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Civil Engineering

Towards Real-Time Design Collaboration

LiveCol Final Report

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LiveCol

Real-time collaboration for construction projects

SENAATTI   Trimble.   Tampere University   VTT   AFRY

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Management Summary

Purpose

LiveCol set out to develop and validate methods and tools that enable real-time, data-driven collaboration in construction design. The project aimed to move from differentiated, semi-coordinated workflows toward parallel, open, and up-to-date information management supported by 3D tools and integrated communication services.

Background & Context

Industry Need: Design processes typically operate in their own "swimming lanes" with reactive, meeting-based coordination and long feedback loops. Growing complexity (technical, social, ecological, economic) and sustainability requirements intensify the need for faster, cross-disciplinary collaboration.

Consortium & Funding: LiveCol was a Business Finland Co-Innovation project with support from the European Union's NextGenerationEU funding. The involved actors were: AFRY Finland, Senaatti-kiinteistöt, Tampere University, Trimble Finland, and VTT Technical Research Centre of Finland.

Approach: Utilizing federated real-time collaboration architecture, LiveCol examined the potential of this type of technology across a set of use cases. Research on technology, processes, legal/contractual frameworks, and sustainability and circularity impacts were conducted iteratively and in parallel with the use cases.

Key Findings

Technological Development: LiveCol developed a distributed, federated modelling environment enabling real-time information sharing and communication among designers. The technology is able to link between various different native authoring tools, and real-time communication may take place through shared sessions, tasks, annotations, measurements, and clip planes. The technology offers advanced visualization capabilities, but these may be extended through other technologies such as Augmented Reality. All in all, these real-time updates provide a situational picture of design edits and improve coordination.

Use-Case Evidence: Real-time collaboration accelerated iteration and improved communication between structural engineers (e.g., concrete–steel connections); between structural and MEP/HVAC designers (coordination of openings), between on-site workers and off-site designers (model verification and modification), and between real estate owners and designers (AI-based circular portfolio mining).

Performance & Limitations: Benefits include reduced coordination lag, fewer full-model exchanges, and protection of stakeholder IPR through federated sharing. Improvements can be made around clash detection integration, versioning/change logging, authority/responsibility boundaries, comment/history retention, and maturing AR platform support.

Adoption Factors: Technological interoperability, usability, and legal/contractual clarity drive acceptability of real-time collaborative solutions. While sociological resistance (e.g., work visibility, client conservatism) and current compensation models based on either hourly or fixed designer fees hinder proactive collaboration. Current contract formats seldom embed BIM collaboration goals, roles, and incentives explicitly. Different contract formats in the spirit of the alliance-model or specific target/bonus mechanisms could help in increasing real-time collaboration technology adoption.

Data Governance Trend: Similarly, a shift from file-based transfers to data sharing and data-based transactions could accelerate the adoption of real-time collaboration technologies. This shift is influenced by evolving EU data regulations, such as the Data Governance Act and the Data Act. Early tool development could focus on enabling decision-making across projects and asset lifecycles, potentially aided by data-space models.

Conclusions

LiveCol validates real-time collaboration as a viable next level technology for construction design. Federated, incremental sharing can increase the collaboration clock-rate among designers and third parties. However, wide-spread adoption depends on further developing the technology, as well as updating the operating environment of the industry in the form of contracting and incentive structures. Until then, real-time collaboration technology offers a valuable addition to design work but is not yet ready to replace current ways of working completely.

Recommendations / Actions

- **Embed real-time collaboration in project setups:** Pilot real-time collaboration technology in selected projects and assign clear scopes and success metrics from the outset.
- **Strengthen governance & traceability:** Further develop versioning, change logs, decision recording, and role/authority definitions within live sessions and workflows.
- **Update contracts & incentives:** Include BIM collaboration protocols (e.g., ISO 19650-aligned), IP ownership, and liability allocation in construction contracts. Adopt target-fee/bonus models rewarding cross-disciplinary outcomes. Involve BIM coordinators in procurement stages.
- **Integrate clash and issue management:** Prioritize automated clash detection, modification tracking, and richer interaction with shared objects to reduce rework.
- **Advance data-sharing readiness:** Prepare for data-space participation and data-based transactions over the whole lifetime of assets, not only during construction.
- **Targeted AI augmentations:** Evaluate the potential to apply AI to

selected workflows to further maximize efficiency gains of real-time collaboration technologies.

Preface

This report presents the results of the 2.5 year LiveCol research, development and innovation project. LiveCol was a Business Finland Co-Innovation project that received support from the EUs NextGenerationEU-programme. The report aims to inform industry professionals, researchers and the general public of the work that has been done during the project, its outcomes and significance.

LiveCol has brought together a consortium of industry stakeholders and research institutions — AFRY Finland, Senaatti kiinteistöt, Tampere University, Trimble Finland, and VTT Technical Research Centre of Finland — to improve collaboration in construction design processes. The project has allowed all stakeholders to take significant steps forward in their technological development, process development, and business development. We think that this will become clear to you when reading this report.

The report has been written in such a way that it may be read front-to-back or that every chapter may be read separately. While we may have edited the report, every sub-chapter has been written by those LiveCol researchers that have directly contributed to those particular results. You may find their names in the Table of Contents and at the top of every sub-chapter. This means that you might encounter some repetition while reading, however our aim has been to allow readers to utilize those parts of the report that they find most interesting also as stand-alone pieces.

We are thankful to everybody for their contributions and commitment throughout the project, to Business Finland for funding our efforts and hope that you enjoy reading the report.

Contents

1. The need for Real-Time Collaboration

In the present design process, designers still operate relatively individually, each in their own "swimming lane". Coordination between different design trades typically takes place in Building Information Modelling (BIM) coordination meetings organized by consultants. The process is reactive, and feedback loops are long and error prone. Reaching multi-criteria design solutions successfully can be very difficult without more advanced collaboration methods.

It is widely acknowledged that comprehensive and profound collaboration is essential for long-term success in the modern construction business environment. Modern construction operations have many dimensions: at least technical, social, human, ecological, political and financial. The complexity of construction is thus plain, and this complexity is evidently continuously growing. The sustainability push for example, is setting various growing requirements and whole industrial transitions can be expected. The growing requirements are in turn creating even more complex construction projects. In short, the key points for our departure towards higher levels of collaboration are (a) continuously growing complexity of construction operations, (b) multi-dimensional and often conflicting project requirements, and (c) understanding collaboration as working together for optimal project outcomes.

Traditionally, the collaboration between different project partners has taken place in joint gatherings such as design management meetings – arranged e.g., every second week – which then define the frequency of collaboration. Co-location arrangements, such as big rooms or technology enabled location independent collaboration with virtual workspaces and new building model data sharing possibilities are showing the way ahead and changing the overall picture of collaboration. Shortening the collaboration response time can be extremely valuable since it can speed up the whole process towards the final design solutions. We need to draw attention to the frequency of collaboration between different trades of designers, engineers and other key professionals of construction projects. The frequency of collaboration in construction projects can indicate the response time after identifying and informing of design failures or on needs for design changes. A higher frequency of collaboration can be enabled by certain technologies (Figure 1).
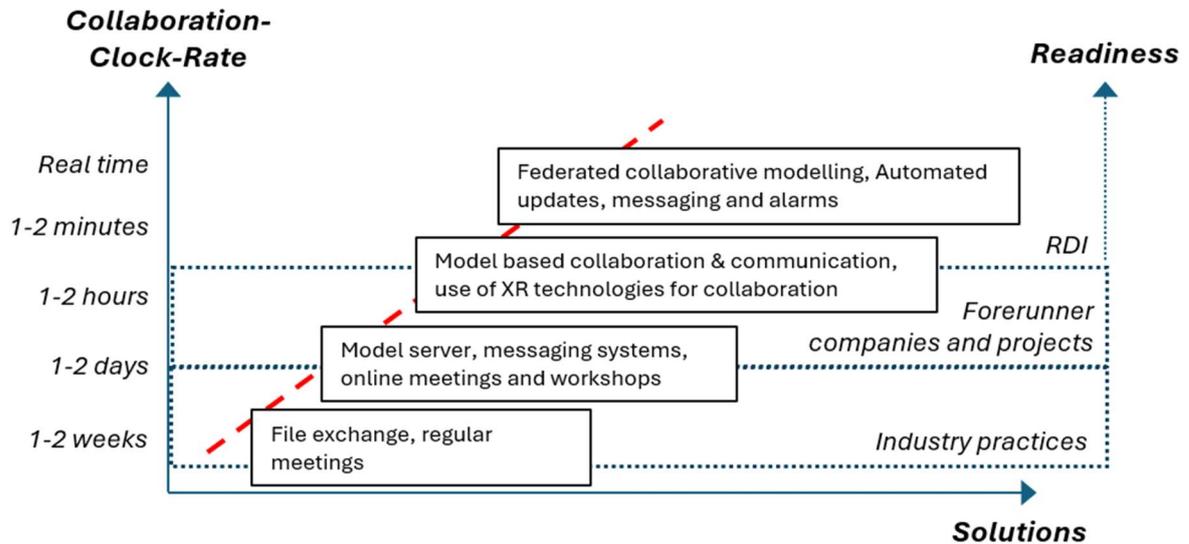
Figure 1: Higher frequency of collaboration in construction projects towards real-time or near real-time practices is a technology enabled avenue.

Given industry developments, it looks obvious that the operational logic of collaboration in construction projects is developing towards constant collaboration where collaborative activities are taking place in real-time or near real-time manners.

Real-Time Collaboration is the next level of collaboration in construction operations
 - Data-driven
 - Fast cyclic
 - Location-independent

The power of BIM to support collaboration has been proven in several studies. Eadie et al. (2013) found a two-way relationship between BIM and collaboration: Collaboration is the key to successful BIM and on the other hand collaboration, enabled by BIM, produces a positive financial impact on projects. Technological advancements for BIM-based collaboration include different functional elements needed by real time collaboration. As a summary the following structuring of key elements is proposed:

1. Real-time information sharing
   - Federated modelling environment[1]
   - Adaptive dynamic data sharing
   - Cloud-based live modelling
2. Real-time communication
3. Data governance and management (non-personal and personal data)
4. Digital involvement[2]

This trend is changing the collaboration phenomenon with new requirements for needed technology and organizations with their professionals who are involved. Research, development, and innovations are needed for realizing the potential benefits of real-time collaboration in construction.

LiveCol addressed the changing collaboration phenomenon through a solid methodology that is presented in Chapter 2. Chapter 3 elaborates upon the pathways to new ways of working that real-time collaboration will enable. Chapter 4 provides our findings of experimenting with real-time collaboration technology in certain use-cases. After that, Chapter 5 discusses the significance of LiveCol findings in light of the wider academic and professional context. Finally, Chapter 6 will draw overall conclusions and point to future developments.

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[1] A single, unified digital model created by combining multiple, separate discipline-specific BIM models (like architecture, structure, MEP) into one view, allowing different teams to see the whole project in context for better coordination, clash detection, and data-driven decisions, without merging them into one single file, preserving each discipline's ownership and data.

[2] Use of online tools (internet, apps, platforms) for active engagement in certain joint activities. Here: building design and engineering with professionals of other fields and trades.

