



COST Action HELEN – Holistic Design of Taller Timber Buildings

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Abstract. The construction sector is responsible for a large amount of greenhouse gas emissions, energy and raw materials consumption and waste production. Thus, a shift towards sustainable construction methods is essential. Engineered timber, a leading material for sustainable construction, has advanced to a point where it can now be efficiently used for taller buildings. Unfortunately, designing taller buildings made from timber is more demanding compared to their concrete and steel counterparts. A successful design and construction of taller timber buildings requires intensive collaboration between different fields. COST Action HELEN aims to support the transformation from research on isolated topics to a more integrated, interdisciplinary approach. This shift is essential for the safe and economic design, construction, maintenance, and recycling of taller timber buildings.

Keywords: Taller timber buildings · Holistic design · Robustness · Reuse and repairability · Deformations and Vibrations · Accidental Load Situations · Sustainability · Durability

This book chapter contains content from other documents and contributions created from the authors [1–3], where you can also find more detailed information about COST Action HELEN.

1 Introduction

With the worldwide construction sector being responsible for a significant amount of the carbon dioxide emissions, the world's energy use and waste production, a shift towards sustainable and renewable construction is crucial. Engineered timber will play an essential role in this transition, as it has evolved to a stage that enables the construction of taller buildings that are commonly built from concrete or steel. The number and height of multi-storey timber buildings has seen significant growth over the past decade. Each year, these boundaries are being pushed further. As of 2020, the tallest pure timber multi-storey apartment building stands at 18 storeys (85 m), while the tallest timber-concrete hybrid reaches 24 storeys (84 m). Buildings up to 10 storeys are now considered midrise. Contemporary multi-storey timber buildings are increasingly seen as a long-term sustainable solution, particularly in urban areas, where they offer a greener alternative to concrete and steel constructions while also improving living quality and fostering healthier environments.

The current design process for taller timber buildings is, in principle, not different to other buildings. Typically, architects create the concept, followed by various engineering disciplines working on their respective areas. Structural engineers are responsible for dimensioning building elements and connections, mechanical engineers design heating, ventilation, and plumbing systems, fire engineers ensure fire safety measures are in place, and acousticians help architects to select the right components to minimize sound transmission. Nevertheless, designing taller buildings made from timber is more demanding than their concrete and steel counterparts. Whereas different designers (architects, structural, fire engineers etc.) of concrete buildings can work almost independently, the design of taller timber buildings should be performed with intensive collaboration among the design team members. Designing multi-storey timber buildings has always involved highly specialized engineering teams with in-depth knowledge of the unique challenges and demands these buildings present.

Despite the construction of several midrise and some taller timber buildings, the understanding of how to design such structures remains far behind that of concrete and steel buildings. Taller timber buildings present additional challenges that are yet to be fully addressed. Over the past 15 years, research in timber engineering has intensified, and this knowledge is gradually being integrated into design codes and handbooks. North American codes are being updated more rapidly than European ones, with the 2021 US International Building Code permitting timber buildings up to 18 storeys tall. In contrast, European building directives vary by country, and the revised Eurocode for general structural design is not expected to be available before the end of 2025. Despite these efforts, most global research on multi-storey timber buildings has focused on specific aspects such as connections, vibrations, acoustics, fire safety, and durability, rather than considering the design in a holistic manner. However, an integrated approach is crucial for designing taller timber buildings, and is the primary challenge addressed by this COST Action.

2 Aims and Objectives

COST Action CA20139 – Holistic Design of Taller Timber Buildings (HELEN) is a research network that started on 12/10/2021 and will run until 11/10/2025 [2] and is funded by the European Cooperation in Science and Technology (COST). The main goal of HELEN is to support the transformation of building construction research from isolated topics to a more integrated, interdisciplinary approach. This shift is essential for the safe design, construction, maintenance, and recycling of taller timber buildings.

