><td colspan="2"></td></tr>
<tr><td></td><td colspan="8">Bonuses, subsidies and tax reductions; Tougher requirements and client demands; LCC calculation; One person in charge of decisions follow-ups</td><td colspan="2"></td></tr>
<tr><td></td><td></td><td colspan="7">Capacity-building activities; Co-working and information sharing; Certifications for professionals; National requirements and client demands</td><td colspan="2"></td></tr>
<tr><td></td><td colspan="8">Translate information in an easy-to-understand ad trustworthy way (by energy champion)</td><td colspan="2"></td></tr>
<tr><td></td><td colspan="8">Change values through long-lasting processes; Champions to lead these processes</td><td colspan="2"></td></tr>
<tr><td></td><td colspan="6">Cooperation among stakeholders; make the best out of the given situation</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Eon et al (2020):</td><td colspan="5">Planning & design</td><td>Procurement</td><td>Construction + Installation& commissioning</td><td>Verification</td><td>Occupancy & maintenance</td><td></td></tr>
<tr><td></td><td colspan="8">Training and upskilling of professionals</td><td></td><td></td></tr>
<tr><td></td><td colspan="8">Tools to record, maintain and share information between stakeholders. Closed feedback loops.</td><td></td><td></td></tr>
<tr><td></td><td colspan="8">Better management processes. Sustainability champions appointment.</td><td></td><td></td></tr>
<tr><td></td><td colspan="5"></td><td></td><td colspan="2">Mandates for testing and verification</td><td></td><td></td></tr>
<tr><td></td><td colspan="5"></td><td></td><td colspan="2">New guidelines and standards</td><td></td><td></td></tr>
</table>

All the barriers (***what***) per building stage (***when***) and the related recommendations (***how***) discussed and reported in Tables 1-4 are a summary of the findings of Carlander and Thollander (2023) and Eon *et al* (2020), which were here reorganized in the 4 groups of Fig.1 and related to the 10 stages of the Norwegian standard NS3467:2023. Critical conclusions and additional data will be reported only later in this report (section 4).

The literature quoted so far includes the most comprehensive works on barriers and good practices encountered throughout the process when pursuing energy and environmental performance goals. However, further works were found on cases having specific ambitions on the implementation of process-related/managerial measures, as discussed in the next subsection.

3.2. Implementing process-related measures

As emerged from the findings reported in the previous subsection 3.1, the success of a project in terms of met or unmet goals is different but strictly related to successful or unsuccessful process management. The former concerns the strategic level, the latter the tactical level (Meistad *et al* 2017), and they both have to do with a potential gap between expected results and actual delivery.

The identified literature concerning the implementation and assessment of tactical measures are mostly addressing the design stage, where BREEAM or LEED certifications are adopted, followed by the hand-over phase.

Regarding the **design stage**, two theories/strategies emerged from the literature as good practices:

- Integrated Design (ID): a strategy based on collaborative design process in multidisciplinary teams,
- Soft Landings (SL): a framework that maximizes the knowledge flow and extends the involvement of contractors beyond the delivery.

Their implementation can be a response to some obstacles towards goal achievement mentioned before (subsection 3.1), like lack of accountability on the real performance of building projects, or lack of knowledge and information sharing. However, their implementation requires an effective management effort to face the related challenges, as discussed in the following.

ID emerged as a good practice in the previous subsection of this report (subsection 3.1). It is based on the involvement and collaboration of the relevant stakeholders throughout the building process, leading to more stakeholders' interactions. The development of collaborative workflows (such as ID) requires attention to contractual, organizational, and cultural elements (Engebø 2022). Among the organizational aspects, the adoption of simulation tools to study alternative scenarios and assess options collaboratively is a valuable support to decision making. Also, certifications like BREEAM and LEED can support the definition of clear and measurable project goals.

