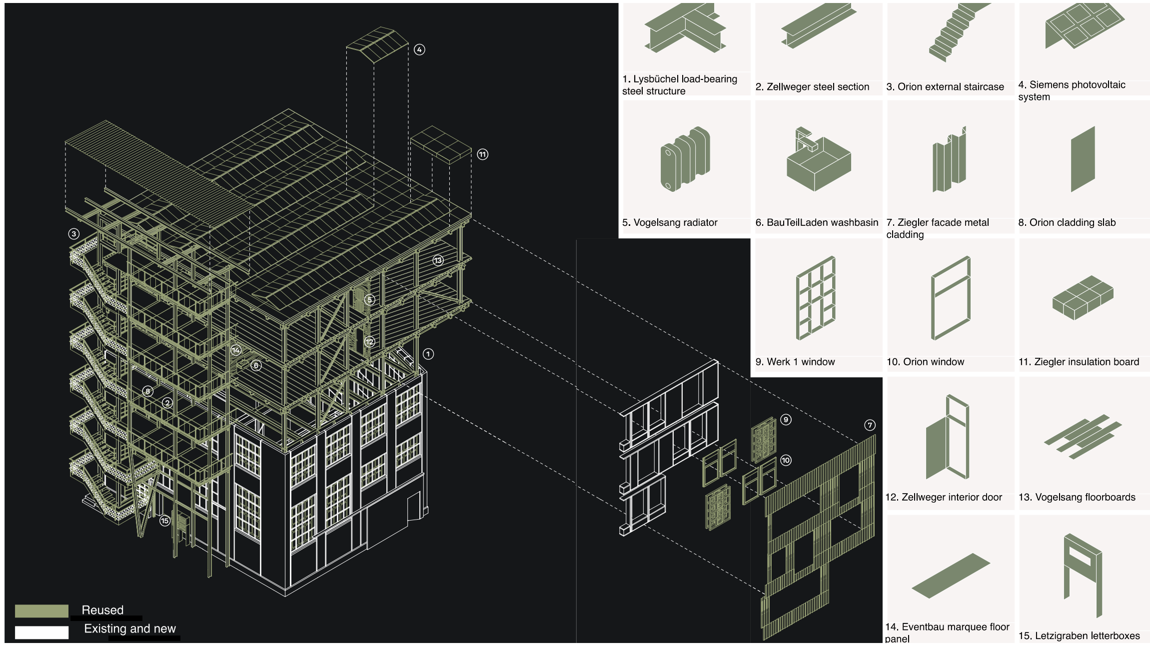
SINO-SWISS ZERO EMISSION BUILDING PROJECT

让我们共同打造气候中和的未来
Building a climate-neutral future together

Circular construction – Swiss Experiences



中华人民共和国
住房和城乡建设部

IBE环能科技

中国建筑节能协会

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

intep

skat_ Swiss Resource Centre and Consultancies for Development

IMPRINT

Editiorial Information

August 2024, Version 1.0

Commissioned by

SDC / Mohurd

Lead Author

Team intep-skat

- Roland Stulz
- Dr. Feng Lu-Pagenkopf
- Wesely Wojtas
- Jilong Zhu
- Fabienne Hugi
- Xinyu Wang

Team IKE and IBP ZHAW

- Prof. Dr. Andri Gerber
- Patric Fischli-Boson
- Guido Brandi
- Adrian Kiesel
- Yasaman Yavaribajestani

Team UAD

- Yin Li

Co Authors

- Team Demo Project Shanghai
- Team Demo Project Shaoxing
- Team Willers
- Team CABR

Many Thanks to the Investor and Planning team of Shanghai and Shaoxing Demo Project of Sino-Swiss ZEB Project to provide the project data to this report.

CONTENT

1. PROJECT BACKGROUND OF SDC ZEB CHINA

1.1 About the Sino-Swiss ZEB Project

In order to jointly address global climate change and to strengthen cooperation between China and Switzerland in the field of emission reduction in the construction industry, the Ministry of Housing and Urban-Rural Development of the People's Republic of China and the Swiss Federal Ministry of Foreign Affairs signed a Memorandum of Understanding (MoU) on 24 November 2020. The Memorandum is about the development of cooperation in the field of building energy efficiency. Within the framework of this MoU, the Swiss Agency for Development Cooperation (SDC) initiated and funded the Sino-Swiss Zero Emission Building Project. The project aims to support China in formulating the technical standard of zero carbon buildings and long-term roadmaps for reducing carbon emissions in the construction industry. Switzerland contributes by sharing know-how and use cases of zero emission building demonstration projects in different climate zones, while carrying out various forms of capacity building activities, so as to ultimately promote the carbon-neutral development of China's construction industry.