A key challenge in the design of timber buildings lies in the inherent design complexity of timber buildings due to the material's nature and properties. Without the collaboration of experts from different fields, significant conflicts can arise, affecting both the load-bearing capacity and serviceability of the building. An example is the acoustic insulation methods used in timber buildings that often contradict the design strategies against wind or earthquake loads. Whereas acoustic requirements might result in decoupling building elements in order to reduce the noise transfer, wind and seismic forces demand elements to be tightly connected to resist lateral forces.

HELEN aims to promote international collaboration and interest in developing a shared understanding and common guidelines for the holistic design of taller timber buildings. This is achieved through the exchange of technical and scientific expertise from the diverse research profiles within the network, as well as leveraging their research facilities. Cooperation within this network enables coordinated research efforts to accomplish the objectives (Fig. 1).

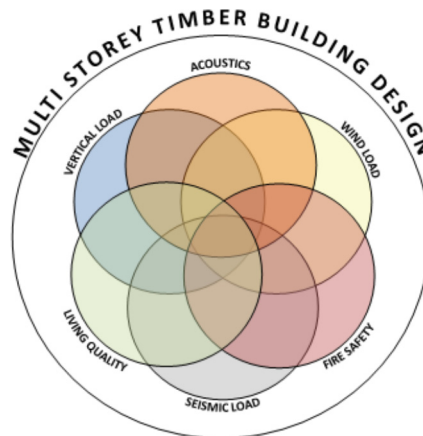


Fig. 1 Illustration of the interaction of different building design fields and their inherent collisions [1, 2]

3 Working Groups

HELEN is structured in four working groups (WGs). It was acknowledged early on that overlap existed between the WGs due to the multifaceted, timely and challenging research questions to be addressed and collaboration between WGs was also prioritised (see also [1, 3]).

3.1 WG 1 – Robust Design for Adoption, Reuse and Repair

The Working Group 1 (WG1) deals with aspects related to robustness, adaptability, design for disassembly and reuse, and repairability. Given the broad range and interdisciplinary nature of the topics assigned to WG1, it has members with different backgrounds in both engineering and architecture, as well as in research and industry. After the first years, WG1 has been reorganised into two sub-groups (SG), one dealing with robustness and another dealing with design for extended service life.

The SG “Robustness” deals with the topics of resistance to disproportionate damages, including structural and non-structural robustness and resistance to progressive collapse. The SG has worked on developing a framework for the design of timber buildings against disproportionate collapse, which includes identifying all stakeholders and their interests and responsibilities. Case studies of structural design for increased robustness have been analysed and the most important strategies have been identified. The ongoing research projects and exchanges with structural engineers involved in designing timber buildings against progressive collapses have allowed the SG to identify some key issues: guidance to adjust the necessary measures to increase resistance to disproportionate collapse to the risk category of the building; simplified structural analysis models for alternative load-paths (ALPs), e.g., with dynamic amplification factors; behaviour of connections under large deformations, e.g. catenary action; connections as fuse elements in segmentation strategies, which has similarities with capacity design for earthquake resistance; and “power storeys” for vertical segmentation in taller timber buildings.

The SG “Design for extended service” results from the merger of previous SGs “Adaptability”, “Design for disassembly and re-use” and it dealt with topics related to changes in the functional use of buildings, how the design of tall timber buildings can account for adaptability-related requirements, and their impact on other requirements (e.g., robustness, acoustics, durability). The SG has focused on the evaluation of the demountability of timber connections and on identifying solutions that facilitate disassembly of timber buildings. Design for disassembly is not only important for increasing the reuse and recyclability potential, but primarily for repairs in case of local damage. Damages and repair of modern timber buildings have also been addressed, since it is a critical aspect for insurance purposes.

3.2 WG 2 – Deformation and Vibration

WG2 focused on aspects and design issues primarily related to deformations and vibrations, in the framework of taller timber structures. WG2 took a primary advantage from the interaction of scientist and professional engineers (i.e., representative of research

institutions, universities and industrial partners) that have different experiences and technical skills on these themes. To optimize the impact of networking activities, the internal organization of WG2 was established into two SGs: “Deformations” and “Vibrations”.

