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Advancing Timber for the Future Built Environment

TIMBER BASEMENTS – FROM CHALLENGE TO TECHNOLOGY AND PROOFED SOLUTIONS

Bettina Franke[1], Stefan Zöllig[2], Christoph Renfer[3]

ABSTRACT: Due to the need of more sustainable solutions in the construction sector, even timber construction should start with a timber basement! Concrete basements are standard today - this should change for sustainable buildings. Timber basements are more environmentally friendly and can be installed in much less time. However, we need a proven concept, proper waterproofing and durable long-term performance. New parameters must be determined, especially for structural aspects, because of the light weight. For the long-term behaviour, various building physics estimates are made. The results were validated by experimental test series, a monitoring campaign and a pilot project in a multi apartment building. The results and build projects confirm that timber basements are feasible and reliable.

KEYWORDS: timber, basement, new technology, building physics, statical concept, sustainable construction

1 INTRODUCTION

The construction sector is a significant contributor to global CO_2 emissions, accounting for approximately 40 % of the global world emissions, [1]. In response to the urgent need for sustainable and environmentally friendly construction practices, innovative solutions are being explored to reduce the carbon footprint of buildings. One such solution is the incorporation of timber basements in construction projects. Timber, as a building material, offers the dual benefits of sustainability and carbon sequestration. In contrast to conventional concrete basements, timber basements emit less carbon and have the capacity to store carbon throughout their whole lifespan, thereby contributing to the reduction of CO_2 levels in the atmosphere.

The use of timber in basements is not only a novel approach but also aligns with the broader goals of sustainable construction by minimising environmental impact and promoting the use of renewable resources. The installation of timber basements can be completed more expeditiously than concrete basements, and their well-designed layered construction enables them to maintain a comfortable indoor climate without the necessity for a heating system. These factors contribute to the attractiveness of timber basements as an alternative to conventional construction methods. However, the successful implementation of timber basements requires in depth validation, including the development of proof-of-concept designs, effective sealing methods, and assurance of long-term performance in terms of structural stability and building physics. The proof of timber basements as quality assured, economical and durable timber construction has been provided together with universities and trade associations.

2 STATE OF ART OF TIMBER BASEMENTS

2.1 HISTORY AND NOWADAYS

Pile foundations from wood were used extensively from antiquity until the 19th century in Europe and other regions worldwide. However, with the invention of steel during the Industrial Age and the subsequent widespread use of concrete, a technically and economically viable solution with a low carbon footprint gradually disappeared, [5]. Many historic urban districts, particularly in Northern Europe, such as Trondheim and Bergen in Norway, Stockholm in Sweden, Hamburg in Germany, St. Petersburg in Russia, or Amsterdam in Netherlands, were constructed on timber piles. In the Netherlands, timber pile foundations became a standard construction practice by the 15th century, and their use continued for smaller structures. Venice, a city built on a mosaic of islands and islets with marshy ground, has a dense forest of timber piles, ranging between two to four metres in length, that still underpin its bridges, palaces, and plazas,

[1] Bettina Franke, Timbagroup Holding AG, Thun, Switzerland, bettina.franke@timbatec.ch, ORCID 0000-0002-8087-9347

[2] Stefan Zöllig, Scrimber CSC AG, Thun, Switzerland, stefan.zoellig@scrimber.com

[3] Christoph Renfer, Bern University of Applied Sciences, Biel/Bienne, Switzerland, christoph.renfer@bfh.ch

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[5]. The timber was sourced from forests extending as far as the Balkans, including oak, larch, alder, and elm, and was combined with thick planking to distribute the loads of the palaces onto the piles.

In the contemporary context, there is a resurgence of interest in the construction of buildings on timber pile foundations. Modern engineering advancements and sustainability considerations have led to a reassessment of this historical technique, recognizing its durability, adaptability to challenging soil conditions, and environmental benefits, [5]. In Geneva: in 2016, the Opera des Nations, a temporary structure, served as the venue for the Grand Théâtre de Genève's performances for a period of three years, while it underwent renovations, [6]. The 2760 m^2 wooden floor was constructed using 300 spruce piles sourced from the cantonal forests. These piles, with a minimum diameter of 260 mm and a length of 5.30 meters, had undergone a process of debarking and bevelling at the ends, and were driven into a soil with low mechanical properties. The piles were connected to a grid of beams on which a distribution board made of glulam panels rested, [5], [6].