In this context, we can learn from literature about the following **barriers** that are affecting the adoption of Building Energy Simulation (BES) and Life Cycle Assessment (LCA) tools and quality assessment tools (i.e., LEED) in ID context:

- BES and LCA can be perceived as **too complex** by the design team, who would refuse or drop their use throughout the process. The timely support of specialists is needed to exploit their full potential.
- When adopted, LCA potential can remain untapped if it is used only for **stand-alone** decisions (e.g., main structure, specific materials, etc.) instead of for the whole project. The same can happen if LCA is used for validation of individual options rather than as a decision-support tool among alternatives.
- When adopted, BES and LCA present **limitations** in terms of elements that they can handle (for instance, requiring some parallel computation outside the dedicated software) and **data** that are required. Indeed, the results of simulations rely on assumptions about aspects of the project that in the early stages are generic or uncertain.
- Risk of **fragmentation** of the decision-making, meaning that the decisions are taken without considering an overall impact assessment of the choice.
- Despite the availability of tools (e.g., LCA), there is **not enough focus on the embodied** energy and, more in general, on the (embodied) impacts of the construction, prioritizing the optimization of the (expected) building operation.
- Despite BES and LCA being effective tools to support decisions, choices always have a **subjective dimension** that cannot be anticipated in performance simulation exercises.
- In ID meetings, the **focus** can be shifted too much towards the mere discussion of the LEED (or other certification) **credits**.

These reflections are based on three building projects located in Canada (Leoto and Lizzaralde 2019). The lack of attention to construction impacts might not be applicable in ZEB/ZEN projects, especially in Norway, where the environmental impacts of energy consumption in operation are relatively small due to a ‘clean’ energy supply system. However, a **lack of life cycle thinking** in AEC is more generically associated with an inattention to whether the performance is delivered to the users over time.

Since ID is based on the idea of bringing experts together to solve problems, it can itself be a promising framework to overcome some of the challenges mentioned above and to achieve ambitious project goals via early involvement of relevant experts, knowledge and information sharing, integration of disciplines, etc. Indeed, one of the case studies from the literature underlines how the availability of LCA results prepared by an LCA specialist in the ID process led to optimizing the design for the sake of deploying less carbon-intense materials (Leoto and Lizzaralde 2019).

The **drivers** for a simulations-informed ID process can be:

- Development of **more** and better **simulation tools**.
- Adoption of a **life cycle thinking**.
- Evaluation of **trade-off** between goals (e.g., energy efficiency in operation vs materials use).
- Gain more **empirical data** to make decisions.
- Dedication of more efforts into **team work** rather than BREEAM/LEED credits monitoring.
- Development of a practice for **overall impact assessment**.
- Increase in **knowledge about life-cycle analyses** among stakeholders.
- Guarantee of **early involvement of experts** (e.g., LCA specialists in ID meetings, engineer in pre-design)

Beside ID, another tactical measure to be adopted in the design phase to increase the chances of projects' success against defined goals is SL. **SL** is a framework that aims to maximize the knowledge flow between all the stakeholders in a project and to keep the focus on the initial objectives from briefing/-programming until and beyond hand-over, extending the involvement of the contractors (both design and construction teams) in the aftercare (BSRIA). From the literature it is possible to read about the following **challenges** in the implementation of SL in the UK context:

- The **design process is longer**, potentially making clients nervous due to time and cost constraints.
- Since the process is long, a **change in responsibility** throughout the process can be observed, with possible inefficiencies and loss of information. This is a challenge if it concerns the so-called 'SL champion', who is the manager of the SL process.
- **Communication breakdown** can still accidentally happen, even under such a structured framework.
- Even though one of the principles of SL is the involvement of all stakeholders' perspectives, including users, it is **impossible to address all the users**. Typically, target groups should be identified.
- SL does not guarantee that **complaints** by end-users are fully eliminated. This is why the involvement in the aftercare of the design and construction team is important – they are accountable for actual performance, and they can learn from feedback.

These reflections are based on one project developed in the UK as BREEAM certified building (Gana *et al* 2018).

Extending the stakeholders' involvement past the delivery (which is a key concept in SL) already emerged as a recommendation for facing the problem of lack of accountability on the real performance of the building (subsection 3.1), and SL looks like a promising way forward in pursuing ambitious project goals (Gana *et al* 2018).
To enhance the SL framework, **good practices** can be:

- Appointment of 2 **SL-Champions**, one on the client's and one on the contractor's side, to ensure smooth communication and information flow, and to guarantee a continuous review of decisions in light of clear objectives.
- **Early involvement of sub-contractors** to save time and get information from them that is relevant to the project design.
- **Collaboration** and involvement of users and Facility Managers to gain practical feedback on the decisions, which must be implemented in the design.
- Definition of a clear **strategy of communication** and multiple communication channels.
- **Tracking** of changes and timely **reality-checked** decisions.
- Development of more user-friendly **interfaces** of building controls and **training** of staff to avoid complaints in operation.