Talking about the SG “deformations” in tall timber structures, the attention was spent on a multitude of aspects and issues that have major effects in research and industrial applications, and are often fairly addressed by existing standards and regulations. As a matter of fact, deformations in timber structures are primarily associated to joints and connections. There are however no doubts about the complexity and variability of possible technological solutions in the field of joints and connections for timber structures. Also, the type of load, the boundary conditions and the assessment of their mechanical performance suggests the need of a robust background in support of optimal and safe mechanical design of these systems. The SG “vibrations” is implicitly related to deformations and corresponding gaps in engineering knowledge / design tasks. Starting from the assumption that vibration itself is a rather general definition and can cover a multitude of practical / technical aspects in the framework of timber structures, WG2 members actively contributed to the elaboration of a State-of-the-Art document in which most of engineering terms and problems could be first defined in their context. So far, do we implicitly talk about vibrations in floors or partition walls for timber structures? And which kind of design action should be primarily addressed in terms of vibration serviceability, for the specific solutions in use in tall timber structures? But indeed, how can we monitor and control, or possibly minimize and mitigate the effect of vibrations in typical load-bearing components for tall timber structures? There are no doubts, first of all, about the inter-correlation of vibrations and deformations, which again suggest an intrinsic mutual interaction of load-bearing components for tall timber structures and the final user/the design actions.

In most of WG2 elaborations, one major gap emerged from various sub-tasks, that is the need of standardized operational procedures and guidelines which could be efficiently applied to any type of building component. This general consideration implicitly recalls the complexity of the topics, as they are strictly interconnected to the effects of different design actions (see WG3).

3.3 WG 3 – Accidental Load Situations

WG3 activities were aimed at exploring optimized approaches for the holistic design of taller timber buildings under accidental load situations. Specifically, accidental load scenarios due to earthquake, fire and blast were considered acting either as separate actions (single hazard) or as simultaneous or cumulative events (multi-hazard).

The WG3 was composed of four different SGs, dealing with “seismic”, “fire”, “blast” and “multi-hazard accidental load”. Each subgroup focused on a deep examination of the state-of-the-art for each load situation in order to identify the current limitations that can be met in the design phases of mid-to-high rise timber buildings. Moreover, the potential interactions and collisions among different accidental load scenarios were analysed. A survey was circulated among WG3 members to assess the urgency of filling gaps in knowledge in different design situations as well as evaluating the collisions between seismic and blast, seismic and fire and fire and blast loads.

For seismic load situations, the need of developing innovative high-performance connections can be considered as a priority in the field. Most of proprietary connections are characterized by values of resistance primarily suitable for low-to-midrise buildings but further investigations are still needed to explore the ductility performance and the brittle failure modes of customized anchors (e.g. hold-down) in taller buildings.

Three main research topics were identified as primary to overcome the current limitations in taller timber buildings under fire loads, namely the contribution of timber element to both external and internal fire spread, the structural robustness and the timber's contribution to fire development. Regarding the design for blast loads, research and technological development in the near future should be mainly aimed at investigating the redistribution of internal loads after an element loss and ensuring appropriate redundancy.

The design of timber connections characterized by adequate ductility, the adoption of proper capacity-design approaches and the design of shearwalls for both in-plane (seismic) and out-of-plane (blast) load are example of strong interactions for accidental load design situations involving seismic and blast. Regarding fire and blast, further investigations should be conducted to investigate how the structures behave under fire occurring after blast (fire following blast). The damages of structural components and of the protection elements caused by blast need to be carefully assessed to determine the residual fire resistance of structural components. Similarly, the damages of structural connections and non-structural elements caused by strong earthquakes may significantly influence the capacity of structure under fire load (fire following earthquakes).

Many of these topics have been largely discussed withing WG3 meeting and summarized in some of the chapter of this book with the aim of addressing new research advancements.