2. The LiveCol approach

Moving from manual practices to advanced use of IT-technologies provides possibilities for a higher collaboration-clock-rate where the needed information – details, guidance, comments, feedback, changes, approvals – is available with minimum intervals based on collaborative work. This is a multi-faceted development possibility with human, organizational and technological challenges.

The main goal of the project is to develop and validate novel methods and tools to empower the collaboration of design and construction teams with real-time 3D data sharing and communication in virtual 3D environments. Benefits of the approach will improve engagement of the teams and enable instant communication to reduce lag times. The controlled sharing of 3D design data will provide better awareness of the design progress and support the right timing of activities and management of the process. These will conclude with more streamlined design and construction processes, improving lead times and reducing resource needs.

2.1 Methods

LiveCol can be seen as a major innovation project. It has a mission to create transitions towards sustainable constructions, their design, implementation, and maintenance with the aid of real-time data and digital models enabling real time collaboration between different stakeholders. The research approach is in essence design research supported with technology experiments (use-cases). The technology partners provide demonstration tools and the use cases will be defined, demonstrated, and evaluated together with the project stakeholders. The application of technology in the use cases serves to recognize the most valuable solutions.

The first step for renewing design related collaboration is to share 3D design data as small datasets based on receivers needs instead of less frequently shared full BIM. The same technologies are applied also for real-time communication with interconnected BIMs of different design disciplines and other viewers. The target is to test methods in currently existing coordination and co-design use cases but also in new raising topics, especially related to sustainability requirements in construction.

The Technology side of research shall support the development of overall LiveCol solutions in co-operation with Trimble. This research is focusing on integration of the Metaverse and Omniverse technologies. Methodologically this effort can be seen as software engineering that is producing valuable research material (resulting in software, relating data

and experiences). When viewing software engineering through a research lens it is possible to recognize possibilities for the presence of both qualitative and quantitative research along the research data that can be obtained during the various phases of software development effort (Saeed et al, 2019).

The Professional side of research has three main domains which are: (a) technology experiments, (b) Use case testing, and (c) transformation pathways for new ways of working. These research efforts can be characterized as real-world research where research objects are industry operations, relating technological solutions, processes and humans as actors (Robson & McCartan, 2016). Methodically, the principles of action research are to be applied and the studies shall produce both qualitative and quantitative research data.

2.2 Real-Time Collaboration technology
Thomas Bagge, Kim Nyberg – Trimble Finland

In LiveCol, technology development work iteratively took place alongside the experimental work done in the use cases. The technology development work established the foundational architecture and tools required, focusing on enabling real-time collaboration, data sharing, and advanced communication within the construction industry. The team defined and implemented a distributed system architecture based on a federated model, which allows multiple independent entities to communicate and collaborate while maintaining local control over their own resources and data. At the core of this implementation is Trimble's TrimBIM technology. To support the implementation, the team developed a generic semantic model for lossless transformation of model data between various authoring applications and created a geometry-based tool to handle change identification for formats that lack unique object identifiers. Furthermore, the architecture development included the definition of a Semantic TrimBIM database using Trimble Lumo for high-performance data management as well as the establishment of URI schemas for authorized data access.

Building upon the architectural foundation, the project deployed next-generation sharing technologies to facilitate real-time BIM modeling environments with dynamic data sharing. A proof of concept for an intelligent intermediary system was constructed using TrimBIM Live Sharing and TrimBIMdiff technologies. This system was integrated with Tekla Structures and supported by a generic linking mechanism. The linking mechanism is capable of connecting with various design tools. The team also enhanced the Live Collaboration solution by adding annotations, measurements, clip planes, and selection sharing capabilities to improve real-time communication between stakeholders. Additionally, BCF tasks were bi-directionally integrated into Live Collaboration sessions.

To ensure practical applicability of these innovations, their functionality was tested through Proof of Concepts in real project use cases from selected customers. Based on early customer feedback, support for Autodesk Revit was added during the LiveCol project. This allows real-time updates

between Revit and Tekla Structures (and vice versa), as well as having a real-time situational picture of the edits made in Trimble Connect.
To ensure high acceptability and a superior user experience, the project also focused on digital involvement and advanced visualization integrations. The team integrated TrimBIM model data with NVIDIA OmniVerse to support advanced visualization and simulation scenarios. This effort involved developing efficient TrimBIM and USD formats converters (including their respective different schemas) to handle model updates efficiently between the systems. Additionally, a pipeline was established between Trimble Connect, Tekla Structures, and the Trimble Connect Visualizer to facilitate faster real-time visualization updates, which proved especially useful for CAVE systems like CollaPrime.

Through these comprehensive development tasks, a robust technology stack was developed for and during the project that supported the use cases that will be described in Chapter 4. Beyond the project frontier, these developments support the transformation of construction industry workflows towards real-time, data-driven collaboration.

3. Finding pathways for new ways of working

This chapter develops a research-based understanding for the application of real-time collaboration practices in construction. LiveCol looks beyond technological tools and includes the following perspectives that together form the pathways for new ways of working: (a) the added value and revenue logic of real-time collaboration, (b) the impact of sustainability on the design process, (c) human and institutional issues and required transitions posed by new ways of working, and (d) the possibilities new solutions offer to change current processes.

By considering such a wide array of perspectives, LiveCol acknowledges that the successful adoption of technological real-time collaboration tools requires changes that go beyond technology development and should include consideration of social, societal, and business environments.

3.1 New needs in construction for circular transitions

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Juha Franssila, Kalle Kähkönen — Tampere University
(edited by Robert van den Brink)

Sustainability is finding its way into the operating environment of the construction industry through increasing regulation and voluntary initiatives on a global, European, and national level. Within the wide range of sustainability perspectives, circularity has become a focal research and development point in the construction industry. Circular economy can be defined as an "economic system that uses a systemic approach to maintain a circular flow of resources, by recovering, retaining or adding to their value, while contributing to sustainable development" (ISO 59020:2024, 2024). Circular economy aims for maximizing material, component and product value and system regeneration in the long-term.

However, circularity has not become commonplace in industry practices. Many general barriers and enablers to the adoption of circularity in the industry have been mentioned in literature, but practical insights into how circularity can be included into design processes are less frequently described. This study aimed to link the development of circularity in the industry with the design process.

Methods
Design process requirements were studied through a literature review, case-study review, interviews with international experts, and a workshop with

the project stakeholders. Both the reviews and the interviews served to generate input for the workshop. This chapter will solely focus on the workshop results, for the results of the other parts of the study, the authors refer you to Van den Brink et al. (2024).

The goal of the workshop was to gain a perspective on which circular strategies are deemed most important, and after that to assess their impact on the design process. The latter goal was approached by focusing on the types of information that should be shared between industry stakeholders in order to facilitate circular strategies.

The workshop started with a general introduction of the circular strategies, their purposes, and goals through the LiveCol conceptual framework. The framework served as introductory material for the participants, who after that selected those strategies that they deemed most important. Then, these chosen strategies were linked to use-cases where different stakeholders' information needs were identified. The workshop ended with a discussion between the participants on the workshop findings.

Findings

To translate the findings from the workshop to implications to the design and modelling context, an analysis was made where the findings are offset against the ISO 19650 (BIM Management) process description. This is done for two requirement categories; (a) process management requirements (see Table 1), and (b) data requirements (see Table 2). The requirements are described below for every stage of the BIM Management process. If a certain stage is not described, this means that there were no workshop findings pointing towards design process requirements for that stage.

Table 1: Overview of circular design process management requirements.

ISO 19650 Phase	Process management requirements
1. Strategy and need	- Build wisely and according to the established needs. Prevent waste. - Overcome possible issues already in contracts, not only in the software. - Building models need to be flexible and updateable throughout the life-cycle. - The client determines the to be applied Circular Strategies.
2. Execution	- Determine the archiving protocol. - Link object/component data with additional and maintenance data through live databases (note that there are currently no standards for this, need to be developed). - Solve possible data protection issues that might prevent later reuse. - Determine an appropriately scoped course of action.
3. Delivery	- Determine and describe the methods of cooperation between designers.

4. Brief	- Model space reservations for the most important building components, to ensure possibilities to change the building (purpose) later in the life-cycle (e.g., sufficient ceiling heights). - Use best-practices (improve efficiency): use standard and/or prefabricated products.
5. Concept	- Determine and describe the design principles and boundaries.
6. Design	- Model service areas of different components, to ensure feasible building changes later in the life-cycle.
7. Build and Commission	- Verify that the building is constructed as designed and ensure that the as-built models precisely reflect the physical reality.
8. Assessment	- Search and offer suitable circular building components in libraries and marketplaces. Currently, these components are unavailable and need to be developed. - Ensure that the component designated for reuse is in suitable condition. Note that there are currently no established standards for this, which need to be developed.

The data requirements are explained with the help of the ISO19650 process description in four categories: (a) currently available in graphical model, (b) currently possibly available in graphical model (depending on building age), (c) currently available in documentation / as non-graphical data, and (d) currently not available in any of the above categories.

Table 2: Data requirements for circular design processes.

ISO 19650 Category	Data requirements
a. Currently available in graphical model	- Requirements - Dimensions, Geometry, Visual & Technical properties
b. Currently possibly available in graphical model	- Digital models of the to be dismantled building components - Location of the 'connector'-points - Measurement and transportation information of components - Technical information on components (e.g., surface treatment, fire rating, etc.) - Designated building service areas (HVAC) - HVAC designs in adjustable (original) data format
c. Currently available in documentation / as non-graphical data	- Component requirements - Original product certificates (CE, DoC) - Material information (e.g., technical strength) - Technical specifications (HVAC) - Component age and maintenance information - Logistics and transportation information

d. Currently not available in any of the above categories	- Carbon Emission figures after 'harvesting' components - Connection points between elements - Needed storage conditions for different components - Demand and supply of components - Original product EPD's

Conclusions

This report has shed some light on the possibilities and consequences of including circularity into design processes by establishing a circular strategy framework, conducting interviews, case studies and a workshop. From those efforts it has become clear that effective implementation of circularity in projects requires a structured process: gathering data on existing buildings and materials, evaluating which components can be reused, and developing new use plans based on this evaluation. This entire process demands continuous and robust collaboration among contractors, project owners, architects, and consultants. Regular interactions, workshops, and weekly meetings between stakeholders are essential to define evaluation criteria and plan for reuse. Therefore, it seems that sustainability – and circularity in particular – create an increased need for collaboration during the design process.

It is clear that for this collaboration to be effective, certain types of information and data should be available for different stakeholders. Currently this data and information is not always (easily) available. This task has given some indications where technology might aid in facilitating collaboration by supplying stakeholders with the information, data, tools, and platforms needed. At the same time, stakeholders should be aware that the unavailability of certain information and data in the process may not be the result of failing or missing technology, but rather of legal or business limitations.

This text consists of excerpts from Van den Brink et al. (2024). Please consult the original source for further information and results.

3.2 Acceptability and Barriers in Real-Time BIM Collaboration

Jaakko Huusko – Tampere University

The purpose of this task was to identify the acceptability and barriers for real-time collaboration in building design. As design projects increasingly demand synchronous cross-disciplinary coordination –due to amongst other needs for more sustainable solutions–, understanding what prevents or enables adoption of real-time collaborative methodologies is critical for both technology providers and design organizations. This task examined acceptability and barriers through two integrated research approaches: a comprehensive literature review and an industry workshop documenting current coordination practices.