Two five-storey buildings were also built in Geneva next to the Opera des Nations [6]. They were only meant to be used for a short time. Acau architecture used wood to meet the challenge of building in a way that could be taken apart, moved, and used again. In the basement, 128 larch beams, each at least 260 mm wide and 5.30 metres long, were cut from the trees and driven into the ground. There is a technical shaft made of glulam boards under each building, carefully protected with an FPO membrane. The two buildings are supported on a grid made of spruce, which distributes the loads onto each of the piles and can take up to 300 kN of pressure. As there are no reinforced concrete foundations, restoring the site after deconstructing is simple and cost-effective, [5], [7].

Figure 1. The Opera des Nations in Geneva was built on spruce piles. It was a temporary structure. Source [6]

Figure 2. Opera des Nations Geneva, installing the spruce piles, Source [6]

In North America, the rules for building wooden foundations are set by the American Association of Wood Conservation Specialists, which has the most important design information. Now, studies are focusing on mass timber foundations for houses and small buildings. Two approaches are presented in [8]: One uses wood that has been treated with chemicals to protect it, like Nailed laminated timber NLT, Dowel laminated timber DLT, Glued laminated timber GLT and Mass ply panel MPP and the other uses untreated fully protected (tanked) mass timber foundation systems like Cross laminated timber CLT and GLT.

2.2 TIMBER BASEMENTS AS MONOCOQUE SOLUTION

In recent constructions, sealed timber basements are being used as a monocoque solution, offering a sustainable alternative to conventional concrete basements. The concept of environmentally sustainable housing, extending even to the basement level, was pioneered in Germany around the year 2000. This innovation has evolved since then, with Switzerland's Timbase Schweiz AG advancing the technology through continuous improvements and the implementation of monitoring systems to ensure quality and durability. The development of these technologies was significantly furthered by a research project. The construction of a timber basement requires careful consideration of structural engineering principles and building physics. From a load-bearing perspective, wood is fully capable of safely transferring structural

Figure 3. A five-storey apartment building (left) has been built on wooden piles and the construction site of the building (right) [7]

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loads to the ground through a full-surface floor slab. Appropriate design and engineering are essential to ensure the stability, durability and resistance of timber basements to external forces, making them a viable and sustainable alternative in modern construction.

The second point pertains to the assurance of timber durability. It is imperative, that wood with surfaces in contact with the ground, be permanently protected against moisture impact, [11]. In this instance, a black seal with an EPDM film is used on the outside against the ground. There is no surface treatment on the inside, as the wood remains open to diffusion. An outside thermal insulation layer is used to ensure the moisture gradient due to the temperature differences between inside and outside. The thermal insulation properties of the component structure and the moisture limits of the individual component layers were calculated and defined according to the standards. As demonstrated in Figure 4 and Figure 5, the solutions for a foundation comprise a slab-on-grade or a timber basement, incorporating a single storey. The slab-on-grade is the perfect solution for shallow foundations in houses, garages or extensions. The timber basement solution provides an entire floor plan with a floor slab and walls. With sufficiently insulated timber basements, you can achieve high quality living spaces without requiring any additional effort.

3 STATICAL CONCEPT

The load-bearing system of timber basements relies on biaxially load-bearing wall and floor diaphragms, ensuring an efficient transfer of vertical and horizontal forces. The TS3 technology is used for rigid connections within the panels and between the floor and wall elements, [4]. This innovative method enables the creation of moment-resistant joints through the application of a casting resin, which fully cures within a few days, reaching its ultimate load-bearing capacity.