3.4 WG 4 – Sustainability and Durability

Timber constructions have gained the (rightful) reputation of being a sustainable building option. On the other hand, they also raise questions regarding their durability. They are more susceptible to damage, either induced by moisture or insects, as well as design mistakes due to their complexity. They are also less forgiving when it comes to construction mistakes, possibly leading to premature failure of their building components. WG4 looks into the issues dealing with taller timber buildings' environmental footprint and their longevity based on the design details, all assessed through the interdisciplinary prism of the consortium's experts. The results of this Working Group's work are in close correlation to WG1, where the initial design assumptions are considered. As in other WGs, work in this group is also country dependent as, apart from local legislation, local climate properties are also of great importance. The possibility to build safely and effectively in areas with heavy rain and snow differs greatly from drier places. This, in turn, influences the construction technologies, which, in turn, affect the building erection price, which makes the timber alternatives to concrete or steel more or less viable. For Europe, which strives for an increase in sustainable timber construction, this opens a discussion on state subsidies for timber construction in order to make them more attractive to investors. The interdisciplinary consortium, also including Life Cycle Costing (LCC)

and Social Life Cycle Assessment (S-LCA) experts, is able to provide answers to such questions. WG4 is mainly divided into two SGs: “Sustainability” and “Durability”.

4 Activities and Outcomes

4.1 Network and Participation

The COST Action HELEN has successfully built a global network of researchers, educators, and practitioners from across Europe and beyond. The network has been continually growing during the last years and has currently more than 410 members from more than 40 countries. The network is well-distributed between the individual working groups, with more than 150 participants in each of them. More than half of the WG members are early-career investigators. About one-third of the WG members are from inclusive target countries, which ensures knowledge distribution among various COST members. HELEN targets a high female participation, and could achieve 31%. In the second year of HELEN, a Diversity, Equity, and Inclusion (DEI) Coordinator was appointed to oversee and implement initiatives aimed at promoting diversity and inclusivity within the COST Action, providing equitable opportunities among members and facilitating an open network of knowledge among a diverse community of researchers, professionals, and manufacturers, that reflects the wide range of skills required for the design, construction, and research of taller timber buildings. To promote collaboration in such a diverse group, a tailored session was designed in the fourth working group meeting in Hasselt, Belgium, in May 2024. The session aimed at understanding different social identities (e.g., age, gender, religion etc.), individual experiences and personality traits, and creating a safe environment for open dialogue and effective communication, fostering productive collaboration within and between working groups. Key aspects highlighted from this session are: (a) members may perceive themselves at a disadvantage, if they come from a country with no forestry industry or without seismic activity, as this can limit their background knowledge in timber engineering and earthquake engineering; (b) there are still steps to be done in the engineering sector towards more inclusive career opportunities, and (c) increased work/study mobility within Europe facilitates broadening horizons with exposure to different cultures and knowledge hubs. The HELEN activities facilitate cross-pollination and knowledge transfer between practitioners and researchers irrespective of their backgrounds, providing equitable opportunities to expand their knowledge (e.g., through Short-Term Scientific Missions), and showcase their work (e.g., through WG meetings), supporting effective collaboration.

4.2 Workshops and Conferences, and Training Schools

HELEN organizes conferences, working group meetings, management committee sessions, and specialized events (see also Fig. 2). These gatherings facilitate the transfer of knowledge from basic research to practical industrial applications, with contributions from industry experts and selected keynote speakers. Face-to-face meetings are considered key elements for engaging more actively those involved in research, education, and practice. Particular focus is placed on Inclusiveness Target Countries (ITCs) and Early Career Investigators (ECIs), with attention to gender equality. Synergies between institutions, as well as collaboration with other COST Actions, help extend the reach.

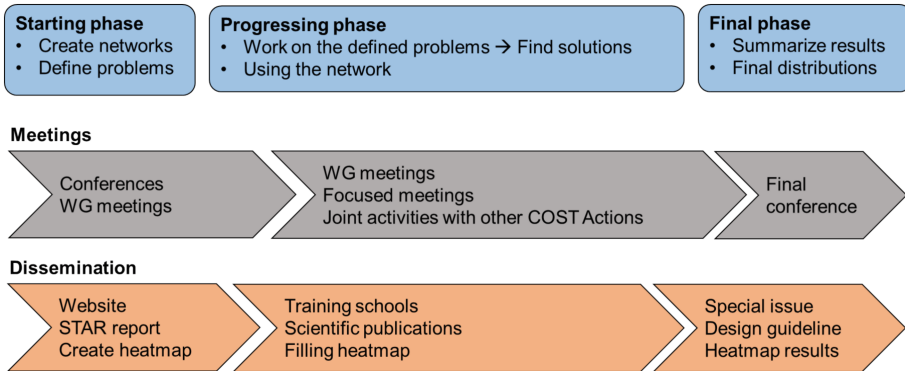


Fig. 2 Overview of aims and activities during the course of the COST Action HELEN