Acceptability criteria are defined here as the measurable conditions and user-centered requirements that real-time collaborative technology must

satisfy for adoption within design organizations, by encompassing technical functionality, user experience, organizational compatibility, and economic viability. These criteria are evaluated through the lens of perceived usefulness and perceived ease of use, drawing from the technology acceptance model (TAM) framework that predicts behavioral intention towards adopting new technology (see Figure 2).

Methods

Literature Review
A thorough literature review of technology acceptance and BIM collaboration barriers was conducted. The review examined different categories of BIM implementation barriers and found that the acceptability and barriers in collaborative design environments can be divided into three primary categories: technological, sociological, and legal/contractual. Figure 2 illustrates the TAM framework, which shows that users' adoption intention depends on perceived ease of use and perceived usefulness. This framework provides the theoretical lens for interpreting how identified barriers affect technology adoption.
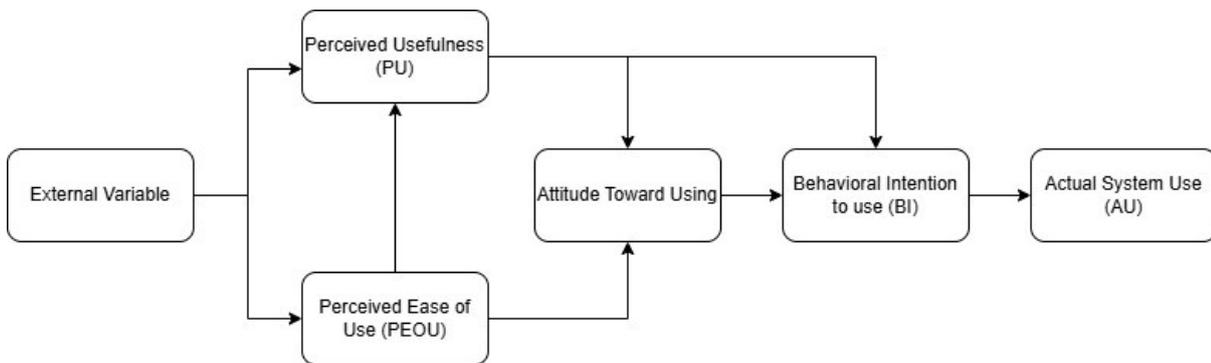
Figure 2: Technology Acceptance Model by Davis (1989)

Workshop
The industry workshop gathered professionals in structural engineering, MEP engineering and BIM coordination to present current information management and coordination practices in building design projects. While the professionals gave their presentations, other workshop participants recorded a total of 110 observations on current design challenges. These observations were thematically tagged and systematically analyzed through network analysis using the Leiden algorithm.

Key Findings

Workshop Results
The network analysis revealed 19 distinct groups of related observations. The three highest-contribution groups directly addressed collaboration, information management, and federated BIM, which are the core areas relevant to understanding real-time collaboration acceptability.
Design teams currently operate within fragmented information ecosystems where information from multiple sources is shared asynchronously and in

different formats. Multiple simultaneous information channels create coordination complexity, as formal data (IFC, DWG) coexists with semi-formal documentation (such as meeting memos and specifications) alongside informal communications through discussions, calls, and conversations. The presence of these parallel information flows requires professionals to synthesize data from multiple sources before starting their own design work.

Rather than replacing these three information channels, real-time collaboration technology must integrate formal data structures with semi-formal documentation and informal discussion streams within a unified interface, enabling practitioners to contextualize design data with decision rationale and maintain decision traceability. This integration is critical because design decisions often emerge from informal discussion but must be documented formally for reference and legal accountability.
In current design processes, information updates occur weekly or bi-weekly rather than continuously, creating delayed problem identification, which may lead to cascading rework throughout the design process. This asynchronous synchronization rhythm misaligns with the urgency of design problem-solving and creates coordination failures where design conflicts are identified only after downstream work has already been completed. Designers do not always require instantaneous updates, but rather notifications of changes relevant to their discipline and design phase. Furthermore, real-time collaboration systems that allow continuous or near-continuous model updates must maintain clear versioning and change logging to prevent confusion about design intent.

Multiple disciplinary models coexist simultaneously with different local optimization criteria, requiring separate design coordination as well as BIM coordination. The coordination of these federated models demands understanding of how architectural decisions define structural constraints and how both influence HVAC/MEP engineering decisions. The workshop documented that practitioners value synchronous coordination, noting that *"discussion and interaction is much easier on site"* and that co-located teams have *"faster ways"* to collaborate. This validates the synchronous coordination principle underlying real-time collaboration approaches. Contractual structures that create economic disincentives for proactive cross-disciplinary collaboration represent another barrier category, as current compensation models do not reward effort expended to help other disciplines achieve better outcomes. The workshop also documented that *"traditional commercial models do not encourage design-team for experimentation"* reflecting how current contractual approaches create risk aversion conflicting with the transparency requirements of real-time collaboration.

Literature Findings
The literature review identified three primary barrier categories affecting BIM collaboration and real-time coordination adoption: technology, sociology, and legislation/contracts.

Technological Barriers
Interoperability challenges represent a fundamental technological barrier due to specialized software tools used by different disciplines (Nnaji et al., 2023). Incomplete Industry Foundation Classes (IFC) format support

creates data loss during file conversion processes (Du et al., 2024). Data synchronization problems persist in maintaining consistency between original BIM models and collaborative environments, particularly when design changes occur frequently (Pham Van et al., 2025). Additionally, software version discrepancies across project teams can disrupt established collaborative workflows (Nnaji et al., 2023).

These technological barriers directly undermine the perceived ease of use construct within TAM, as interoperability challenges, data loss during file conversions, and version discrepancies increase the cognitive load and training requirements for practitioners seeking to adopt real-time collaboration technologies. When perceived ease of use is compromised by fragmented software ecosystems, adoption intention declines regardless of perceived usefulness.

Sociological Barriers
Resistance to change within organizations stems from the construction industry's traditionally conservative practices and established workflows. Research indicates that resistance to change affects different stakeholder groups unequally, with client organizations experiencing higher change resistance than design and construction professionals (Halttula et al., 2019). The lack of standardization across the industry creates confusion and interoperability issues, making it difficult for organizations to develop consistent implementation strategies (Wang et al., 2024; Pham Van et al., 2025). Resistance to change, particularly among client organizations, reflects a mismatch between the perceived usefulness of real-time transparency and organizational identity. Professionals fear that visible work-in-progress reveals uncertainties that may undermine client confidence.

Legal and Contractual Barriers
Intellectual property concerns and liability issues related to shared data models present significant obstacles to collaboration (Erpay & Sertyesilisik, 2021). The absence of standardized legal frameworks for BIM collaboration creates uncertainty and potential liability concerns that can impede adoption (Erpay & Sertyesilisik 2021). Traditional design-bid-build and paid-by-hour compensation approaches do not reward proactive cross-disciplinary collaboration, as designers receive no compensation incentive for expending effort to help other disciplines achieve better outcomes (Jobidon et al., 2021). Research by Jobidon et al. (2021) suggests that contractual documents must be restructured to reflect multidisciplinary and collaborative design processes that blur the lines of parties' roles and responsibilities and provide for joint authorship.

Conclusions

Based on workshop discussions and literature review, acceptability in real-time collaboration contexts requires that technology demonstrates clear value for design problem-solving while remaining intuitive for professionals with varied technical backgrounds. Furthermore, acceptability demands that real-time collaboration aligns with or improves existing design processes and culture norms rather than imposing additional complexity or risk.

The workshop reveals that practitioners recognize and value real-time collaboration's problem-solving potential for the documented coordination challenges: information fragmentation, decision-making, and cross-disciplinary alignment difficulties. However, professional culture norms regarding work visibility, software interoperability, and contractual structures create substantial resistance for adoption.

For real-time collaboration technologies to achieve adoption in building design, acceptability requires:
- Technical interoperability enabling information exchange without manual translation or loss of integrity across disciplinary software tools
- Usability that reduces coordination burden for design professionals with varying technical proficiencies
- Legal and contractual frameworks that explicitly allocate intellectual property ownership and liability for collaboratively produced design work
- Economic incentives rewarding proactive cross-disciplinary contribution rather than individual discipline optimization
- Organizational culture that values transparent work-in-progress visibility as a problem-solving strength rather than professional risk

3.3 Revenue logic for real time collaboration services
Riku Riiheläinen – Tampere University (edited by Kalle Kähkönen)

Contracting
Contracts are of prime importance in construction business. Those are setting possibilities, limits and obligations for operations and their revenue.

When drawing up a design contract, it is important to note that the contract defines the designer's performance obligations with sufficient precision (Junnonen, 2009). When contracts are drawn up clearly, disputes arising from disagreements are prevented, which can disrupt the progress of the work and, in the worst case, cause delays and additional costs (Liuksiala & Stoor, 2021). Design tasks should be defined in the contract by mentioning the design field in question, referring to the task list of the design field in question, and other annexes that affect the scope or content of the design task. The task list should be attached to the contract and tasks that deviate from the basic scope should be noted. Design tasks can also be defined by directly listing in the contract those tasks in the task list that are part of the assignment (Savolainen, 2023).

Inclusion of BIM operations and related principles in design contracts looks still rather limited. Advancing this inclusion is seen as a necessary step also for creating the grounds for real time collaboration.

Qualitative study on present contracting practices
The aim of the study was to improve collaboration in BIM-based construction projects by analyzing current design contracting practices. It was expected

that based on such knowledge useful recommendations can be presented for improving contracting practices.

This study specifically focused on design processes and design contract processes in building construction, as well as how building information modelling affects these processes, particularly from a collaboration perspective.

The research consisted of two parts. First, the topic was examined through a literature review, followed by an interview study. The literature review addressed construction project contracts in general, the contracting process, design agreements in Finland and abroad, as well as methods for promoting collaboration in construction projects. The material included industry literature, scientific publications, and previous research. The interview study aimed to gain deeper insight into design agreement practices and collaboration in construction projects. It was conducted as a semi-structured thematic interview, in which eight professionals from the construction industry were interviewed.

Key results
Based on the study, it can be concluded that design contracts play a key role in enabling effective collaboration, but current contractual practices do not sufficiently support collaboration or building information modelling. Modern BIM projects require more clearly defined collaborative procedures and efficient and fast information sharing, which current design agreements do not systematically address. The influence of BIM on design contracts is also inconsistent and insufficient. Although the use of BIM is widespread in the construction industry, its role in contracts is often very limited. This results in the full potential of BIM not being utilized. The interview study identified, among other things, the inadequacy of current compensation arrangements in promoting collaboration. To improve this, a compensation model linked to goals was proposed to encourage effective cooperation. The practices of alliance models were also seen as offering good examples of how collaboration can be achieved in other implementation models. Furthermore, involving a BIM coordinator already at the design agreement stage was viewed as a potential means to enhance BIM use and collaboration.

Useful practices for incorporating BIM into design contracts can be found in international contract models or guidelines. These include, among others, the FIDIC White Book, which acts as a counterpart to KSE 2013 and also includes a contract template, the NEC PSC, which also acts as a counterpart to KSE 2013 and focuses on the effectiveness of collaboration, and the CIC BIM Protocol, which corresponds to YTV 2012, but deals more with legal and contractual issues.