It is important to note that timber has a considerably lower density than concrete. This is a pivotal factor in guaranteeing the stability of a foundation in the ground. Friction is the key to keeping the structure stable when it is under single-side pressure from the earth. Laboratory and on-site experiments have shown that timber bases are stable. The sliding friction required for horizontal load transfer has been determined through experimental analysis of specific friction coefficients, [10]. The integration of various layered structures allows for optimized performance in mitigating lateral displacement. The established coefficients of friction have enabled the design phase to accurately predict and mitigate potential movements due to earth pressure, ensuring a stable and durable timber basement structure.

4 BUILDING PHYSICS

Properly protected timber can remain durable forever. It is well documented that the maintenance of a moisture content in wood that is below the fibre saturation point results in a significant reduction in the risk of fungal decay. The resistance of technical dried wood to insect infestation is documented too. However, timber that is in direct contact with the ground is not inherently protected over time unless it is adequately protected or sealed in the ground as specified in DIN 68800. This emphasises the importance of effective moisture management and protective strategies to ensure the longevity of timber basement structures.

In the context of timber basements, the lessons learned from decades of experience in waterproofing technologies for flat roofs and landfill sites can be applied to en-

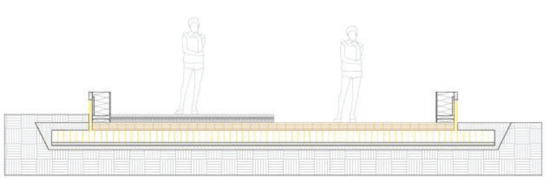

Figure 4. Slab-on-grade, Source: www.timbase.com

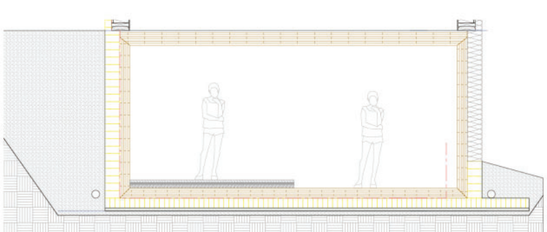

Figure 5. Timber basement, Source: www.timbase.com

Figure 6. Experimental test set-up for the friction test on a laboratory scale. Source: [10]

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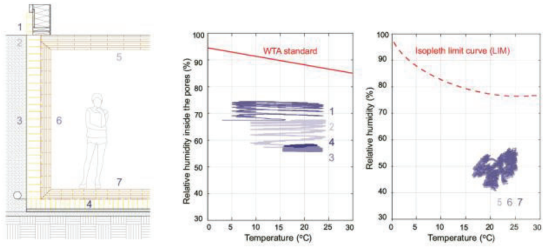

Figure 7. Simulating the possibility of moisture build-up in wood by comparing it to standard and WTA criteria, according to [2][3][10].

hance durability. The robustness of the moisture protection of the component structure was evaluated. To comply with building physics requirements and ensure durability according to DIN 4108-2 and DIN 4108-3 it is recommended to apply a layer of sealant and insulation.

Therefore, numerical programs for one- and two-dimensional simulations of the coupled heat and moisture flows are set up in WUFI [2]. The simulation of diverse climate scenarios has been successfully executed, and the outcomes are being systematically evaluated in accordance with the WTA 6-8-2016 guidelines and the German standard DIN 4108-2 and DIN 4108-3, as illustrated in Figure 7. The findings confirm the short-term drying behaviour and indicate, that there is no risk to the wood for the long-term prediction (>50 years), as evidenced by a comparison to the WTA 6-8-2016 guideline, DIN 4108-2 and DIN 4108-3 criteria.

5 MONITORING

For a robust timber basement, a comprehensive full-surface monitoring system should be installed on the exterior of the timber structure facing soil. This advanced system constantly checks for moisture over the complete area of the ground plate and pinpoints its location by measuring the voltage at several points (marked by blue crosshairs) within a grid of special cables embedded in a geomembrane, as shown in Figure 8 top, [13]. This monitoring system is highly effective in detecting even the smallest amounts of water, providing early warning before significant problems arise. This monitoring system provides a reliable way for building owners and the construction company to check the quality of the timber basement construction. The system also allows for precise tracking of the moisture movement over time, as shown in Figure 8 bottom. In this measurement protocol, there are two events that occurred due to water leakage from the ventilation system and the washing machine. The moisture content has risen quickly, but a good drying could be achieved through natural ventilation. No special measures have been taken.