1.1.1 Project Purposes

- Upgrading existing building energy efficiency standards to Zero Carbon technical Standards.
- Implementing demo projects in 4 typical climate zones for testing the new ZEB standards and finding optimization potentials.
- ZEB capacity building and knowledge dissemination

1.1.2 Project duration

Phase I: 15. Mar. 2021 – 28.Feb. 2025

Figure 1: The Ambassador of Switzerland to China Bernardino Regazzoni met with Ni Hong, Vice Minister of China's Housing and Urban-Rural Development on 24th Nov. 2020 and signed the agreement , ©Swiss Embassy in Beijing

1.1.3 Project impact on climate protecting

Reduce CO_2 Emission in building sector

1.2 The Role of ZHAW IKE and IBP-team

The Institute for Constructive Design (IKE) and the Institute for the Building Process (IBP) at ZHAW are the leaders of applied research in Switzerland on the topic of circular construction, which specifically includes 1:1 reuse of building components and Design for Disassembly.

The IKE and the IBP see themselves as an interactive hub for research into design and construction topics. They advocate a generalist professional profile for architects and civil engineers.

The two institutes were able to give various practical and direct inputs as the various Demo Projects were presented. Suggestions ranged from the reuse of specific interior partitions, the use of prefabricated wood elements with thatch insulation for the façade, or the use of steel structures with demountable structural nodes using Design for Disassembly principles.

In addition, specifically for the China trip and the meeting with the Demo Projects teams, IKE developed a board game, following the studies of Serious games, in order to be able to explain the reuse of components and the paradigm shift that takes place in the design and planning of a project with reused elements. The goal will be to continue to use the game for future training in Chinese universities.

2. CIRCULAR CONSTRUCTION

2.1 Introduction and Definition

Circular construction means giving new usage cycles to the fabric of buildings, thereby allowing their actual lifespan to be exploited to the full. In the model shown here, the smaller the cycles become, the lower the loss of environmental, economic, and cultural assets, and the more circularity and architecture become intertwined.

Recycling building waste into new material such as recycled concrete or steel is primarily a question of processing that has only peripheral relevance to design and planning and still calls for a lot of energy and sand (in the case of concrete). By contrast, the reuse and reusability of entire building components, like the repair, repurposing, and extension of existing buildings and parts of buildings, are genuine architectural challenges in which every aspect of sustainability needs to be considered. In our research, we use the umbrella terms 'preservation', 'reuse', and 'recycling' for those three cycles, though each of these terms can be differentiated depending on their different contexts (i.e. regarding environmental impact, economics, cultural significance, etc.).

The diagram in Figure 1. shows how the various phases of reuse (R1, R2, R3, R4, R5) fit into this life cycle model, which is based on the SN EN 15804+A1/SIA 490.052+A1 norms and underpins the environmental footprint assessment of Swiss buildings.

- Preservation ('Erhalt'): the in situ retention of the fabric of buildings or parts of buildings in order to extend their usage.
- Reuse ('Wiederverwendung'): the reutilization of building components irrespective of any divergence in quality standards between their original and new usage contexts (these may be dismantled and reclaimed or surplus items, processed or unprocessed, and either repurposed or used as per their original function).
- Recycling ('Verwertung'): the conversion of building material into new materials or products via processes in which their original form is broken down (such as shredding or melting).