Collaboration is not considered carefully enough in contracts, even though there are numerous practices that support collaboration. Because these practices are not considered carefully enough in contracts, their implementation remains dependent on the practices of companies, and these are not monitored or guided systematically. In order to make the best use of collaboration and BIM practices in projects, clear expectations and goals must be set for them already at the tender stage and in contract negotiations. For example, including concrete collaboration goals in

contracts and including a BIM coordinator in the contract process would create good conditions for collaboration. The practices of alliance models provide good examples of the implementation of collaboration in other implementation models as well.

Current compensation arrangements do not support collaboration. Designers' fees are mainly based on hourly pricing or a fixed total price, which does not encourage collaboration or reward efficient design. Collaboration could be encouraged by moving from hourly pricing towards target fees or bonuses tied to goals. These goals could be tied to costs, schedule or quality, for example. Such compensation could improve the incentive nature of contracts and increase designers' commitment to the project. The compensation arrangements of alliance models could serve as a model for developing compensation arrangements.

Further information about this study and its results can be found in Riiheläinen (2025).

3.4 Data governance and management methods in construction collaboration
Jutta Suksi – VTT Technical Research Centre of Finland

Introduction
This study focused on data governance and management in construction collaboration. The task included two workshops to ideate future data governance and management directions. This was followed by desk research to deepen the knowledge about said future directions and resulted in an interactive tool for early-phase BIM application decision-making.

Workshop 1
The task commenced with Workshop 1 combining a top-down and bottom-up approach (see Figure 3). The top-down perspective covered the regulatory landscape relating to data, which is currently in a dynamic development phase. The bottom-up approach identified sectoral initiatives and developments, such as emerging types of services, data environments, and data flows.

As the basis for the workshop, we introduced the developments currently taking place in the regulatory sphere. These included aspects on the general overview of the European regulatory landscape for data; the Data Governance Act; the Data Act; complemented with a snapshot of other horizontal regulations and possible sectoral implications.

The workshop addressed for instance the following questions:
- What are the most relevant regulatory areas for data management in construction project co-operation?
- What kind of actors, services and data environments exist for data management in construction project co-operation?
- What kind of data and data flows exist for data management in construction project co-operation?

- What kind of sector specific mechanisms arise in connection with data management in construction project co-operation?

The key takeaway from the workshop was the phenomenon of a **transition from file based transfers to data sharing and data based transactions**.
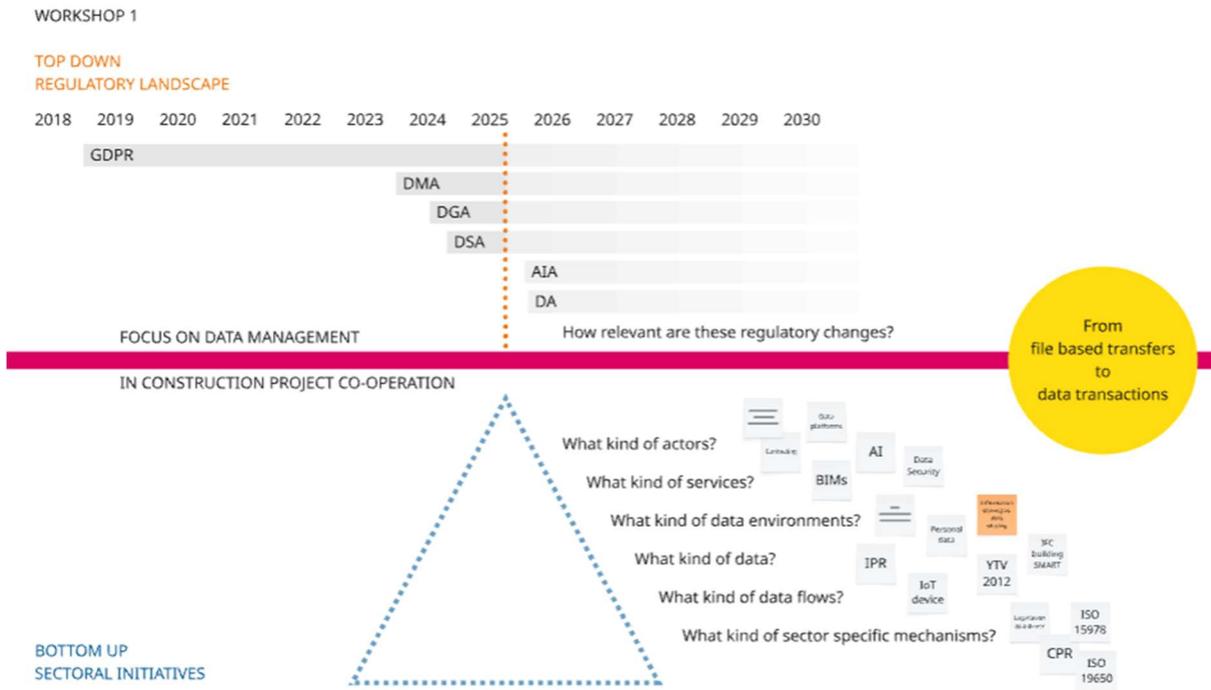

Figure 3: Visual overview of the topics that were discussed in Workshop 1. The image shows the top-down regulatory landscape and its connection to bottom-up construction environment considerations.

Workshop 2

Workshop 2 delved more into the key takeaway of Workshop 1: a transition towards data sharing, instead of file sharing. The workshop collected examples of the phenomenon, investigated what kind of opportunities it would create and addressed the question of what it would require from the perspective of data management. Figure 4 shows the gathered notes of Workshop 2 on several levels.

Based on the workshop, we identified some core questions. These included the question on what kind of changes in the data and information flow can be expected in the future and what kind of implications those have on value creation opportunities and liabilities. Special attention should be given to the interconnection between the data/information flow and liability/value flow. Additionally, the value flow is deeply embedded in physical production chains, and data management in a construction project co-operation is only one phase in the whole lifeline of a smart building. The workshop inputs led us to posing further questions: Could data-based services be deployed in and drive all phases of smart buildings? How far in the future would this kind of a scenario be? What kind of processes would be needed? What kind of contractual practices and terms would be required?

Figure 4: Screenshot of the input gathered during Workshop 2.

Desk research

To answer the questions identified as a result of the workshop phase, we explored for instance the following issues, initiatives and specifications during the desk research phase:

- Data descriptions (e.g. buildingSMART Finland, YTV 2012)
- Data products (e.g. Open Data Product Specification, Data Spaces)
- Contractual practices for construction in Finland (e.g. KSE 2013,YSE 1998)
- Contractual practices for BIM (e.g. BIM Protocol, ISO 19650 EN, IMI Framework)

Results

As a result of the work in this study, we produced an interactive information package tool. It is aimed to be used for informed decision making within organizations involved in Building Information Modeling (BIM). It contains basic information on BIM, how BIM serves the production of the Project Information Models (PIMs) and Asset Information Models (AIMs), and what can be expected, when moving towards additional purposes of use, for instance in the building's end-of-life phase and data usage outside the direct use within the building itself. In order to make a transition from file-based transfers to data sharing and data-based

transactions, major contractual practices and changes need to take place, as well. These are collected under the interactive tool (Navigator for BIM contracting) to be made available for public.

3.5 Conclusions

Based on the work done in this chapter it can be concluded that sustainability and circularity in particular will increase the needs for collaboration between design stakeholders. There is a need to develop certain circular data and process requirements that to appropriate adoption in collaborative design processes. It was also established that real-time collaboration technology should meet certain technical requirements, but that sociological and legal/contractual barriers should not be forgotten during its development. For instance, users of real-time collaboration technology stated that they valued the synchronous collaboration capabilities it offered. However they had concerns about, for instance, potential liability and Intellectual Property Right (IPR) issues. After a further analysis of current design contracts, it was identified that these do not facilitate collaboration efforts in the industry. Also, current compensation agreements between industry stakeholders do not facilitate collaboration, as these are mostly based on hourly rates instead of output. A possible development here could be the move from file-based data transfers to contracts and business models that are based on data-sharing transactions. This would require co-development of contracts, technology, and business models. All in all, real-time collaboration proved to be viable technology, provided that it is developed along certain pathways such as those established in this chapter.

4. Learnings from Use Cases

Experimenting in use-cases has been a large part of the LiveCol project. The researchers have used the experiments to identify characteristics, barriers, enablers, and future development directions within the boundaries of particular use-cases. Every use-case has utilized tools that were provided by LiveCol's technology partners and the relevance of each use-case has been verified with the consortium stakeholders before commencing the experiments.

This means that LiveCol has been able to execute a fair amount of use-cases, which have led to increased understanding of real-time collaboration capabilities and improvements. This chapter will present each of the use-cases, its setup and findings.

4.1 Design data sharing
Thomas Bagge, Kim Nyberg — Trimble Finland

The original idea for this use case was to develop the "change transmission mechanism" technology based on data from real projects. Due to a last-minute modification to the LiveCol consortium, unfortunately this proved to be difficult. Instead, we chose to keep the intended main use case that was centered around the co-operation between a steel detailer and a structural engineer (both using Tekla Structures), but utilizing testing data to replace real project data. Due to this change the development of the technology has taken longer than anticipated. Defining the concept of the "change transmission mechanism" was also prolonged. For these reasons the technology has not been developed as far anticipated before the LiveCol project, however a patent for the concept has now been applied for. This section will focus on the technology development, while the use case and its findings are presented in more detail in section 4.2.

The developed technology works so that the system consists of multiple independent models that each produce their own federated model that includes a geometric TrimBIM model and its associated semantic data. Other parties can visualize this federated entity within their own design environment, which enables seamless collaboration between different models. When models are connected, the system accepts both native model objects and federated model objects as input. The latter is then internally converted into native proxy objects. This technical solution enables connection algorithms to recognize proxy objects as native, eliminating the need to modify existing connection code. To ensure usability, these proxy objects remain hidden from the user interface and reports and cannot be selected

directly on the screen, although they remain programmatically manageable via a unique GUID.

Once a connection is established, all objects that belong to the other model, including those parts that mainly consist of proxy objects, are marked with a proxy status. A transmission package containing the necessary TrimBIM geometry and semantic data is created from these objects. When a designer initiates a change, the sending model renders the TrimBIM geometry specified in the package and hides the original parts. Thereafter, the package is transferred to the original model. A corresponding visualization render is performed in the receiving model, displaying the new geometry while hiding the old parts for the duration of the approval process. If the change is rejected, the original parts are immediately restored to the view, and a rejection notification is sent back to the sender. However, if the change is accepted, the semantic parts are converted into genuine native parts. An approval notification will then be forwarded, and the recipient publishes the updated federated model for use by other parties.

Trimble has demonstrated the technology to the LiveCol consortium members, as well as some customers. Feedback thus far has been good, and a lot of suggestions for improvement have been collected. The technology has now transferred to "customer discovery" mode. At the moment, Trimble is demonstrating the technology to select customers from different segments. The plan is to collect the necessary feedback and data to decide upon further technology development direction. A key step in this phase is to determine the right customer segments e.g., structural engineers, steel detailers, steel fabricators or cross segment collaboration. Other trades like MEP and architecture are also being considered.