4.3 Training Schools

During the course of HELEN three training schools have been organized on targeted topics related to taller timber buildings. These training schools are carried out by members and for members of the COST Action. Through a holistic concept, it provides learning opportunities for members at all career levels.

The first training school, held in Cortaccia, Italy, covered a broad range of topics around timber connections [4], from the basic theories towards innovation and developments in structural modelling. The lectures included the evolution of timber connections, with emphasis on dowel-type connections in line with the new Eurocode 5. Special connection aspects, such as 3D connectors and reinforcement techniques, were explored, along with the use of Cross-Laminated Timber (CLT) and screws in modern timber construction.

The second 3-day training school, held in Zagreb, Croatia, focused on Sustainability of Taller Timber Buildings focused on pathways to achieve zero-emission buildings, exploring decarbonization strategies across different materials: steel, concrete, and timber. A significant portion was dedicated to sustainability in timber buildings, emphasizing sustainable forest management practices. The training further examined the concept of whole life carbon, introducing participants to the distinction between embodied and operational carbon. Through lectures and hands-on sessions, students gained familiarity with related standards and the practical application of life cycle assessment tools. Special attention was given to the modelling and validation of LCA results, with discussions on sensitivity and uncertainty analysis to strengthen the reliability of environmental performance evaluations.

The third training school, held in Zurich, Switzerland, focused on the topic “Case studies in Taller Timber Buildings” [5]. During the training school, experts from various fields who have been involved in the design of tall timber buildings presented their projects and shared their expertise with the participants.

4.4 Short-Term Scientific Missions and Conference Grants

Short-Term Scientific Missions (STSMs) are a valuable tool for promoting collaboration within HELEN and are especially encouraged for ECIs. These missions foster synergies between institutions, accelerate student learning and knowledge transfer, and offer both academia and industry access to emerging talent and fresh perspectives. So far the Action supported 41 STSMs. Documentation from these missions is available on the HELEN website, and all STSM reports will be compiled and published in a dedicated “Book of STSMs”. This publication will provide an overview of each mobility, including the problem statement, a concise summary of the research activity, and details about the grantee and host institution. The submission, evaluation, and approval process for STSM proposals followed DEI principles and considered ITC, ECI, and gender balance. The outcomes of STSMs are regularly presented and discussed in plenary sessions during workshops. In total, researchers from 20 different countries participated, either as grantees who travelled abroad or as hosts who welcomed visiting scholars. This wide geographical distribution reflects the strong collaborative network fostered within the Action. Furthermore, HELEN has funded so far 6 researchers from ITC to participate in international conferences to present their research results.

4.5 Dissemination

HELEN provides a network framework for individual researchers, which has resulted in several national and international research proposals and research initiatives. Beside individual contributions and initiatives three joint contributions have been realised or are currently under development.

The key achievement of the first year was the creation of the state-of-the-art report titled “Holistic Design of Taller Timber Buildings (HELEN)” [6–9]. This report explores various aspects of the subject, including both the drivers and barriers. It is available on the HELEN website, where it can be downloaded as a complete document or in four separate sections: (1) Design for robustness, adaptability, disassembly, reuse, and reparability of taller timber buildings; (2) Design of taller timber buildings to prevent deformations and vibrations; (3) Design of taller timber buildings to withstand accidental loads; (4) Sustainability and durability of taller timber buildings.

Furthermore, HELEN published a special issue in the journal *Wood Material Science and Engineering* [10]. The special issue includes a variety of research topics that have been carried out during the Action: The topics covered in the special issue are related to timber connections, timber-concrete composites, reinforced timber elements, fire safety, and durability. Particular attention has been given to the reuse of structural timber as well as the potential of disassembling wood construction.