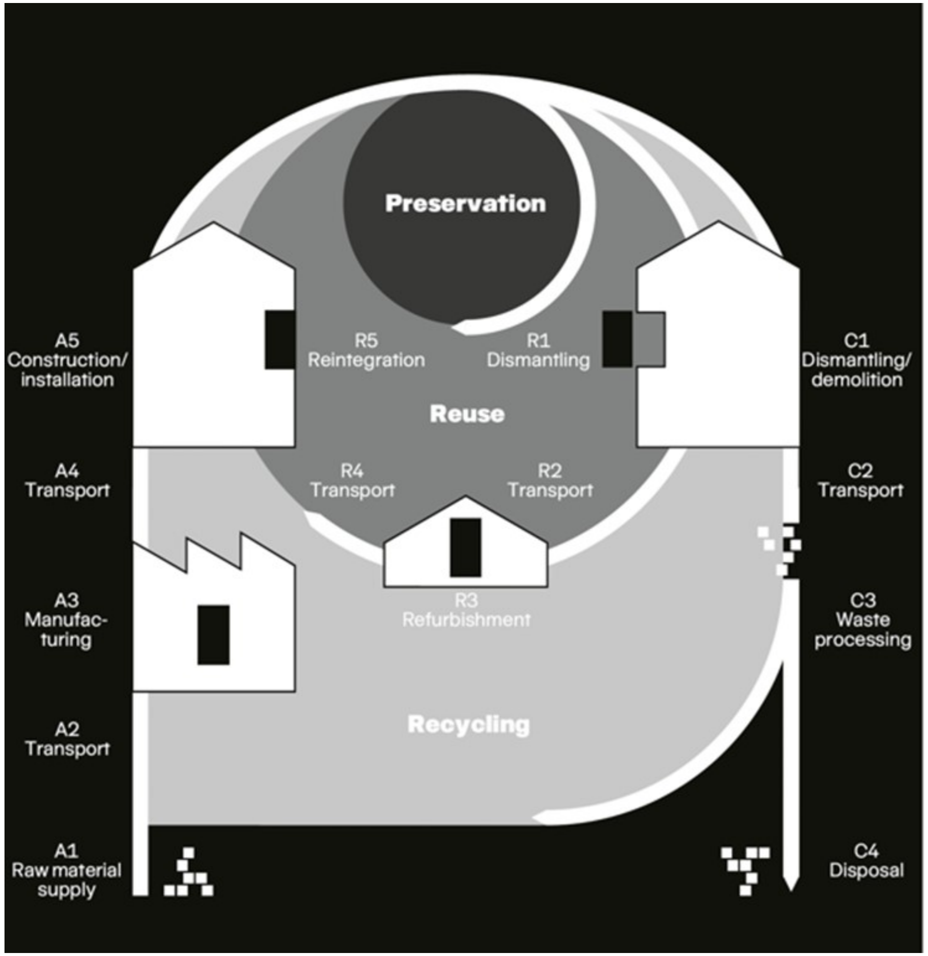


Figure 2: DIAGRAM OF THE LIFE CYCLE MODEL. ©ZHAW

Considering all the phases of linear process of construction (from A1 to C4), the circular practice of Reuse is the most effective and immediate shortcut to avoid the production of greenhouse emissions. With our current standards, the reuse of building components could let us save 90% of grey energy emissions. A striking result that has no equal in every other process.

2.2 Five possible approaches to circularity

There are various approaches to circularity in architecture: these include using reclaimed products wherever possible, focusing on natural and local raw materials, tailoring construction to the life cycles of components, and ensuring component assemblies are reversible.

For now, circular construction is an idea that exists only as the inverse of linear construction, a process in which everything used in construction subsequently goes to waste. If we exclude operational energy use (which has, in recent years, been actively tackled and reduced and whose impact also depends on the primary energy source), then the ultimate goal of genuinely circular architecture would be a process in which no waste is ever generated and therefore all embodied energy is conserved. It goes without saying that achieving this goal will be a long and difficult process. But it should also be said that, as we move away from linearity towards circularity, there are numerous intermediate steps we can implement and design approaches we can realize.

Drawing on five different reference projects, this report presents five possible strategies that can help us to achieve circularity in architecture. In some cases, these strategies are complementary; in others, they are mutually incompatible.
Architecture, after all, is not simply a case of implementing lists of proposals. The approaches discussed here are all shaped by their relationship with modern architecture, which, in conjunction with the development of reinforced concrete in the late 19th century, continues to define the worlds of architecture and construction to this day. Circular architecture needs to understand the modernist movement—but also to move beyond it: in doing so, it should not, however, neglect the economic viability of its chosen resources. After all, modernist architecture was able to spread by virtue of its designs' ease of execution, the ubiquity of its materials, and the formal freedom afforded by building in concrete, as well as the material's outstanding fire and water resistance.
For it to be economically competitive enough to take hold, circular architecture needs to embrace the following principles:

- minimization of waste;
- use of fewer but more sustainable materials;
- use of components produced and processed in the building site's local area;
- separability of the various layers of a building;
- design amenable to disassembly.