4.2 Online design collaboration

Gayan Kankanamge – Tampere University (edited by Kalle Kähkönen)

Tekla Structures, Finland's most widely used BIM software, provides structural engineers with a platform for effectively managing and coordinating their designs, particularly through its live collaboration features. The software integrates cloud-based services and advanced data-sharing protocols, allowing real-time model updates to be instantly visible to all participants (*Working collaboratively within a Tekla Structures model | Tekla User Assistance*, 2024). This creates a collaborative environment where potential conflicts can be identified and resolved early in the design phase, significantly reducing costly changes during construction. In addition to the robust "Tekla Model Sharing" feature, Trimble Tekla has introduced the novel "Tekla Live Collaboration" tool (hereafter referred to as "Tekla Live Collaboration") to facilitate enhanced dynamic collaboration among users.

The study presented in this chapter has explored the role of live collaboration technologies in structural engineering. By examining their applications, benefits, and challenges, the research aimed to provide

insights into how these technologies can enhance collaborative practices, ultimately leading to more efficient and resilient structural designs.

Real-Time and Synchronous Collaboration Technologies

Building on BIM, the most recent advances enable synchronous, real-time collaboration within digital workspaces. These go beyond uploading a model to the cloud; they enable multiple users to interact with the same model or virtual environment simultaneously, often with integrated communication capabilities (Architizer, 2015). Figure 5 illustrates the flowcharts that compare asynchronous and synchronous workflows.
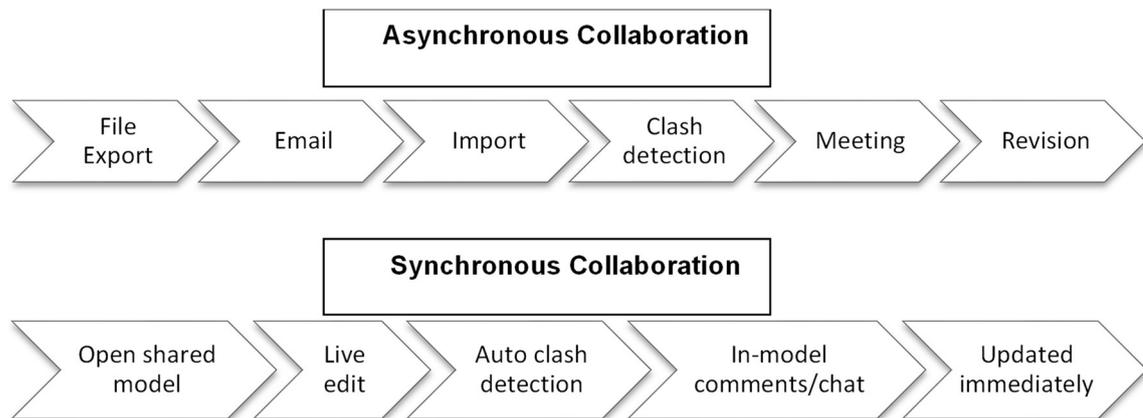
Asynchronous Collaboration

File Export → Email → Import → Clash detection → Meeting → Revision

Synchronous Collaboration

Open shared model → Live edit → Auto clash detection → In-model comments/chat → Updated immediately

Figure 5: Asynchronous vs. Synchronous Collaboration

One class of tools involves cloud-hosted BIM platforms that offer real-time model reviews. For example, Graphisoft's BIMcloud or Trimble's Connect platform lets users review IFC models and chat in the model. Such tools also allow simultaneous viewing: a manager might be in an office in Finland while an engineer in India, both zooming and rotating the shared model together. The key advantage is that decisions can be made together rather than through email exchanges. Several industry articles note that real-time BIM collaboration reduces misunderstandings and accelerates decision-making since project partners "facilitate real-time communication" through shared models (Interscale, 2025).

Tekla Live Collaboration

The Live Collaboration feature in Tekla Structures allows users to collaborate on 3D models in real-time without needing to export or share any files (*Real-time collaboration with Live Collaboration for Tekla Structures (Preview) | Tekla User Assistance*, 2025). Furthermore, this feature brings the project team together to review work done in Tekla Structures and Trimble Connect. As part of the review process, users can share their models in real-time with other Tekla Structures and Trimble Connect users and observe the modifications and navigation of other collaborators in their Tekla Structures model. Trimble Connect users can also share models stored in the Trimble Connect project (*Real-time collaboration with Live Collaboration for Tekla Structures (Preview) | Tekla User Assistance*, 2025).

This setup allows companies to collaborate effectively without compromising model ownership or intellectual property. For example, one company may be responsible for designing the concrete structure of a large project, whilst another focuses on designing the steel structure. With Tekla Live Collaboration, they can work together on the connection design between concrete and steel structures without sharing their native Tekla models. This makes Tekla Live Collaboration a solution for enabling secure, real-time collaboration between different project stakeholders.

Experimenting with the Tekla Live Collaboration software
An experimental methodology for testing live collaboration software in structural engineering was developed and applied. This included design and construction of a dedicated test bench. The core components of the test bench included:

1. **Tekla models**: detailed concrete and steel structural models
2. **Trimble Connect Project**: Both structural models (concrete and steel) were linked to a single Trimble Connect project (see Figure 6)
3. **Workstations:** Three workstations were set up for the study (Tekla Structures 2024 with Live Collaboration, web access to Trimble Connect, speaker devices for having Microsoft Teams design meetings)
4. **Live Collaboration Session:** collaborative task to finalize the geometry and detailing of the concrete wall—steel beam connection (see Figure 6)
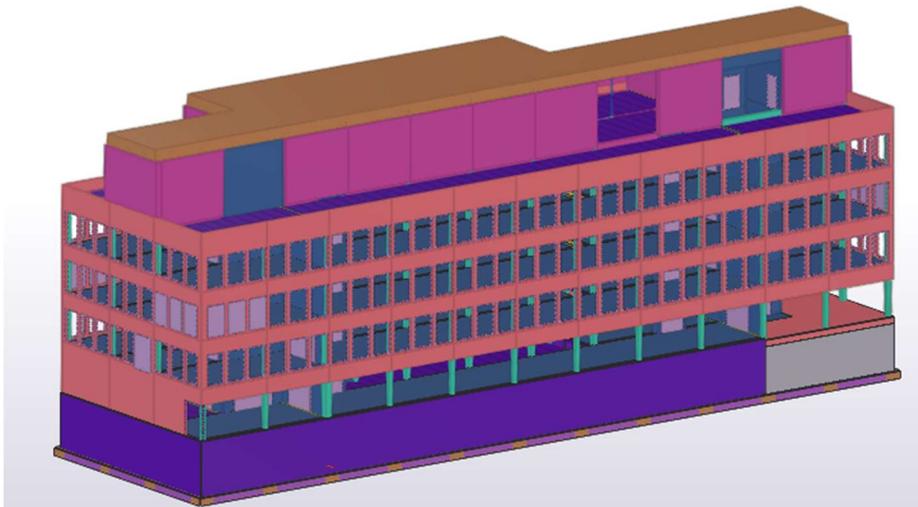5. **Participating engineers**: by invitations towards engineering consultancies

Figure 6: Shared concrete structural model and sample connection design as a collaborative design task
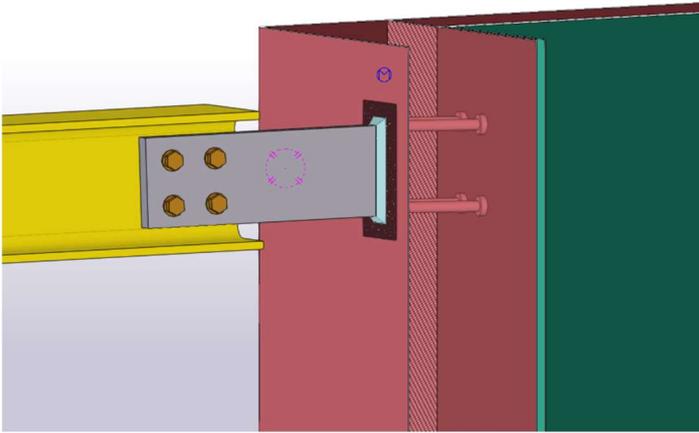
Figure 6 (continued): Shared concrete structural model and sample connection design as a collaborative design task

The experiments involved industry experts from VTT, Ramboll, and A-Insinöörit. All collaboration sessions were recorded, and the participants' survey responses were collected for subsequent analysis.

Key results
The data indicates several potential advantages of live collaborative modelling for structural engineering. Despite the advantages, the study also revealed various challenges in different levels. Among those were certain fixable technical shortcomings (which have been already fixed in succeeding versions of the Live Collaboration tool). But also higher level challenges were found that relate to design culture, processes and contracts (see Table 3).

Table 3. Summary of observed benefits and challenges of the tested Tekla Live Collaboration tool

Benefits	Challenges
- Real-time synchronization (no file exchange) - Enhanced communication through shared visual context (seeing others' actions) - Easier modelling of alternatives (rapid design iterations) - Potential for faster issue resolution - Supports remote co-design (especially useful in large, complex projects)	- Moderate usability - No built-in clash detection (collisions managed manually) - Inability to edit/select others' elements (Tekla-enforced restriction) - Lack of status and change tracking - The feature is still in development (some instability)

These findings support the research premise that live collaboration can benefit structural design by enhancing communication and reducing coordination delays with mature software solutions. Future work (with future software versions) should focus on integrating clash management,

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modification tracking, and enabling richer interaction with shared objects. When these challenges are met, live collaboration may become a valuable complement to traditional BIM workflows in structural engineering.

Further information about this study and its results can be found in Kankanamge, 2025.

4.3 Collaborative design team management
Jaakko Huusko — Tampere University

The aim of this study was to improve the current 'opening management workflow' with a more collaborative way of solving clashes and suggesting the positioning of the openings in a more context specific and real-time manner. Managing openings in structures is an essential part of building design that ensures ducts and other services can be efficiently routed through structural elements. It involves defining, reviewing, and coordinating openings in structural models to avoid clashes and facilitate smooth installation on-site. This process is usually executed either before or during the detailing phase of structural elements. The spatial reservations for ventilation shafts and HVAC equipment are made in the previous phase of the design and are not included in this development process.

BIM streamlines the opening reservation process by enabling precise coordination between structural and MEP designers. This leads to improved accuracy in opening positioning and minimizes costly rework during construction. Effective collaboration and communication between structural and MEP designers are essential to ensure accurate opening placement and prevent conflicts during construction.

Methods

This study focused on researching current practices in the opening reservation process and identifying the main challenges faced by designers. Based on these findings, three workshops were organized to explore and test alternative workflows. The aim was to improve coordination between structural and HVAC/MEP disciplines and to reduce manual effort in managing opening reservations. The first two workshops focused on testing and demonstrating the BCF-based spatial reservation process, and the final workshop explored the potential of Trimble's live collaboration technology. During the first workshop, the BCF-based opening management and its technical implementation were tested. BCF topics were transferred manually by sending the files via email, demonstrating the role of the BCF server without the need for integration of the MagiCAD's BCF server to Tekla Structures.

During the second workshop, a BCF-based opening management system was presented to AFRYs design team. To evaluate system effectiveness, designers completed pre- and post-workshop questionnaires. The pre-workshop questionnaire gathered baseline information on participants' familiarity with the current spatial reservation process and their work experience level. Following the presentation, a post-workshop questionnaire requested

feedback and improvement suggestions regarding the BCF-based spatial
reservation management system.

The third workshop featured a real-time demonstration of the spatial
reservation process, allowing designers to collaborate in real-time using
Trimble's Revit - Tekla Structures live collaboration technology.