Improving the design process allows for to capture of the potential for actions with the maximum impacts on the project's success and the minimum cost. However, another critical stage to ensure a project's success in terms of matching planned and operational performance is the **hand-over phase**. In this stage, good **commissioning** practices are important to ensure building performance. However,

- the **lack** of a fixed **framework**/**definition** for commissioning,
- the **non-prioritization** of an optimal building operation when allocating resources,

- and the demand for specific **competences** (including legal obligations, documentation, and testing processes)

can be the cause for its failure, as it was observed in the Danish context (Kjerulf and Jensen 2020). Indeed, Denmark is among the countries that at the time of the observation did not have a clear **commissioning framework** and definition. In Norway, NS3935 Integrated technical building installations (ITB) - Designing, implementation and commissioning, responds to this need by trying to ensure the process of securing technological installations.

Despite the findings being based only on a limited number of studies, it seems reasonable to conclude that **SL** and **commissioning** frameworks are tactical measures that have the potential to bridge the gap between design ambitions and the operational status of a building, where users' and Facility Managers' involvement is one of the elements of success. Moreover, **ID** and, more in general, **collaborative workflows** are acknowledged again as best practices. For them, better tools are needed, but cultural elements like shared understanding of goals, effective communication, and knowledge sharing cannot be overlooked.

3.3. Tools to enhance ambitious goals

As emerged throughout the previous subsections, ambitious projects and related processes require support-tools, like the already mentioned BES and LCA. Besides them, other tools can be more organizational-related (Engebø 2022), such as the introduction of strategies/methods to support integrated design and delivery. Among them, Soft Landings has been mentioned to guarantee better performance in operation, which is also supported by effective commissioning. Other strategies/methods not mentioned yet but relevant in supporting an integrated approach are set-based design and Target Value Design (TVD), which fall under the umbrella of Lean principles for project delivery.

The literature search pointed out some of those tools that can support the achievement of ambitious targets. They can be intended for the whole building process, the design stage, or the operation and management stage only. The tools can be:

- **Quality assurance methods** to close (energy) performance gaps throughout the process.
- **Information technologies** that can improve stakeholders' collaboration during the design stage.
- **Early stages simulation tools** to support design choices in low (embodied) carbon buildings.
- **Extended Reality technologies** for maintenance and operation of smart buildings.

An example of a quality assurance method is the Swedish ByggaE (Lane *et al* 2017). It is a publicly available method, based on routines and tools like checklists or guidelines, to work with energy issues throughout the entire building process. The concept is about documenting, communicating, checking, and verifying energy-critical elements in the construction of a building to make sure that they are followed up with the involvement of all relevant actors. This proposal is in line with the need for collaboration and information integration in the context of building design for energy efficiency. In this context, literature (Niu and Pan 2016) suggests that the development of collaborative technologies for energy design is undermined by mismatches in terms of knowledge gap (between research and industry), implementation gap (between industry and technologies provider), and technology gap (between research and technical solutions providers). In other words, the industry deals with energy issues from a 'comfort zone', preferring simple tools characterized by low integration, where low information processing capability is required. The providers of tools do not always initiate innovation but rather follow the industry demand. However, there is a clear need for more and better integration between solutions (including management tools) and innovation in terms of decision-support tools using design information to better inform the stakeholders. An input in this sense could come from academia, where, however, there is a lack of translation of methods into usable tools with dedicated user-interfaces (Niu and Pan 2016). More collaboration between academia and technological solutions providers would enable knowledge transfer to improve industry practices. An example of valuable input from academia in this sense emerged from the literature review as well (Schneider-Marin *et al* 2022). It is a new tool for early design LCA studies. Its ambition is to cope with two conflicting aspects - the need for early LCA analyses as a decision-support tool in the design stage and the high level of uncertainty typical of the characterization of the project's components in the same stage. This is done by developing a new and more transparent database of components with functional information for designers and attached LCA data. Its application on an early-design BIM model for a building allows it to compute a range of possible outcomes in terms of environmental impacts and to identify the most carbon-intense elements of the functional components, making the tool useful decision-making support.