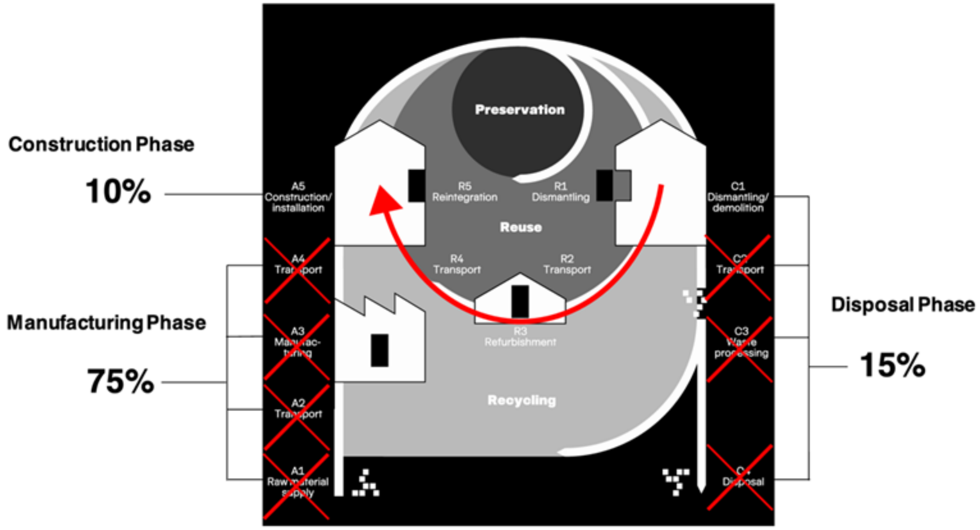


Figure 3: DIAGRAM OF THE LIFE CYCLE MODEL HIGHLIGHTING COMPONENT REUSE PROCESS. ©ZHAW

2.2.1 Discard nothing

If we are to avoid construction waste, the first step is to try to reuse demolition material wherever possible. Discarded building components contain the craft skills and design knowhow that went into their making; they thus have an intrinsic value and a potential value that goes beyond just what they are worth as scrap. In Europe, we are seeing a new public appreciation of the value of working directly with materials and of rediscovering as a society or community the feel for how individual components are assembled and disassembled. One particularly notable example is the UK's Assemble Studio, a heterogeneous collective of architects, artists, and philosophers that gained international recognition — and won the 2015 Turner Prize — for its urban renewal project Granby Four Streets in Liverpool. Other examples include Rotor in Brussels and the French group Bellastock, whose architecture festivals display pavilions made from waste material.

It's an approach Emanuele Almagioni, Giacomo Borella, and Francesca Riva of Milan's Studio Albori have been exploring since the 1990s. Demolition and disposal have always been anathema to the trio; instead, their projects always endeavour to reuse as much of the material and history of existing components and buildings as possible. Examples include their proposals for reviving Milan's abandoned San Cristoforo station, originally designed by Aldo Rossi and Gianni Braghieri, and their installation for the Chicago Architecture Biennial in 2015, which featured an old wooden staircase that the architects themselves transported piecemeal by bicycle then reassembled at the Chicago Cultural Center.

A recently rebuilt family home in the centre of Laveno, a town in the province of Varese, offers a particularly good example of the studio's approach. The initial plan was to preserve as much original structure as possible of the small two storey house, which had been built with brick walls, a wooden roof, small windows, and views of Lake Maggiore, and to focus mainly on remodelling the interior, perhaps creating a larger opening towards the lake. Unfortunately, the structure turned out to be in such a poor state that the only option was to pull it down and start again, retaining the original volume in order to conform to the municipality's strict building regulations. Faced with the task of having to demolish the original building, Studio Albori's chief concern was how to reuse and integrate as many existing elements as possible in the new structure. Windows and doors were individually catalogued, and the traditional hexagonal cement tiles, stone thresholds and steps, as well as the wooden ceiling and roof beams were all dismantled and transported to the building contractor's storage facility, as were the roof tiles and metal railings, while the limestone and brickwork were used to fill in the excavated pit. Next the architects had to decide what to use for the new supporting walls. They opted for a lightweight wooden structure filled with 36 cm thick Straw bales, which in themselves constitute a natural waste product; the wood was sourced from a local joinery and complements the existing roof and floorboards. When it came to the old hexagonal floor tiles, their initial idea was to reuse them as cladding for the blind façade looking towards the church, which would echo the red and white zigzag pattern that is typical for villages around the lake. This, however, was vetoed by the client, and the studio was left with no other choice but to use leftover terracotta tiles from the client's own stock. It took ten years in total for the entire design and building process to be completed, due to a combination of long waiting times, sudden changes, and disagreements with heritage conservation officials, along with the great sensitivity shown towards the site. It's a way of practising architecture that, while not likely to becoming the global norm, does at least point the way towards a more sustainable and exhaustive approach to the built environment.