The final book publication of the COST Action HELEN, which you are currently reading, provides in-depth knowledge and insights into the complexities of the designing, planning, assessing and construction of multi-storey timber buildings. The intrinsic need for a holistic and interdisciplinary approach in these activities is highlighted. Buildings, by nature, are complex systems that function optimally when all their subsystems, with their specific roles and functions, operate in harmony. This is particularly relevant for taller timber buildings, which introduce a layer of complexity beyond their counterparts in conventional construction materials such as concrete, steel, or masonry.

5 Heatmap

The HELEN COST Action aims to support a paradigm of building construction research, shifting R&D from isolated topics to an integrated interdisciplinary approach, which is critically necessary to safely design and build as well as correctly maintain and recycle taller timber buildings. In order to achieve this aim, potential conflicts between the different areas of expertise need to be identified. Analysis of such data are assumed to be used to direct policy and shape research directions.

Identifying and addressing potential design conflicts, is the cornerstone to effectively contribute to improved and safer timber buildings and, hence, transition to a decarbonised built environment. During the MC meeting in 2020, a list of topics with potential conflicts was drafted and further developed in the subsequent meetings. Eight main areas, each with several sub-categories, resulting in a total number of 42 categories, have been identified. A compilation of the criteria is presented in Table 1. Along these criteria and topics, experts from the COST Action have identified and commented on the different conflict risks throughout the duration of the action.

From the responses, possible conflicts can be mapped and visualised. The results are illustrated in Fig. 3, where the number on both axis represents the conflict categories as given in Table 1 and the colour represents the “average conflict” from the participants who filled out the specific field, with ‘3’ representing the highest degree of conflict. It can be seen that for the construction and the use phases significantly higher conflicts were identified.

The following 10 categories are those with the highest number of identified conflicts (all of them had 15 or more conflicts): Timber structures, Timber connections, Fire behaviour of timber, Seismic response, Wind response, Maintenance, Repair, Fire spread modelling, Moisture, Architectural design. The category Timber Structures may have been interpreted too broadly (akin to Timber Engineering) and thus showed conflicts across nearly all other categories. The remaining conflict areas are explored in more detail below. From these matrices, the conflict of different topics in the different processes during the entire lifetime of taller timber buildings from design, construction, use, to recycling can be identified.

For connections, challenges are identified for all stages of the life cycle of the building, but particularly regarding waste management (#33). Proper detailing is important to ensure maintainability but this can be compromised during construction due to issues like moisture ingress. Training and education is needed in order to impact and enhance the quality of timber structures for their entire lifetime.

Both the fire behaviour and the fire spread modelling are considered to be in large conflict with architectural design (#23–27). Experts also noted that certain materials used to improve sound and acoustic performance often perform poorly in fire scenarios.

In terms of seismic and wind response, conflicts were observed with acoustic performance (#18) and floor vibrations (#9). A key challenge arises from the need to increase the building’s mass to reduce wind response. This, however, leads to higher inertial loads during seismic events.

During the construction and use phases, notable tensions exist between structural reliability (#7) and robustness (#8) on one hand, and maintenance (#10) and repair (#12)

Table 1 Summary of the conflicts categories

Timber engineering	
1. Timber structures	8. Robustness
2. Timber connections	9. Floor vibration
3. Fire behaviour of timber	10. Maintenance
4. Environmental influences	11. Repair
5. Seismic response	12. Monitoring
6. Wind response	13. Disassembly
7. Structural reliability	14. Duration of load
Computational modelling	
15. Fire spread modelling	17. General finite element modelling
16. Seismic modelling	
Building physics	
18. Acoustics	21. Thermal behaviour
19. Volatile organic compounds	22. Moisture
20. Indoor air quality	
Architecture	
23. Architectural design	26. Urban planning
24. Room design	27. Roofs
25. Facades	
Construction management	
28. Factory management	31. Industrialisation
29. Construction site management	32. Prefabrication
30. Logistics	33. Waste management
Material science	
34. Material production (EWP)	36. Coatings
35. Adhesive	37. Wood modification
Human health	
38. Restorative design	39. Ergonomics
LCA	
40. Life cycle analysis	42. Social life cycle analysis
41. Life cycle cost	

on the other hand. Currently, there is a lack of clear guidance on how robustness relates to reuse and recycling.