Key Findings

Description of the current spatial reservation process
The spatial reservation process of openings in Finland typically involves
coordination between structural and MEP/HVAC designers using Tekla
Structures and either MagiCAD for AutoCAD or Revit. The structural designer
first uploads the IFC model to the project's common data environment (CDE).
The MEP designer subsequently downloads it, converts it to 3D DWG, and
proceeds with creating the proposed spatial reservations, which are then
exported as a separate IFC model. The structural engineer reviews these
proposals in Tekla Structures using the HoleReservationManager-plugin,
approving or rejecting them with comments. These decisions are then
exported from the plugin as an XSR-file and uploaded to the CDE. Following
that, the MEP designer updates their model based on the comments in the
XSR-file and, if necessary, consults the structural engineer about critical
locations. Updated spatial reservations are then re-exported as a new IFC
model. The cycle is repeated until all spatial reservations are approved.
Due to the need for manual coordination and re-routing, this process often
takes several weeks.

The BCF-based process and its proposed benefits
MagiCAD has introduced a BCF-based spatial opening reservation workflow
where each spatial provision is managed as a separate BCF topic. These
topics are hosted on a BCF-server and imported into Tekla Structures, where
structural engineers review, comment, and approve or reject proposals
individually. A key improvement over the traditional process is that
engineers can now modify the spatial provision positions directly,
proposing new locations within the same BCF context. This makes spatial
adjustments clearer and eliminates ambiguity from current verbal
instructions (e.g., "move the hole 200 mm to the right").

Workshop participants recognized two primary benefits of the BCF-based
workflow: (a) accelerated information exchange between design disciplines,
enabling faster communication and more efficient coordination, and (b) a
paradigm shift from text-based to visual communication. By communicating
opening relocation possibilities visually and spatially rather than through
text-based instructions, designers gain intuitive understanding of
constraints and design flexibility, fundamentally improving
interdisciplinary understanding.

Implementation challenges
Despite the conceptual value of the BCF workflow, the workshops revealed
several significant technical and process challenges that must be addressed
before implementation. Workshops identified fundamental ambiguities in the
new workflow's governance model. Key unresolved questions include: *Who has
the authority to reposition openings? If a structural engineer modifies an
opening, can it be approved and returned to the MEP designer as "accepted,"*

or does it revert to "changed" status? These status distinctions carry workflow implications, and altered spatial reservations may require re- review or re-notification procedures. Additionally, MEP designers' initial spatial reservation proposals are often "exploratory," meaning they may not satisfy all structural requirements from the outset, requiring a collaborative iteration between disciplines rather than a sequential review. This challenges the assumption of a sequential, linear approval workflow.

While the BCF format enables visual communication, two documentation challenges surfaced: (a) adding comments to spatial reservations is not reliably supported, yet structural engineers emphasized that comments are essential when rejecting proposals, and (b) comment history should be embedded within BCF topics for project documentation purposes. Additionally, uncertainty exists about whether all required information for spatial reservation drawings (such as firestop specifications) flows correctly into Tekla objects.

Alternative Approach: a zone-based solution
The workshops generated strong support for a conceptually different approach: defining landing zones (acceptable placement areas) and no-go zones (restricted areas) rather than repositioning individual spatial reservations. This zone-based method would offer advantages in preventing conflicts and optimize placement efficiency before problems arise. However, this approach faces practical limitations, because applying landing zones to all structural elements is "nearly impossible," requiring selective application to high-coordination elements only.

Real-time Collaboration between disciplines
In the third workshop, Trimble demonstrated their newly developed live collaboration technology, which enables HVAC/MEP designers and structural engineers to collaborate in real-time with their own specific software. This innovation captured the attention of AFRYs designers, who recognized that real-time coordination within context-specific tools, streamlines problem-solving and reduces communication friction. The designers recognized the practical value of this approach for resolving complex interdisciplinary challenges, but they underscored that the conventional spatial reservation workflow remained essential for comprehensive coordination across projects.

However, some participants expressed concerns about the maturity of the technology and its integration into existing project workflows, particularly regarding version control, comment history and responsibility boundaries. Moreover, they emphasized that contractual practices and internal quality assurance procedures would need to be adopted before such real-time collaboration could be widely adopted. Overall, the workshop suggested that real-time collaboration should be seen as a complementary layer on top of established coordination practices, rather than a complete replacement of current processes.

Conclusions

The current spatial reservation process is characterized by professionals as "laborious, slow, and heavy", reflecting frustration with coordination

inefficiencies and repetitive, effort-intensive coordination tasks. The exploration of alternative opening management workflows through three structured workshops has demonstrated both promising potential and practical complexities of modernizing spatial reservation coordination between structural and MEP/HVAC design disciplines. While the current process remains functional, it is time-consuming and vulnerable to miscommunication, making it a clear candidate for improvement. The research identified two viable technological pathways: (a) BCF-based opening management systems that enable visual, comment-driven coordination, and (b) real-time collaboration that allow simultaneous work within discipline-specific software environments.

During the workshops, participants proposed a third, conceptually different approach to opening coordination: defining landing zones (acceptable placement areas) and no-go zones (restricted areas) rather than managing individual spatial reservation repositioning. A particularly promising avenue for future research involves combining the preventive strengths of landing zones and no-go zones with real-time collaboration technologies to create a more cohesive opening management ecosystem. Real-time collaborative platforms could enable structural engineers and MEP designers to jointly define and refine spatial constraints in real-time, transforming landing zones from static geometric boundaries into dynamic design spaces where both disciplines iteratively optimize opening locations within established safety margins. This integrated approach would leverage the intuitive visual communication of real-time tools while maintaining the conflict-prevention benefits of zone-based coordination, potentially reducing both rework and coordination cycles significantly.

Equally important is the integration of firestop modeling into this comprehensive workflow framework. As outlined in the Building Smart Finland's case description (bSF Drive, n.d.), firestop design is an essential complementary process to spatial opening reservation, requiring close coordination between MEP designers, structural engineers, and specialized firestop designers to ensure that proposed openings can accommodate appropriate fire-stopping solutions while meeting structural and architectural performance requirements. Future processes should embed firestop modeling constraints and data requirements directly into the opening coordination workflow, allowing firestop designers to provide earlier feedback on proposed opening locations and dimensions relative to available firestop product specifications and installation requirements.

4.4 Design change management
Toni Teittinen — Tampere University

The purpose of this work was to develop and evaluate a technology framework that enables automatic management of design model changes without the need to share native design files. The objective was to explore how intelligent design systems can react to modifications in IFC-based data and how an in-tegrated approval mechanism can support controlled adaptation to those changes.

This work also utilizes findings from earlier work done in the project, which analyzed the nature and causes of design changes. In simplified form, the stages of the change process are illustrated in Figure 7.
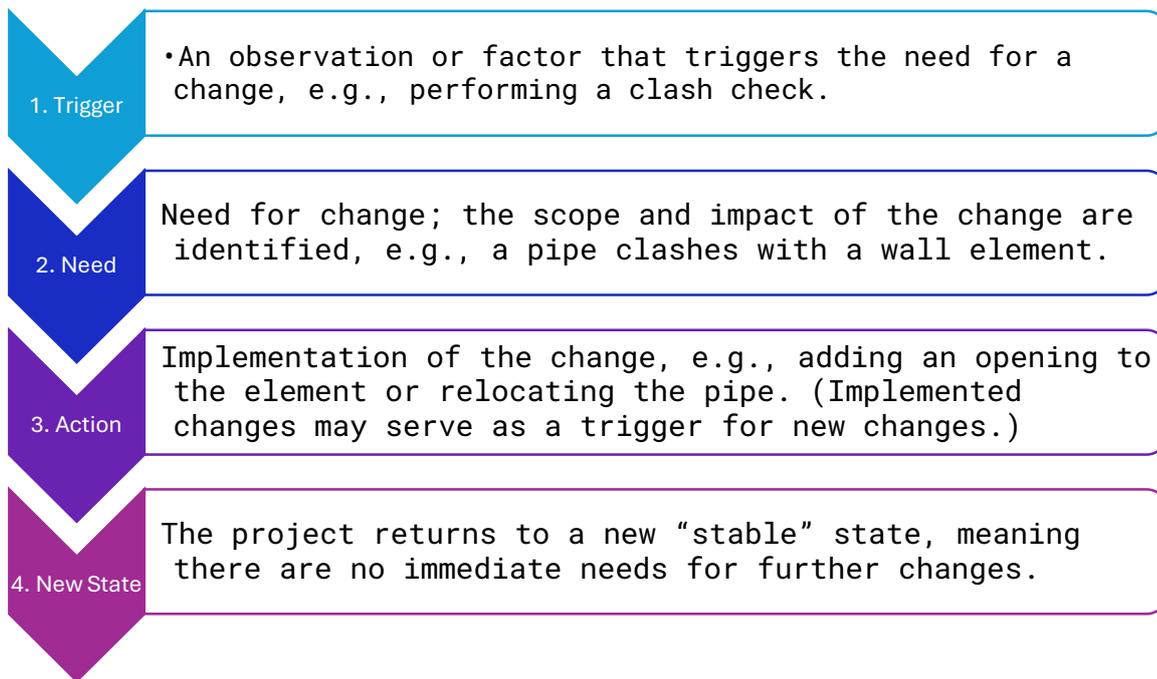
1. Trigger — •An observation or factor that triggers the need for a change, e.g., performing a clash check.

2. Need — Need for change; the scope and impact of the change are identified, e.g., a pipe clashes with a wall element.

3. Action — Implementation of the change, e.g., adding an opening to the element or relocating the pipe. (Implemented changes may serve as a trigger for new changes.)

4. New State — The project returns to a new "stable" state, meaning there are no immediate needs for further changes.

Figure 7: The conceptual change process

New technology related to the task was presented in several workshops and meetings, providing an opportunity for experts and researchers to familiarize themselves with its core functionalities. To assess usability and gather practical insights, small-scale demonstrations were conducted. These demonstrations allowed participants to interact with the technology in a controlled environment, explore key functionalities, and identify potential limitations, without engaging in full-scale case project trials. The purpose of these activities was to collect early feedback, highlight practical challenges, and guide further development and integration strategies.

The features examined during these sessions included Model Sharing, which enables multiple users to make separate changes to the same model that can later be combined, and Live Collaboration, which supports real-time multi-user editing. Observations from these demonstrations and discussions focused on practical aspects of managing design changes, coordinating work between users, and identifying opportunities to refine the software to better support collaborative design workflows. These observations can be used to inform and support the direction of ongoing development efforts.

Findings

The need for change management during the conceptual design phase arises primarily from internal change requirements within the design team. Among these, various internal design adjustments, often related to geometry were identified as the most significant source of changes, highlighting the importance of flexible and responsive design workflows.

The evaluation of the new LiveCol technology indicates that it does not replace the previously used Model Sharing functionality but complements it by providing additional mechanisms for managing design changes. A key aspect of the LiveCol approach is the incremental sharing of changes, which enables near-real-time propagation of updates between users. This incremental exchange allows designers to receive and respond to changes more quickly compared to traditional batch-based workflows, thereby supporting more continuous coordination.

LiveCol also supports multi-user collaboration across different software platforms, albeit with certain limitations. This cross-platform capability facilitates coordination in projects where designers rely on diverse tools, improving the potential for communication and conflict resolution within the design team.