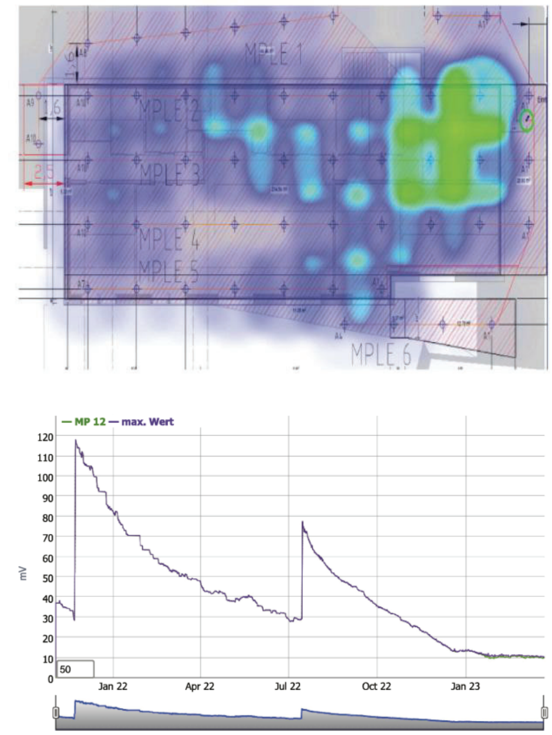

Figure 8. Due to a water leakage from the ventilation system and the washing machine, the moisture increased rapidly and then dried out again. Source: www.timbase.com

6 PROJECTS RELIAZED

6.1 MULTI FAMILY APARTMENT HOUSE THUN

In Thun, Switzerland, a first apartment building with a basement made of timber was built, see Figure 9. The building serves also as research object for validation. No concrete or steel was used as construction material in the entire house with 5 residential units - not even in the full basement storey. The construction of the basement is a solid wooden structure made of cross-laminated timber panels (CLT). The CLT panels lie on a 160 mm thick insulation board. Black insulation encases the wood for moisture protection. The interior walls are non-load bearing; columns and the exterior walls support the top CLT floor slab. Thus, the basement is very flexible in use and can be used in many ways, thanks to the pleasant indoor climate due to the visible and tangible wood. The exterior walls in the timber frame construction are optimally insulated as innovative approaches to building physics, which makes it possible to dispense heating as. Therefore, there is no conventional heating system in this building.

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Figure 9. Appertement building in Thun: outside view, visualisation of column and panel construction with TS3, timber basement under construction and interior view of the finished basement (clockwise). Source: www.timbase.com

6.2 LIVING HOUSES CANADA – EXAMPLE FOR SLAB-ON GRAD

In the Canadian province of British Columbia, three residential buildings with a flat-foundation timber floor slab have been constructed. The objective of the project is to provide affordable and sustainable housing on First Nations reserves in Canada. The timber basement is a solution for cost-effective, environmentally friendly and sustainable lifestyle homes for the future.

Timber basement plates represent a perfect solution for modular construction. Following the rapid preparation of the foundations, and the subsequent minimal curing times, these structural elements facilitate the swift and effective erection of entire residential structures, as shown in Figure 11. The construction process, using standard timber and dry substrate techniques, enables efficient progress in the construction of residential structures. This method represents a substantial enhancement in the efficiency of space construction.

Figure 11. Modular house constructed on a timber slab-on-grade foundation in Canada. Source: www.timbase.com

7 ADVANTAGES AND CARBON SINK

Timber basements can be built much faster than conventional concrete basements. A comparison of the Thun project reveals that installing a basement for a six-apartment block took only six days. In comparison, installing a concrete basement would take approximately 45 days, not including the curing time of the concrete, as shown in Figure 10. The timber-constructed basement allows for a significantly shorter construction time, also because the subsequent works can start as soon as the timber basement is finished, with no delays and significant advantages in terms of assembly.