Casa a Laveno

Laveno, Varese, 2021 • Client: private • Architects: Studio Albori, Milan

Figure 4: FROM LEFT TO RIGHT: THE HOUSE'S 'NEW' FAÇADE; NORTH ELEVATION LOOKING TOWARDS THE CHURCH; PLAN OF THE GROUND FLOOR; LONGITUDINAL SECTION. ©STUDIO ALBORI

2.2.2 Materiality

Today, we are seeing calls for a true-to-material approach, but with a new, ecological slant: concentrating on locally available natural building materials has great potential as a way to reduce embodied energy. But what are the consequences for today's architects of limiting themselves to a few simple natural materials, given the vast range of choices available? And what are the consequences for sustainability and circularity in architecture?

Wood is probably the most versatile of building materials. Not only does it save on embodied energy, it and its secondary products are also capable of meeting all the structural, acoustic, and fire resistance requirements of a building. Even wood needs to be utilized with care, however; derivatives should be avoided, and the natural character of the material shown to good effect. Engineered wood flooring, manufactured by combining multiple layers, uses eight times as much embodied energy as its solid wood counterpart. Glulam timber compares similarly badly.

In Alpnach, architects Patrik Seiler and Søren Linhart have created a house that is also a manifesto. Made almost entirely of wood, this Swiss home was realized in close collaboration with the Küng family, who were both the clients and the manufacturers of the solidwood system used in its construction. The entire structure—façade, internal walls, ceilings, and roof— consists of pieces of solid wood, namely of cross layered Spruce timbers joined using nothing but beechwood dowels, i.e. without recourse to glue, chemical additives, or metal connectors.

The wood was all sourced from the surrounding region and processed locally in the Küngs' own workshop. Each single panel is 21 cm thick and fire resistant for 90 minutes (F90), while twinned panels can be used to create a solid façade that requires no additional insulation and can support the ceiling boards, which are also made of dowel laminated timber.

It's a materially 'pure' building that consists inside and out of one single untreated natural product, a building whose raw materials, being neither impregnated, stained, nor otherwise processed, remain raw materials and can thus be directly reused. Such a structure might seem, at first glance, to involve inordinate amounts of material. It should be noted that all the timber from which the walls are made is of very low aesthetic quality and, had it gone into the manufacture of wood derivatives, would have been recycled anyway. In one sense, such a building simply skips an entire production stage, thus saving all the energy that would have been used in it. The only compromise is the concrete base that anchors the building to the steep slope. It forms the house’s foundations, underlining that it’s not about using one material for every function but about using the right material for every situation. Even here, though, we can learn from this pioneering project: the concrete’s internal structural reinforcement is not steel but bamboo, meaning the concrete will be easier to break up and recycle later. Going to such lengths to replace metal with renewable resources may seem exotic, but it underlines the seriousness with which this project explored architectural and structural means of combining more sustainable materials.

Haus K

Alpnach, 2018 • Client: private • Architects: Seiler Linhart, Lucerne / Sarnen • Loadbearing structure and building physics: Küng Holzbau, Alpnach • Timber construction: Küng Holzbau, Alpnach • Ornamentation: René Odermatt, Küssnacht am Rigi (decorative woodwork)