Maintenance and repair are especially critical in the construction and operational phases, yet they face challenges related to computational modelling (#15–17) and architecture (#23–27). Experts emphasize the need to first develop effective repair strategies for timber buildings to enable future reuse and recycling.

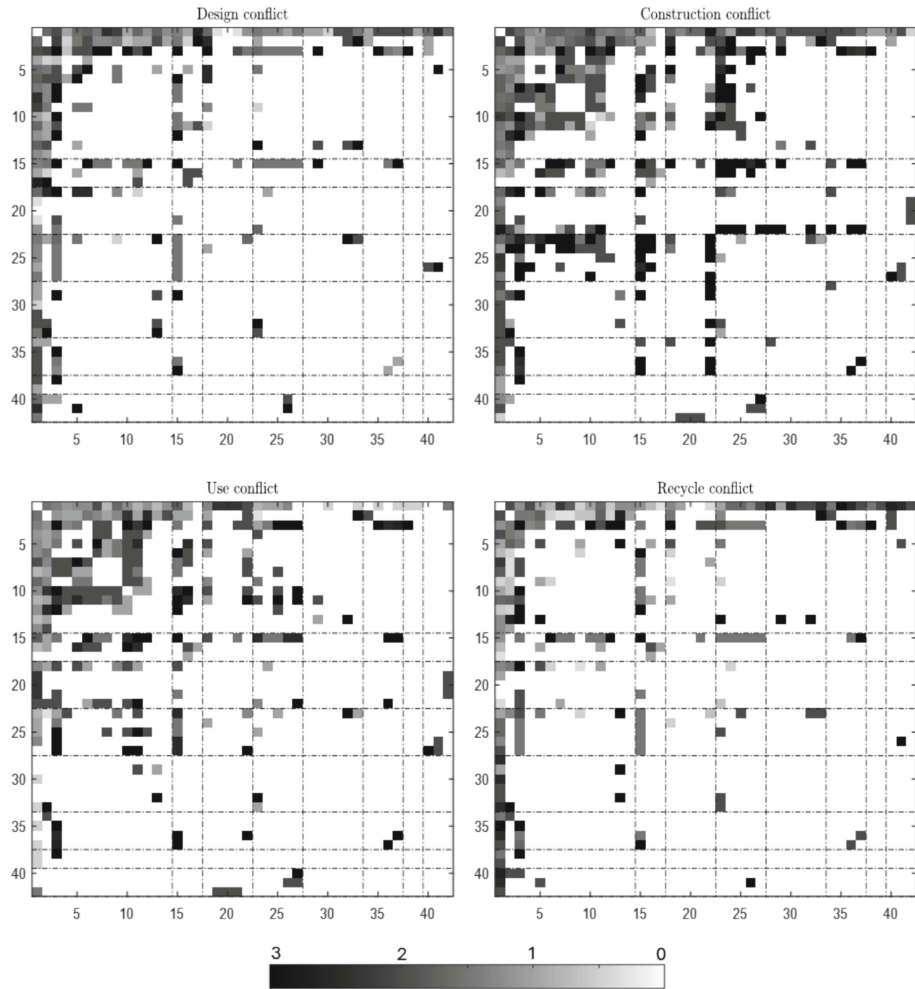


Fig. 3 Identified collision for different construction stages depending on the conflict categories. The colour represents the “average conflict” from the participants who filled out the specific field.

Finally, in timber construction, architectural design must not be viewed solely as an aesthetic discipline but rather as a performance-oriented tool, that takes account of the unique demands and opportunities of the material.

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For further information please consult also the COST website <https://www.cost.eu/actions/CA20139/> and the Actions website: <https://cahelen.eu/>. The authors thank all members of the COST Action CA20139 HELEN, for the discussions, presentations, and contributions. Special thanks also go to Martina Sciomenta and Shady Attia.

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