Besides the design stage, a huge potential to enhance project goals through innovative tools is in the operation and maintenance of buildings. In this context, literature (Casini 2022) elaborates on the potential of Extended Reality (XR), including Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). With the growing attention for digital twins, XR becomes interesting as the bridge between digital models and real-word information. It "allow(s) immersive digital experiences to be created that permit users to easily visualize, explore, and understand designs, models, and site conditions with many benefits in terms of stakeholder engagement, design support and review, construction planning, progress monitoring, construction safety, and support to operations and management, as well as personnel training." (Casini 2022). In terms of stakeholders' involvement, an interesting example comes from a ZEN pilot located in Sluppen, Trondheim, Norway (Wiberg *et al* 2019). The researchers enabled a group of stakeholders to have an immersive experience of the virtual model for the Sluppen area with superimposed written and graphical visual information concerning the indicators of performance (KPIs) on GHG emissions, developed as part of the ZEN Research Centre. Thus, the digital twin and VR allowed the communication of complex information to engage non-experts in the planning process. However, it is not trivial for designers to make use of such data in the design process, and more tests with users are needed to reveal the understandability of such information.

In light of all this, the following **barriers/challenges** in the adoption of all the above-mentioned tools could be identified:

- **Misunderstanding** and **misuse** of available quality assurance methods, like lack or early adoption, misunderstanding or underuse of supportive documentation, etc.
- **Mismatches** between perspectives and practices in collaborative processes.
- Design **uncertainties** (i.e., decisions not made yet) and data/calculation uncertainty, which might hinder the adoption of simulation tools in the design process.
- **Costs** and **maturity** of XR technologies.
- Lack of **digital literacy**.
- Lack of digital twin models (like BIM) with the appropriate **level of detail** for XR applications.
- **Uncertainties** from designers about how to use information coming from the XR experiences in the design process.

The following actions could **drive** their future adoption:

- Ensure the **support** in the deployment of new quality assurance methods to make them used and understood.
- Develop **collaborative paths** between research, industry, and suppliers of technologies to close the gap between perspectives and practices and achieve better information integrity in projects.
- Develop **simulation tools** that are appropriate for early-stage applications as actual support to the decision-making.
- Encourage the exploration of the application of **XR technologies as a bridge** between real-world and digital twins.
- Further, **investigate** the **benefits** of digital twins and XR as perceived by different stakeholders.

4. Discussion

The previous section (section 3) reported the findings from a literature inquiry addressed identifying the potential barriers and best practices in planning and building processes in the context of ambitious projects. They are not exhaustive of all the possible elements that can be studied. However, regardless of the lenses adopted to look at the problem – performance/strategic goals, process/tactical measures, or goals-enhancing tools – some common topics emerged. Among them, the adoption of **collaborative frameworks** (e.g., integrated design, integrated contracts, relational contracts, etc.) appears like a 'leitmotif', combined with the need for **stakeholders' engagement** (including experts, suppliers, users, etc.) and technical and managerial **tools** supporting informed and collaborative decision-making along the process.

In this section results reported in section 3 are discussed against these three core topics thanks to the results of the second round of literature review (as explained in section 2).

4.1. Collaborative frameworks

To meet ambitious goals the AEC sector will require the adoption of innovative technologies and novel design practices and ensure that what is designed is constructed and operated successfully (Kesidou and Sorrell 2018). Many interdependent aspects contribute to the overall performance of a building or district once it is in operation, which requires an **integral approach** to design and innovation. However, the AEC industry is highly fragmented and project-based, meaning that diverse actors are coming together for a limited amount of time, with their own culture, practices, and objectives, hindering the potential for collaboration towards a common goal. This is why literature suggests that a better integration of the supply chain is needed (Kesidou and Sorrell 2018). Supply chain integration (SCI) is defined as "the merging of different disciplines and organisations with different goals, needs and cultures into a cohesive and mutually supporting unit" (Baiden and Price 2006) and it includes the already mentioned integrated design approach.