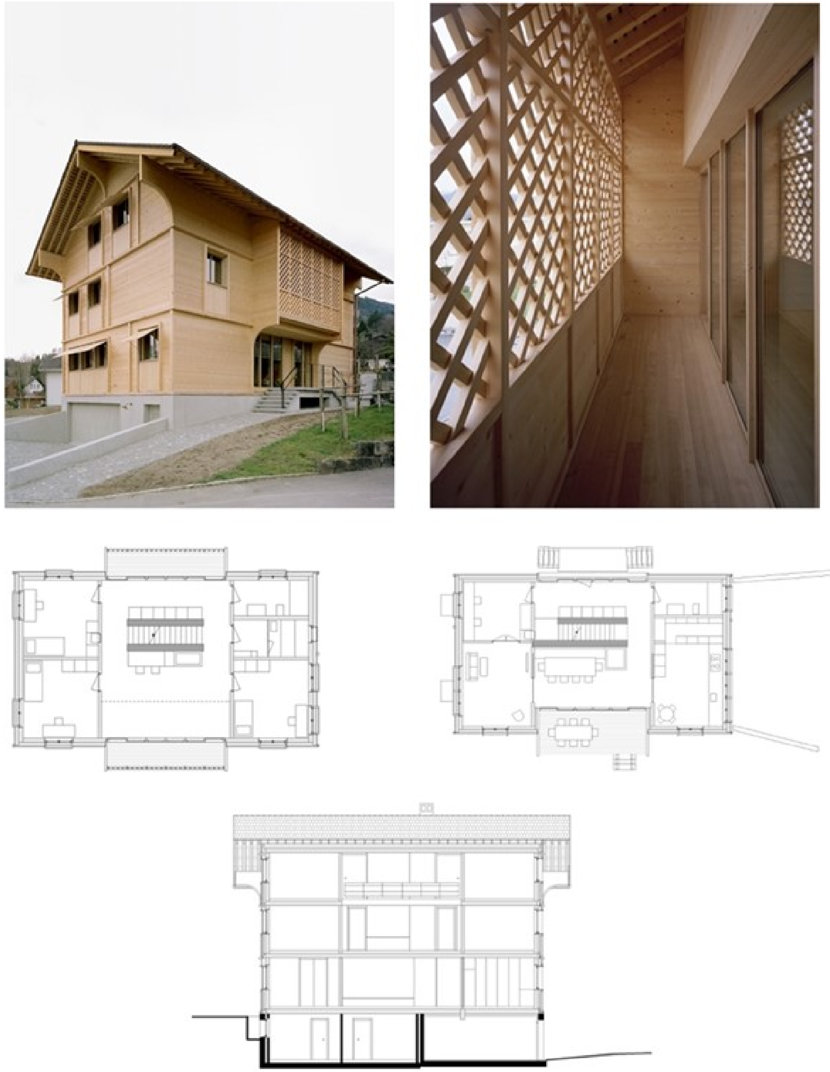


Figure 5: FROM LEFT TO RIGHT: EXTERNAL VIEW; UPSTAIRS LOGGIA; PLANS OF GROUND AND FIRST UPPER FLOOR; LONGITUDINAL SECTION. ©RASMUS NORLANDER

2.2.3 Continuing local tradition

People once built houses using existing materials and handed down methods, but, above all, by looking to what had gone before, something the vernacular and spontaneous architecture presented in Bernard Rudofsky's Architecture Without Architects (1964) illustrates very well.

With the rise of industrial production, the discovery of more high-performance materials such as steel reinforced concrete, and the globalization of transport thanks to standardized methods such as containerization, building components can be supplied to any place on Earth, even if they are alien to that area. As forces of commercial and geographical centralization, cities have brought a sense of interchangeability to construction: anything is possible, any material can be used, any construction method realized. Perhaps the most striking example of this discourse between ubiquity and tradition can be seen in postwar Southern France. In Marseille, a city devastated by air raids, two architects realized their respective visions of the architecture of the future: Le Corbusier built his Unité d'Habitation (1947–1952), thereby demonstrating the versatility of concrete, while Fernand Pouillon, who designed the La Tourette (1948–1953) and Immeuble au VieuxPort (1951–1955) complexes, rejected this new mechanistic architecture, instead creating buildings from limestone from the surrounding region and working with local clients to develop rapid and commercially viable new techniques such as 'pierre banchée'.

Like Pouillon, Gilles Perraudin works with stone from the Fontvieille quarry and draws on handeddown Knowledge. His designs demonstrate the underappreciated value of using natural materials to build houses that are easy to construct and deconstruct, economically viable, environmentally sound, and yet extremely longlasting.

Perraudin's design for a house in Montélimar is a case in point: the walls were made of solid limestone and are 40 cm thick, while the ceilings and roof are of untreated solid larchwood— material choices that avoid industrial processing, eschewing preservatives and proofing agents, in order to reduce embodied energy. The limestone blocks were assembled almost like a prefab system, being joined with lime mortar so that they can be taken apart again and reused. The simplicity of the execution, the avoidance of the usual wait for concrete to dry, and the usage of one single material allowed construction to proceed at pace. A secondary economic benefit is that using locally sourced solid stone not only keeps old building traditions alive, but it also helps keep quarries alive too, particularly when they are in sparsely populated areas far from major urban centres. These choices also aid the house's internal climate, creating a 'living shell': stone breathes and, thanks to its high specific gravity, also stores heat, enabling it to regulate humidity and temperature inside the house and counterbalance daily temperature fluctuations.

Perraudin's experiences, like Pouillon's on a larger scale, show us that traditional construction doesn't have to simply regurgitate lessons from the past; it can also actively reinterpret them and make them the starting point for innovation. That, however, requires building designers to have indepth knowledge of materials, their local production, their construction, and the economics of the building site, to once again be organizers, economists, engineers, inventors, and artists, as Pouillon liked to say. In short, it requires multifaceted architects.