Observations from the workshops and small-scale demonstrations further highlighted practical considerations for implementing these technologies, including the need for structured change approval procedures, clear communication practices, and iterative refinement of the tools to better support collaborative workflows. These insights can be used to guide ongoing development efforts and to adapt the technology more effectively to the needs of design teams during early project phases.

Conclusions

The findings indicate that a substantial portion of design changes originate from internal coordination needs within design teams, with geometric modifications frequently playing a central role. This highlights the value of tools that support continuous coordination and efficient handling of changes across various stages of the design process.

The evaluation of the real-time collaboration technology shows that it complements existing Model Sharing workflows by enabling incremental and near-real-time exchange of changes. This mechanism allows updates to be transferred more efficiently, as only the modifications are shared rather than entire model files, potentially reducing communication overhead and improving the responsiveness of collaborative work.

LiveCol's software-independent design supports collaboration in environments where different designers rely on different tools, thereby helping to bridge technical gaps between disciplines. Furthermore, the technology incorporates improved approaches for managing IPR-related considerations, which may facilitate smoother cooperation between designers representing different organizations.

Overall, observations from the workshops, demonstrations, and expert discussions suggest that the examined technologies can enhance collaborative practices in multidisciplinary projects, particularly in

settings where frequent updates, diverse software environments, and cross-organizational collaboration are present. Although full-scale project trials were not conducted, the small-scale evaluations provided practical insights that can inform the direction of further development and contribute to refining workflows that support effective change management and communication throughout the design process.

4.5 Site operator and designer collaboration

Mika Hakkarainen & Timo Kuula — VTT Technical Research Centre of Finland

The objective of this work was to enable real-time 3D model collaboration between remote desktop-based 3D modeling software and a mobile Augmented Reality (AR) client. This approach applies immersive 3D technologies to support online communication between on-site and remote operators in collaborative use cases, providing augmented information to the on-site operator and a 3D environment to the remote operator.

Real-time collaboration between desktop 3D software and mobile AR is achieved through a shared 3D environment managed by NVIDIA Omniverse Nucleus, which provides live access to a centralized scene (see Figure 8). Synchronization and interoperability are enabled via the Universal Scene Description (USD) format, allowing efficient streaming of geometry, materials, and metadata across devices. At the end, we conducted user tests to assess the usability of the system and gather feedback on feasibility, collaboration and technical limitations.
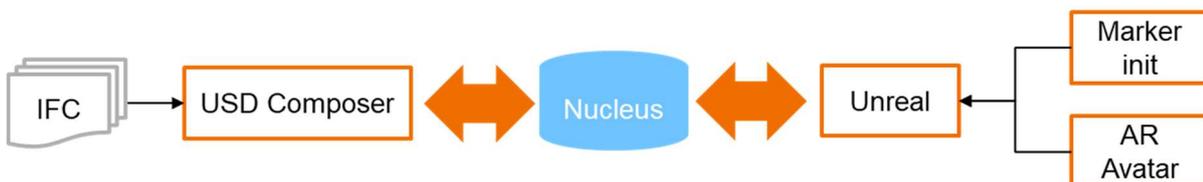
Scenario setup

Figure 8: Setting up the scenario

The following steps were taken to set up the collaboration scenario:
- Import facility IFC model(s) to USD Composer. Save the model(s) in flattened mode (i.e., merge all individual models into a single USD)
- Load the model in Unreal from the Nucleus
- Define the initialization point (marker in this case) in Unreal Editor (this is not part of the USD model)
- Make necessary modifications to the model in USD Composer and Unreal (add extra meshes, remove meshes, colours, visibility)
- Add the AR camera asset/avatar in Unreal and include it in the USD model

Run-time setup

Figure 9: Runtime setup

Both applications first load the same model from Omniverse Nucleus, and then LiveSync is initiated in USD Composer and Unreal Engine, enabling real-time model sharing and editing across platforms. Magic Leap 2 (ML2) glasses connect to the Unreal PC and use OpenXR remote rendering to stream visualization from the PC to the headset via Wi-Fi (see Figure 9). The 3D model is aligned correctly in the user's environment by the AR user using a physical marker. During the live session, updates are immediately visible in both applications as users interact with the shared 3D model.

Execution of the user test

The user test was organised in VTT's building in Espoo, on October 9, 2025. The specific place was a space for air-conditioning equipment. Two test users, both LiveCol project members from the University of Tampere (TAU), participated in the test. The test users performed the test tasks separately. After the test performances, the users were interviewed. The user test was organised and led by LiveCol project researchers from VTT.

The test comprised two main tasks:
1) Verifying whether the as-built corresponds to the 3D model (i.e. the location of air-conditioning tubes in the ceiling) and adjusting the model in AR as necessary (Figure10).
2) Inserting a virtual object (rack) into the model and relocating it to an appropriate position considering the real environment.

Figure 10: Composer (3D) view (left) and mixed reality view (right)

Two user roles collaborated during the test: A remote designer using a desktop computer, and an on-site person (site operator) wearing AR-glasses. Both participants performed the test in both roles. During the test procedure, the remote designer initially instructed the site operator to carry out the verification and positioning tasks, while observing the

process through the 3D model and video feed from the AR glasses. Communication between users took place verbally throughout the test (note: an integrated audio connection was not included in the system).

Results
General perceptions of the system
The test users reported that the system was generally intuitive, easy to use, and functional. The AR-glasses were sufficiently lightweight to be worn comfortably, and no symptoms of simulator sickness were reported. One participant, who had less prior experience with AR-glasses, noted that it took some time to get used to looking through the glasses and learning how to distinguish between real world and virtual elements.

The user test tasks were considered suitable by the users for evaluating usability, and within LiveCol project context. In summary, the tasks involved comparing the existing situation with the planned model, as well as introducing a new virtual element into the model so that it is also visible in the real environment through the AR view.

Feasibility of the concept
Regarding the system set-up, it was noted that the live video feed from the AR-glasses was a useful enhancement for collaborative tasks. While the 3D model is likely to be of primary importance from the designers' perspective, the video feed enhances the understanding of the real world. One user specifically commented that the system would generally improve understanding of conditions on construction sites. According to another user, the most benefit would likely be in repair work and not so much in new construction.

With respect to barriers to the real-world adoption of the system, both users pointed out that the availability of personnel could pose a challenge for live collaboration. And furthermore, who would be the person or stakeholder to organise the live session, for example. Additional obstacles mentioned included the typically demanding conditions of construction sites, as well as the need to acquire appropriate equipment and provide adequate training.

The system could, for example, support collaboration between an architect designer on site and a remote HVAC planner, in cases where certain matters have not been seen as issues during the planning phase. When utilizing live collaboration, the architect would not need to create additional notes on site. Various types of technicians were also mentioned as potential beneficiaries of the system.

Potential use cases might include scenarios where construction has been executed contrary to original plans, or where new elements must be designed—particularly in confined or limited spaces. In such instances, the remote designer can suggest solutions in real time. The live collaboration has a potential to speed up the processes and make it more agile.

Usability considerations
Effective real-time collaboration would require an audio connection between participants. As the test prototype did not include an audio feature, incorporating such functionality would provide an obvious improvement. A

straightforward solution for establishing audio communication would be to use a connection via e.g., a mobile phone.

Overall, system usability was rated as good by the users, with both the visibility of the model and the real environment seen as adequate. However, certain conditions, such as lighting and surface reflections, occasionally led to visibility challenges in the AR-view, especially for real world visibility. The hand-held controller was considered intuitive to operate. Accurately positioning the model using the combination of the AR view and the hand-held controller proved to be somewhat challenging, however, due to minor lag in the system.

It was also suggested that the remote person should be able to see, in even greater detail and with improved fluidity through the AR view video feed, exactly what the on-site person is observing, and to focus the view as needed.

Within the AR-view user interface, it was possible to manipulate the virtual object by rotating, moving, and scaling it (see Figure 11). It was suggested that the rotation functionality should include pre-set options, such as 45-degree increments (etc.), as well as a reset function. Furthermore, when moving the object, it should also be possible to move it in defined steps, and by a specified distance, in addition to the current sliding movement.
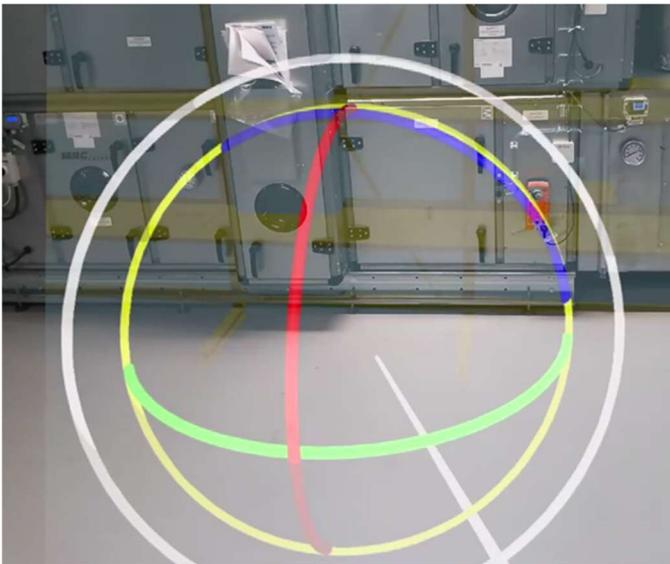

Figure 11: Rotating functionality in AR-view.

Further improvement suggestions included:
- Documentation of the collaborative session by recording the audio (discussion) and providing summary.
- Possibility to create notes, such as an audio note (memo).
- Providing accurate measurements during live session, e.g. between two objects.
- Possibility for remote person to mark points of interest in the shared view (annotating, colouring) for on-site person to investigate.

Conclusion
Test users generally found the system usable and intuitive. Some challenges were noted with visibility under certain conditions and with precise positioning. Users suggested enhancements such as improved remote viewing, more flexible object manipulation, and additional collaborative features to increase feasibility. Key barriers to implementing the system in real-world scenarios include challenges related to staff availability for live collaboration, as well as the necessity for suitable equipment and sufficient training. In general, the system has the potential to enhance understanding of the construction site situation and streamline work processes. For further development, it would be beneficial to gather expert opinions in greater detail regarding the required features.

Unfortunately, for technical reasons, developing this system further is not meaningful. The current workflow offers only partial functionality: AR users can manipulate existing meshes but cannot add objects or modify materials. Critical platform support has been deprecated since Magic Leap 2 no longer supports OpenXR remote rendering, and Unreal 5.3 is the last version with a working Nucleus connection. Future Unreal releases rely on a native USD import plugin without live synchronization. While Omniverse Kit could enable developing custom USD connections, it lacks Android support and would require proprietary software development.