According to Kesidou and Sorrell (2018), in the context of low-carbon projects, multiple strategies can contribute to an **integrated supply chain**. They can be summarized and related to the results of this report as follows:

To enhance **collaboration**, *long-term relationships* between actors are needed to build trust and promote a no-blame common culture, alignment of objectives and experimentation to meet them. As discussed throughout section 3 of this report, such experimentation towards innovative solutions is hindered by industry logic and barriers. They are, e.g., split incentives, risk, inertia, lack of knowledge, etc. Thus, the role of the client/owner in setting ambitious and clear goals is critical towards success. However, clear goals selection and their translation into project requirements is an efforts-intense task, as observed in the Ydalir case study (subsection 3.1). Since ambitious projects can be complex, involving more uncertainties and risks, there is a need for *demanding and knowledgeable clients*, able to follow up on the goals and to recognize the complexity by proposing appropriate and fair contract arrangements. If such a role cannot be taken by owners, innovation champions must be empowered to steer the process towards ambitious goals. **Championing** was mentioned among the recommendations in section 3.1 to ensure the follow-up on ambitious and energy-related choices and in section 3.2 in the context of Soft Landings for effective project delivery. Besides owners, also suppliers can be the initiators of innovation. However, they are not accountable for the performance in operation, and thus they do not have incentives towards its optimization. Their early involvement is still not a common practice, and it must be encouraged at the contractual and organizational level to exploit their knowledge and capacity for innovation, as already resulted in the literature search (section 3). Moreover, recent research based on the experience of the Norwegian industry, suggests that *specialists' engagement* must be encouraged, lowering the barrier related to their employment in consulting companies, which can have a more marginal representation in projects' organization, and their simultaneous work in multiple projects (conclusions of Engebø 2022). As mentioned in section 3.1, the engagement of researchers as experts in an ambitious district project (i.e., Ydalir ZEN pilot) allowed us to perform scenario analysis of the project's environmental performance. Also, in the context of simulations-informed integrated design processes (section 3.2), the early involvement of an LCA expert allowed to steer the design choices towards higher environmental performance for the project compared to his late involvement. However, having a single entity that is contractually responsible for the final performance, playing as a systems integrator, would avoid the split between design and construction management that still characterizes the industry (Kesidou and Sorrell 2018). Taking responsibility for the actual future performance of a building/district during the planning and design process requires a shift in mindset in the industry. Since the performance is highly dependent on **users**, their **involvement** is also recognized among the success factors. This is in line with the Soft Landings philosophy too (section 3.2). It can be done by i) allowing users to affect the design choices, making sure that the ambitions match their needs and expectations; ii) including the users in the optimization of the system, with particular attention to the hand-over; iii) and by adopting post-occupancy evaluations as learning feedback for the industry.

In summary, the strategies for supply-chain integration and innovation suggested by Kesidou and Sorrell (2018) can be divided into 3 categories: collaboration, championing, and users' involvement.

Being concerned with energy, indoor environmental quality, and the operational cost gap between design targets and results, Frei *et al* (2017) confirmed the importance of collaboration, concluding that the "preventions of gaps require an integrated performance and risk management process, for instance through application of the performance-based building design and **integrated project delivery**" (Frei *et al* 2017). In this context, specialists must always be part of the integrated design processes, and knowledge and expertise are mandatory (Terim Cavka *et al* 2022). When it comes to ensuring the energy performance of a project, a framework has been proposed in the literature to identify key energy stakeholders and to bring them together to work collectively to close the performance gap (Zou and Alam 2020). While doing so, analyses at the building service systems' components level must be performed to control the building energy performance (Zou and Alam 2020). However, there is a risk that each actor would focus on his discipline of competence (section 3.1 and section 3.2), while decision-making must go behind individual disciplines to fully exploit the benefits of collaboration. For this reason, “the overall understanding of design process needs to be shifted to **incorporate performance analyses** during design to make informed decisions, and research in new processes and technologies such as BIM plays an important role to achieve this goal.” (Terim Cavka *et al* 2022). Indeed, **BIM** is recognized to be a strategy for SCI (Kesidou and Sorrell 2018), increasing information integration and optimizing its exchange in a transparent and always updated manner.