Stone-built home in Montélimar

Montélimar, 2018 • Client: private • Architects: Gilles Perraudin architectes, Lyon • Build consultation and site supervision: WYSWYG Architecture, Nobouko Nansenet, Lyon • Construction: SAS Lionel Roux, Puygiron, Quarry: Carrières de Provence, Fontvieille

Figure 6: FROM LEFT TO RIGHT: EXTERNAL VIEW; CENTRAL HALLWAY WITH STAIRCASE; BEDROOM WITH EXPOSED STONE; AXONOMETRY; ©11H45

2.2.4 System Separation

'The main architect is time,' says Stewart Brand, founder of the Whole Earth Catalog (1968–1998), a highly successful US magazine that focused on ecology, DIY, and selfsufficiency.

It was Brand who defined the six layers that need to be taken into account in every new build or rebuild—site and foundations, structure, skin, services, space plan, and stuff (i.e. furniture)—stipulating that these should be easily separable without the replacement or alteration of one impacting on the lifespan of the whole. This principle, however, is at odds with a commitment to using just one material wherever possible and standardizing building components as far as possible; here, each component is instead designed according to its function and its life cycle.

The early architects of the Industrial Revolution applied this latter concept extensively. They saw the need for large, modular, and flexible spaces in which the machinery of production could be installed, machinery that was likely to change rapidly over time and would thus necessitate constant remodelling. One of the first instances of architecture embracing this pragmatic way of thinking came around 1900 in Detroit following the birth of the motor car. The factories that Albert Kahn built for Henry Ford followed the principles of industrial production and recognized the need for highly adaptable, well-lit spaces. They represented a new architectural typology, providing a flexible infrastructure that could be reused repeatedly. While the Ford plant followed gravity, bringing raw materials in from above and, at ground level, churning out ready for testing Model T Fords, the first FIAT factory turned the process on its head: at Giacomo Mattè Trucco's 'Lingotto' building (1916–1926) in Turin, cars were produced at ground level then put through their paces on the rooftop test track. Based on a 6×6m grid of supports, this concrete structure with brick infill, which measures 510×72m and features four internal courtyards, has endured for a century, and remains one of central Turin's key commercial hubs. Once the most important car making plant in Italy, it is now home to an exhibition and business centre, a shopping mall, a museum, a hotel, and a university. It turns out the key to longevity was not the building's rooftop racetrack, but its versatile and flexible grid-based construction.

Parisian practice Lacaton & Vassal followed similar principles with their Nantes School of Architecture, the design of which allows students and staff to tailor spaces to different usages and needs. From the outside, it has a deliberately unfinished look, resembling an industrial building sandwiched between various dockland warehouses.

The supersized main structure consists of 80×80cm thick prefabricated concrete pillars and hollow concrete floors, a system more normally used for the construction of multistorey car parks. It's perhaps not surprising, then, that the building also boasts an entry ramp and a publicly accessible external ramp that winds its way from the ground floor up to the open sided flat roof. The three concrete decks are two to three storeys high, allowing steel mezzanines to be inserted and the minimum floor area stipulated in the competition to be tripled.

This secondary structure, which is in theory removable but in practice permanent, represents an additional and separate 'layer' in the building's construction. Each of the concrete decks can support up to 1 t/m2, meaning the architecture students can even build 1:1 model if necessary. The curtain façades are galvanized steel, glass, and polycarbonate, making them completely transparent and extremely light. And the aluminium and glass internal walls allow single height spaces to be thermally isolated and intermediate climate zones to be created in the Higher ceilinged spaces.

By their own account, the architects did not set out to create an architectural object—their response to the task before them was to put the people who work and live in the spaces centre stage. What you get here, therefore, are bare spaces, the result of a modular and mundane structure that, rather like Cedric Price's extravagantly envisioned Fun Palace, has no fixed form other than that produced by its constantly changing configuration.

École Nationale Supérieure d'Architecture Nantes

Nantes, 2009 • Client: Ministère de la Culture – DRAC des Pays de Loire • Architects: Lacaton & Vassal, Paris • Civil engineering, concrete structure: Setec Bâtiment, Paris • Civil engineering, steel structure: Cesma, Merignac • General contractor: Savoie Freres

Figure 7: GROUND FLOOR PLANS SHOWING FIXED SPACES (GREEN SHADING) AND FLEXIBLE SPACES (LUGHT BLUE SHADING); SECTION SHOWING PRIMARY CONCRETE STRUCTURE PLUS SECONDARY STEEL STRUCTURE (THE LATTER WITH GREEN SHADING). ©LACATON&VASSAL

2.2.5 Design for Disassembly

In 1851, Gottfried Semper visited the Great Exhibition at London's Crystal Palace, where, amidst the 'Babylonian confusion', he came across a reconstruction of a Caribbean hut, a simple timber frame structure with walls of colored cloth. It was this encounter that inspired Semper's theory of architecture as 'clothing'. From that point on, contemporary buildings were seen as products of a process of cultural evolution originating with that primitive, easily disassembled hut; the hut led to the temple, which led to the palace, which led to today's skyscraper.