4.6 Circular design support
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Concretely, circularity in the Real Estate and Construction industry (REC) means reusing materials, components, and products from existing 'donor' buildings into new recipient buildings (see Figure 12).
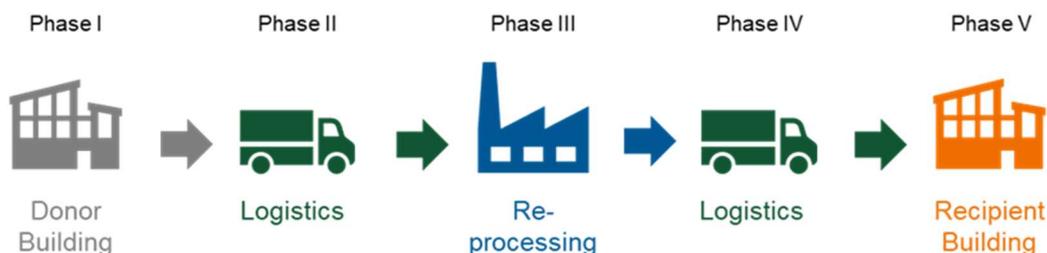

Figure 12: Implementation of Circular Economy in the REC industry.

Therefore, most of the materials, components, and products that we would like to reuse need to come from existing buildings. However, the problem is that: (a) we lack general insight into the materials, components, and products present in existing buildings, and (b) we need granular data in order for reuse to be possible. Section 3.1 earlier introduced the needs particular data types in circular construction processes.

Therefore, this task develops and introduces the concept of Portfolio Mining complemented with a digital tool as a means to bridge this gap. Unlike Urban Mining, which in REC thus far has focused mostly on the recovery of valuable materials from existing buildings within a certain geographical area, Portfolio Mining entails recovery from specific real estate portfolios. This provides three main advantages to solve the research gap. First, real estate portfolios have one specific owner rather than of a collection of owners in a certain geography. This eliminates the need to gather data from different stakeholders and enables direct processing of portfolio owner data. Secondly, the utilization of owner data enables working directly with primary data from project banks, foregoing the need to gather secondary data with external (visual) techniques. Third, portfolio owners are the key demolition decision-makers. Providing them and designers with granular technical specification data, independently of demolition time-tables, would enable strategic portfolio-based decision making instead of current case-by-case decision-making.

Methods

This task applies a literature review to gain deeper insights into the data requirements for the reuse of concrete elements, supplementing the work done earlier in Section 3.1. After that, data is collected from five different Finnish buildings that are part of the same real estate portfolio. The authors received access to the real estate owner's building's project banks. The data of the buildings comprised hundreds of files per building. Consisting of analogue 2D data (e.g., floor plans, sections, facades, systems descriptions), as well as 3D data (both IFC and native software models). The authors qualitatively compared the contents of the 3D models against the 2D data. The 3D models of all five buildings were found to be consistent enough with the 2D documents to serve as templates for further data processing in the next research steps.

After that, an AI-based tool is developed that is able to 'read' the information available from the project banks and can perform a circularity assessment guided by the identified data requirements from the literature review. The tool essentially parses different 3D and 2D data formats to extract the data contents. Afterwards, the parsed content may be investigated through a User Interface (UI) that utilizes a chatbot. The AI-engine used for this tool is Google Gemini Flash 2.5.

Data requirements

The literature revealed a total of 71 data requirements for reusing construction components. Out of those 71 requirements, 33 appeared in more than half of the final literature sample. Therefore, those 33 requirements were chosen to represent the circular data requirements in the further work in this task. The 33 requirements can be categorized into eight different categories: General, Physical, Connections, Adjoining Components, Building Information Models (BIM), Material, Use-Phase, and End-of-Life phase. Examples of data requirements include more general types such as e.g., dimensioning, quantity, location of the building, etc. On the other hand, some data requirements are more specific e.g., reinforcement, density, and fire class. Following section 3.1 we may expect some of this data to be present in the source files, whereas others may be missing.

Application of the AI-tool

The data of the sample buildings was uploaded to the flash memory of the tool. After that, testing commenced with asking simple, easily verifiable questions – e.g., how many 500x500mm concrete columns can be found in building X? – through the tool's chat interface. After testing the initial responses, two types of more demanding questions were tested. First, we asked questions where we knew the answer would require the tool to combine information from several different source documents to be able to provide an accurate answer. Secondly, we asked the same questions as before, but this time for the collection of five buildings instead of for one particular building.

Overall, the tool performed well in combining information from different source documents to provide the requested answers. E.g., when asking the tool about the structural strength classes of the 500x500mm columns, it accurately combined quantity data (the number of 500x500mm columns) from the building's IFC-file with the strength classes that were listed on 2D pdf drawings. To aid users to assess the given answers, the source documents used for the answer are always listed in the tool's response. It will also indicate whether the answer was an 'exact' match, or whether the answer was based on a 'synthesis' of information coming from several sources, or whether 'no match' was found.

When asking the same questions for the entire sample of buildings and not for one particular building, the tool was also able to provide answers. However, the tool generally needed more time to generate answers when compared to situations where we asked for the same information from one building. It is important to note that the tool only utilized flash memory and allowing the tool to store earlier information in its long-term memory would significantly shorten the response time. However, in this particular case this was not possible due to legal concerns.

We also directed the tool to run circularity assessments of the buildings based on the criteria that were identified through the literature review. Since the tool was able to combine data from multiple sources, the assessment contained significantly more information when compared to a scenario where only the 3D or 2D documents would have been assessed. However, certain data requirements such as 'remaining lifetime' or 'circularity assessment' were not available from any of the source documents. Since the tool did not include any calculation abilities that might have been able to calculate such data requirements from the source documents, the assessment did not identify those requirements.

User demonstrations

The tool and its functionalities were demonstrated to the data owner on two separate occasions. In general, the tool was well received by the data owner. Even though the tool is still in a prototype stage, its potential capabilities were recognized. The data owner also mentioned that this kind of tool would bring significant benefits to the information retrieval process for existing buildings. In this context, the client mentioned that the longer time needed for answer generation for multiple buildings was not necessarily a problem, as a similar task would manually take several days to complete instead of a couple of minutes. It was established that further

development should focus on the robustness and transparency of answers, as well as improvement of the information retrieval methods.

Conclusions

The tool development in this task provided conceptual proof of the potential of Portfolio Mining for circular use cases. The circular data requirements were identified through a literature review and the tool prototype was able to assess the circularity potential of the sample buildings by checking the source documents against the data requirements. The prototype proved to be capable of combining several source documents to synthesize answers for the circularity assessments, while referencing to source documents for transparency. The prototype also showed the potential to assess multiple buildings at the same time. This could enable strategic portfolio-based circular decision-making, if the concept and tool would be developed further. This would require further improvement of the information retrieval methods, as well as increasing answer robustness.

As the tool is able to classify and information according to IFC-standards, pushing 3D information of the identified circular components to other design software or real-time collaboration design platforms, should be possible. This would link strategic portfolio decision-making directly with potential users (e.g., designers) of the identified components, drastically shortening the collaboration feedback loop.

4.7 Conclusions

Based on the use-cases, it can be established that use of real-time collaboration tools increases the collaboration clock-rate among designers. Especially the direct communication channels between designers are a valued feature of the technology. Also the faster response times of the federated design model data setup, effectively foregoing the need to share complete BIMs and protecting stakeholder IPR were significant development steps that were taken during the LiveCol project. Two further use-cases proved that real-time collaboration not only has the potential to increase the collaboration clock-rate among designers, but also between designers and third parties, such as site-workers or real estate developers and owners.

Moving forward, the sharing and archiving of design decisions is a point of attention. Retrievability of design decisions is an important part of the current design process and links directly to the responsibilities of certain stakeholders like civil engineers, MEP designers and architects. There is a need to provide clarity about who made certain decisions, who has the authority to make certain decisions, and quantitative documentation of why certain decisions were made. Without further alterations to the operational environment (e.g., new types of contracts or ways of working as laid out in the pathways in the previous chapter), real-time collaboration tooling should include improved retrievability features to increase their adoption among practitioners. Without these additional developments some users suggested that real-time collaboration should be seen as a complementary layer on top of established coordination practices, rather than a complete replacement of current processes.

5. Implications for Real-Time Collaboration

The LiveCol project started from the premise that the frequency of design updates is key when moving towards near-real-time or real-time collaboration solutions. Attempts at increasing this so-called collaboration clock-rate with traditional solutions had been made at the start of this project, but proved difficult to scale (Afsari et al., 2016). More innovative solutions could also be found, however those mostly focused on certain niches, limiting wider industry uptake (Ghosh, 2021).

LiveCol experimented with technological solutions that were based on federated modelling architecture, presenting a new leap towards the real-time sharing of limited and specific data sets. This limits the need for model coordination between designers and should prevent IPR-issues. To prevent LiveCol from catering to a smaller stakeholder niche, the project aimed to include the four following additional perspectives:

  (a) Professionals: user-centered issues on task levels and construction.
  (b) Processes: holistic challenges such as new, arising processes and reshaping of work in construction projects.
  (c) Systems: transition enablers towards new practices and arrangements where near-real-time and/or real-time data/models are a common way of operations.
  (d) Legal: implementing data regulation and applying and validating contractual frameworks to construction collaboration data.

During the project, professionals have established that utilizing real-time collaboration technology does indeed increase the collaboration clock-rate. The developed technology also considers legal issues associated with common modelling environments and provides adequate ways of dealing with sensitive data. Practically, the proof of these improvements can be found in the fact that these features will be rolled out in commercial applications after this project. But also in literature several recent RDI paths can be recognized that are likely to further drive real time collaboration solutions in construction. Examples of those are cloud based technologies (Mohd Fateh et al, 2024), digital twins (Omrany et al., 2023; Jiang et al., 2022), various extensions of VR/AR/XR technologies (Ververidis et al., 2022), applications of AI (Rane, 2023) and industry supported digital platforms (Wang & Jiang, 2025).

The project has also offered a glimpse of systems and processes transition possibilities. If real-time collaboration technology improves its retrievability and accountability features, this could arguably increase acceptance and adoption of the technologies. The use-cases in LiveCol provided clear indications of the demands that such improvements should meet.

Furthermore, LiveCol showed that real-time collaboration technology has the potential to reduce the collaboration clock-rate between designers and third-parties, such as site-workers and real estate developers and owners. This expands the application area of the technology. As the technology improves further, it becomes more adamant that contractual and legal practices are updated accordingly. Current contracts and business models hinder the adoption of more collaborative ways of working in the industry. A transition to data-based sharing systems instead of file-based systems, possibly in connection with emerging technologies such as data-spaces, could offer opportunities here.

6. The future of Real-Time Collaboration

Based on Livecol, we propose two main development paths for real-time collaboration moving forward. These paths are (a) a more practical and incrementally innovative approach and (b) a more forward-looking and radically innovative approach (Dangelico & Pujari, 2010).

The practical approach focuses on reaping the benefits of the work that has been done in LiveCol. This means rolling out real-time collaboration features in upcoming software versions as well as improving the retrievability and accountability features of the federated technology. Moving towards more commercial directions of the AR and circular solutions that were developed in the project is also something that should be targeted.

Likewise, we propose an evaluation of the potential to link targeted applications of AI to the current developments. Although difficult to comprehend due to its current ubiquity, at the start of the LiveCol project AI and in particular LLMs were not widely available. However, in the circular use-case, we can clearly see the potential of applying such technologies, leading to this recommendation.

In the more forward-looking approach, we would propose addressing the more systemic challenges that were brought to light during the project. It seems that current versions of real-time collaboration technology will not be able to overcome systemic legal and business challenged by themselves. This path would therefore focus on the co-development of contracts, business, and technology. Here, one particular avenue of development that was identified in LiveCol could be a shift towards data-based transactions and accompanying business models through, for instance, data-space technologies that could merge these three perspectives together.

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