In conclusion, collaboration is acknowledged as a success factor in ambitious project delivery, and thus we need to build knowledge as the basis for new collaborative practices, involving technical, management and contractual tools. In this context, a well-documented integrated design process is important as a solid knowledge base for future projects (Terim Cavka *et al* 2022) and documenting the effects of collaborative elements in projects is an important future activity to promote them (conclusions of Engebø 2022).

4.2. Decision support tools

Any project is the result of a sequence of choices taken by the design team, preferably in a collaborative and informed manner and keeping the project’s goals in check. Given the complexity of ambitious projects, technical, management and contractual tools need to be studied to support this process.

Technical tools are generally more studied than managerial ones. Among **technical tools**, software for energy and environmental simulations is largely discussed in the literature. They allow us to anticipate the most probable outcomes of a certain design choice, hopefully steering it towards more energy-efficient and environmentally friendly ones. However, as discussed in subsection 3.2, their adoption in the context of integrated design process for ambitious projects can encounter some barriers. Referring in particular to the building energy performance and the BES tools, technical barriers are widely mentioned in the literature and are associated with tools characteristics and complexities/difficulties in providing for input data and in interpreting outputs. However, non-technical barriers cannot be overlooked when we speak about decision-making in the context of collaborative frameworks. Among them, the need to negotiate control over decisions, differences in approaches to problem-solving, late involvement of experts (whose contribution was not in budget), perception of energy performance evaluation as a mere compliant check, and communication barriers can hinder the collaboration between architects and energy consultants (Alsaadani and De Souza 2016). When adopted, BES can inform the design through the study of what-if scenarios and their calculated implications on the energy performance of the building/district. Simplified models are needed to make them useful and applicable in the early design stage through, for example, metamodels built on simulation results (Singaravel and Geyer 2016). However, the level of uncertainty of simulation results is an open question, and it is affected mostly by insufficient information (because the project is not mature enough) and wrong assumptions. Quality information could be guaranteed by involving the various stakeholders (e.g., occupants, suppliers, etc.) early in the design process (Singaravel and Geyer 2016). One of the factors that is widely recognized as responsible for the gap between computed and actual energy performance is the occupancy. Thus, improving occupancy data is a crucial research topic to increase the reliability of BES and their effective exploitation as part of the process in design. Data of post-occupancy evaluation are normally used for this purpose, but the use of BIM models and VR can enable the collection of pre-occupancy data through the implementation of immersive experiences for users to test different design alternatives and their implications on behaviour and use of the space (Niu *et al* 2016b).

Addressing the technical readiness of tools informing performance-based decisions is not enough to secure a successful integrated project. Organizational, contractual, and cultural aspects should be also revised to build the proper **project environment** via the uptake of new tools and practices. In the context of collaborative processes, this problem (among others) is addressed in the "Contracts strategies and specialist-based interaction" ("Kontraktstrategier og Spesialistbasert Samhandling - KSS") NTNU research project. The project provided tips and advice for the industry based on the findings from real case studies in Norway with the ambition to increase the opportunity for value creation in the industry. The topics covered are project culture, contracts as a management tool, conflicts, and communication between experts (KSS). Among the recommendations to ensure successful interaction in integrated project deliveries, they have found:

- Ensure **good communication** by distinguishing misunderstanding from disagreement, establishing feedback loops, and keeping in mind the different perspectives and languages.
- Develop **organizational leaders** and exploit the potential of **specialists' interactions** by, e.g., dividing specialists into multidisciplinary groups to develop alternative solutions, semi-structuring co-location to facilitate informal processes, facilitating co-created learning, etc.
- Develop a **culture of collaboration and performance** in the project, by setting clear standards and framework, ensuring a good start (including trust and common understanding of interests and expectations, process, tasks and responsibilities, driving rules, working methods and arenas, …), taking care of maintaining the culture, promoting process evaluations, ensuring smooth boarding of people into next stage of the project and of new people into the project.
- Take care of the **contract strategy** by ensuring its early definition by the project owner, clarifying the owner's role and competencies, engaging actors at the right time and with the right competencies, assessing actors' qualifications for the project, ensuring continuity, using TVD.