The timber basement is also impressive in terms of cost: thanks to the fast and dry timber construction method, a high standard of finish is achieved after just a few days. The cost benefits can be attributed to the natural timber surfaces and finished floor structure. Concrete requires a curing and drying period before the floor or wall structure, or ceiling finishes can be commenced. Overall, the construction time is much shorter, which means the building can be occupied earlier.

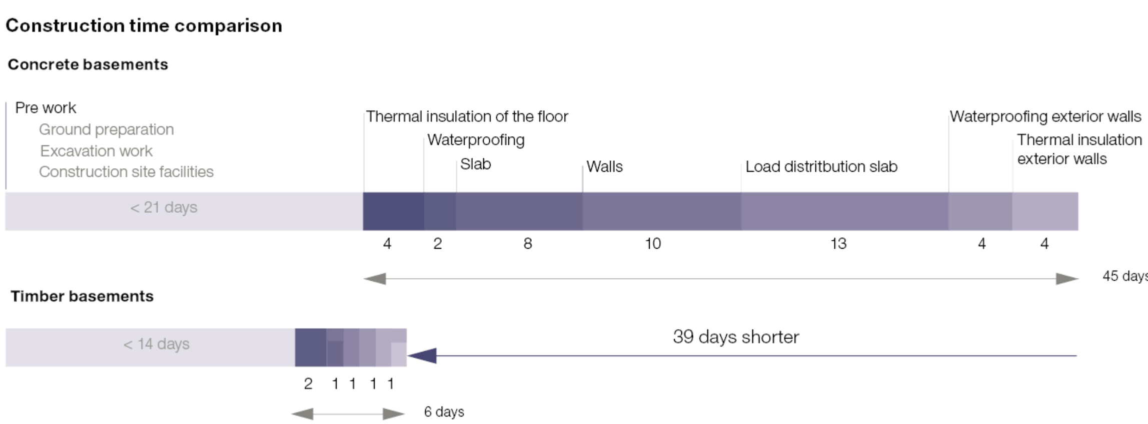

Figure 10. Study for the time efficiency of timber basement construction in comparison to conventional concrete basements. Source: www.timbase.com

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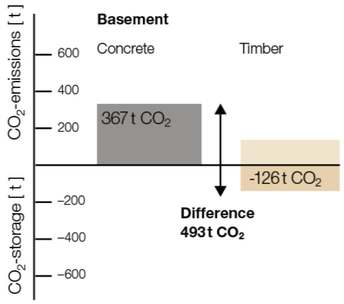

Figure 12. Comparison of carbon emissions and carbon sink of a concrete or timber basement, Source: www.timbase.com

In addition, wood is very efficient from an ecological point of view. To reach climate neutrality by 2050, we must cease building with steel and concrete and instead invest in timber buildings. A total of 222 tonnes of CO_2 is stored in the apartment building in Thun – 126 tonnes of it are stored in the basement alone. 367 tonnes of CO_2 emissions would have been generated by the manufacture of these materials alone if the basement had been built in concrete. There is a benefit of 493 tonnes of CO_2, compare Figure 12.

8 CONCLUSIONS AND VIEW

Timber basements represent an innovative and effective solution for sustainable construction needs. Their viability and performance have been demonstrated through the pilot project in Thun. Supported by researchers from Bern University of Applied Sciences, the apartment house is currently investigating long-term quality requirements and structural aspects of timber basements. In addition, comprehensive experimental test series, and detailed numerical simulations focusing on building physics are carried out. These studies collectively confirm that timber basements are not only feasible but also reliable, offering a sustainable and efficient alternative to traditional basement construction methods.

Building a timber basement is an asset for the future – it makes a significant contribution to the next generation. Choosing a timber basement is a way to take responsibility and promote sustainable building practices. The overall goal of this work was to demonstrate the reliable performance and thus ensure that wood is a viable and sustainable material for underground applications.

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