In conclusion, tools supporting accurate performance assessments and a supportive project environment based on, among others, clear roles and interactions are important for good , smooth and effective decision-making along the process.

4.3. Stakeholders' engagement

As already said, one key element in achieving ambitious goals is stakeholder and, more specifically, actors' engagement, which must target the goals collaboratively.

As mentioned in section 3, the **engagement of the actors in ambitious projects** can be encouraged by underlying the benefits in terms of knowledge gain. It is however important that the project strategy does not overlook the (potentially conflicting) objectives of the different stakeholders in terms of value creation. In particular, the project's ambitions should be in line with the actual final users' needs to make sure that the project will be able to deliver benefits. A collaborative approach is needed to address the diverse interests in the best interest of the project itself. According to Xu *et al* (2019), despite the collaboration between designers and contractors (defined as the main actors in the process) can add 3% to profit margins for all the stakeholders in the supply chain, it is also expensive, and small and medium companies cannot invest in technologies enhancing collaboration and the necessary training to learn their use. Moreover, the benefits are not obtained in the short run. Thus, the decision of whether to **engage or not in collaborative processes** could be modelled based on the following variables – the cost of collaboration, gain from the collaboration, and loss for the missed collaboration (Xu *et al* 2019). Engagement in collaboration could then be enhanced by affecting these variables via i) governmental-led projects, nurturing innovators in pilot projects and showcasing the value of collaboration for the public; ii) subsidies for collaboration; iii) communication and education to raise awareness on the performance gap and the advantages of collaboration; iv) establishment of a system to determine the responsibilities of the various stakeholders regarding the performance gap; v) and definition of incentive-punishing mechanisms. Validation of these (theoretical) conclusions is still lacking, and documenting the effects of collaborative elements in the project is an important future activity (conclusions of Engebø 2022) to engage stakeholders. The measurement of such effects could help to make the benefits of collaboration more tangible.

A study with less of a theoretical approach (Hamdan *et al* 2021b) mapped, through an extensive literature review, what are the elements that impact stakeholders' engagement in collaborative workflows in the context of sustainable neighbourhoods in the different stages of conceptualization, preparation, implementation, and closure (Hamdan *et al* 2021b). Among the most interesting factors, we read:

- **Dialogue and knowledge exchange**. They can be lacking if connections between relevant actors are not built and if some relevant ones are absent. Feasibility studies, interviews, thematic groups, and sustainability assessment tools (e.g., BREEAM-C) can be facilitators of dialogue.
- **Interests and priorities**. They can be in conflict. The most evident conflict is among costs and benefits, where, in the face of recognized extra costs for ambitious projects, benefits must be made more tangible.
- **Agendas**. They can differ and be in contrast, leading to a lack of consensus. Community consultation is important since a delayed one can hamper the definition of shared goals.
- **Innovative and collaborative governance**. It refers to models and contracting arrangements, which are strongly needed, as they can affect the level of collaboration. Integrated contracting facilitates work and forums among stakeholders.
- **Follow-ups**. It refers to the capacity to apply knowledge acquired from the previous stages of the project. Knowledge developed at the beginning of a project is not always implemented, with losses in performance and unmet goals. Changes in stakeholders' configuration and responsibilities are among the reasons and must be taken care of.
- Users and business **value**. It refers to possibly different strategies for value creation. The creation of value for the users in terms of users' satisfaction and benefits is essential for a project's success and acceptance. Also, business value is the key driver for actors being willing to engage in ambitious projects.

Since they have to do with increasing or decreasing actors' collaboration capacity, such and other elements can affect the engagement of stakeholders in the context of ambitious projects, where complexity rises, and finding a common ground becomes more difficult. However, the way stakeholders interact in the different stages of the process is still unknown (Hamdan *et al* 2021b). Thus, their accurate mapping is of primary importance, also because of the shifting in roles that they can experience throughout the process in big ambitious projects (Cheng *et al* 2021). Literature tends to focus on collaboration processes, but there is a lack of tools of use for practitioners to **map stakeholders** (Cheng *et al* 2021). Keeping in mind that the landscape of stakeholders is changing, with a potential effect on procurement choices (conclusions of Hamdan 2022), further research in the context of ambitious projects is needed in this sense.

5. Conclusions

This report contributes to moving further in the design of a strategy for the implementation of ZEN development projects. This was done by screening the relevant scientific literature to find barriers and best practices that can be encountered in the process of implementing ambitious projects like ZEN. The topics of inquiry were all aspects that contribute to characterizing a building process, organizationally, contractually, culturally, and in terms of related tools.

In section 3, the results from the literature search were presented by topics, which were deductively identified thanks to the reviewing process itself. They are:

- Targeting ambitious (energy and environmental) performance goals
- Implementing process-related measures
- Tools to enhance ambitious goals.

In section 4, the results were discussed against three major overarching concepts that emerged throughout the work: collaborative frameworks, decision support tools, and stakeholders' engagement. To do that, a second round of literature search was performed.

The works consulted to prepare this report include almost entirely scientific journal or conference publications, in addition to two doctoral theses (Engebø 2022, Hamdan 2022) and one project report (KSS). Papers are reviews, conceptual/methodological, case studies-based, or mixed. It is important to underline that, to cover more comprehensively the topic, more space should be given to deductive studies on cases' qualitative data, which are the most common in the field of design and project management. Future works should complement the present report by providing empirical findings resulting from the observation of relevant case studies.

The results are not exhaustive of all the possible elements that can be studied. However, recurrent elements emerged, making the following conclusions reasonable.

Collaborative frameworks are crucial in the achievement of ambitious goals. However, the AEC industry is project-based, and hence it is still highly fragmented. As a consequence, the potential for collaboration is hindered. In planning for ambitious goals, a failure could also be due to a lack of stakeholders' engagement in terms of collaboration and commitment, insufficient organizational processes and unsupportive development frameworks. It is thus important that there is a clear picture of the stakeholders involved and that the benefits of committing and engaging in such projects are clear to them. It is also important that the benefits of collaboration are showcased through research and that the project environment is suitable and built on a supportive culture and an integrated approach to project delivery, where responsibilities and incentive-punishing mechanisms are set, but disciplines are not siloed. To increase the opportunities for the project's success, the following actions/elements, among others, should be promoted:

- Exploration and implementation of collaborative frameworks and tools (including digital),
- Demanding and knowledgeable clients pursuing and following up on ambitious goals under fair contract arrangements,
- Long-term relationships between actors to build trust and a 'no-blame' culture,

- Championing,
- Contracts as management tools,
- Early involvement of contractors and suppliers,
- Users' involvement,
- Increasing knowledge across industries,
- Sharing of knowledge, information, risks, and rewards,
- Life cycle thinking and performance assessment tools,
- Building and maintenance of a project culture,
- Improvement of experts' communication,
- Implementation of tools/practices to reduce conflicts.

Building upon the findings, we can more broadly suggest that strategies to enhance ambitious projects should be driven by the following objectives:

- Increase **knowledge** across the industry, improving **communication**, promoting **sharing** and **life cycle thinking**.
- Explore and implement **collaborative frameworks** and tools (including digital ones) that can support integrated project delivery and integrated design approaches. Related contractual and cultural elements cannot be overlooked.
- **Engage stakeholders** in ambitious projects and collaborative workflows, before the mapping of their (changing) landscape.

The common framework developed within the ZEN Research Centre (ZEN definitions and toolsets) has the potential to contribute to the first of the three bullet points. Collaborative frameworks (second bullet-point) have been explored already (Engebø 2022), as well as procurement strategies (Hamdan 2022). More work is needed to showcase the effects of collaborative elements by documenting relevant projects. Also, tools/recommendations are needed to untap the potential for integrated approaches in ZEN developments. Finally, stakeholders' engagement in ambitious projects (third bullet-point) requires increasing the value and reducing the risks for them, first of all through guidance in aligning goals and following up on them. Guidance for stakeholders' mapping is priorly needed.

All these aspects should be addressed keeping in mind the threefold dimensions of every project delivery (organizational, contractual, cultural) and the need to create value for all the stakeholders involved in the project as a driver for success.

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