It is, though, surely time for us to view that evolution as concluded and start trying to reverse the process, to get back to a simpler architecture whose materials can be connected in reversible ways, and whose every element has a precise constructional and aesthetic function? Deliberate provocations aside, if we look back across modern architectural history, it's primarily been temporary pavilions and exhibition buildings that have addressed the issue of disassembly on a larger scale. Perhaps the most famous example is the iron and glass structure of the Crystal Palace, but there are numerous others, too, such as the IBM Travelling Pavilion, created by Renzo Piano Building Workshop using glulam timber, polycarbonate, and aluminium, or Peter Zumthor's Swiss pavilion for EXPO 2000 in Hanover—both lightweight structures capable of being disassembled and reassembled elsewhere. There are, though, also massy examples such as Anne Holtrop's Bahrain Pavilion for Expo 2015 in Milan, which was made entirely from concrete prefab sections and designed to be dismantled after the Expo and rebuilt in Bahrain.

Obviously, such structures don't have to negotiate the complexity of residential insulation standards. Arup's Circular Building, on the other hand, aims to provide a more widely applicable blueprint, as does the Circle House project, a development of simple residential units by Lendager Group, 3XN Architects, and Vandkunsten built as a practical demonstration of design for disassembly (DfD). These projects also illustrate how essential it is to make information such as product details, postconstruction changes, and disassembly instructions available for each component; here, the use of BIM design and virtual digital twins to provide a parallel documentation of every component's life cycle will become standard practice.

One way to achieve reversibility in architecture is by embracing the modularity of standardized components and uniform connections. This is something already seen in system-based construction, a well-known Swiss example of which is the MIDI 100 system developed by Fritz Haller. By contrast, Antón García Abril's research into structures and designs, which explores the possibilities of prefab elements for bridges and viaducts in unorthodox fashion, offers inspiration for those keen to avoid being constrained by repetitive systems. His Hemeroscopium House, for instance, is a structurally highly elegant prefab residence that is a far cry from the standardized architecture of catalogue homes.

A particularly tricky aspect of designing for disassembly is dealing with the various layers added onsite for insulation, sound absorption, or condensation control purposes, layers that are often irreversibly fixed in place using glue or bituminous materials. Likewise, technical services are frequently irreversibly embedded in walls or concrete slabs. Mechanical or plugin connections within technical systems are an oft cited solution to such problems but, really, there's one simple rule for true DfD: ensure all parts of a building can be disassembled simply by reversing the processes and steps used to assemble them.

A genuine trailblazer in the field of reversible architecture, the home that architect and engineer Werner Sobek designed for himself and his family more than 20 years ago makes an excellent starting point for an examination of this approach. Although planned with easy disassembly and relocation in mind, the house has so far stayed put and is therefore yet to prove its promised dismantlability in practice. Nonetheless, the principles underpinning its construction are a useful guide for any design with pretensions to circularity. First and foremost, Sobek's house is remarkably light (the superstructure, which sits on concrete foundations, weighs a total of 40 tonnes) and has net zero energy consumption. Its simple cuboid form is built of standardized steel sections that can be transported by truck. The façade consists of triple glazed standardized panels affixed to the structure via a system of steel cables and screw plates. Internal partitions of hard-to-reuse materials such as plasterboard or brick were avoided; in fact, only the toilets were partitioned, using aluminium panels held together via a system of metal plates and magnets. A secondary solid wood structure supports the parquet flooring, which is also made of solid wood. There are suspended ceilings of removable aluminium panels that allow the copper pipes of the concealed heating and ventilation system to be accessed at any time, and the roof is completely covered by a photovoltaic array that collects solar energy while also keeping the rain out. Building work was completed in around one month and the prefab structure fitted in ten days. Technologically exemplary, Sobek's house remains as relevant today as it was 20 years ago. What's more, it proves that buildings designed with separability in mind can still have a distinctive architectural aesthetic.

Haus R128

Stuttgart, 2000 • Client and architect: Werner Sobek, Stuttgart • Civil engineering: Werner Sobek Ingenieure, Stuttgart • Consultants, steel structure and façade: SE Stahltechnik, Stammham • Consultants, energy engineering: Transsolar Energietechnik, Stuttgart • Construction: Hardwork, Stuttgart

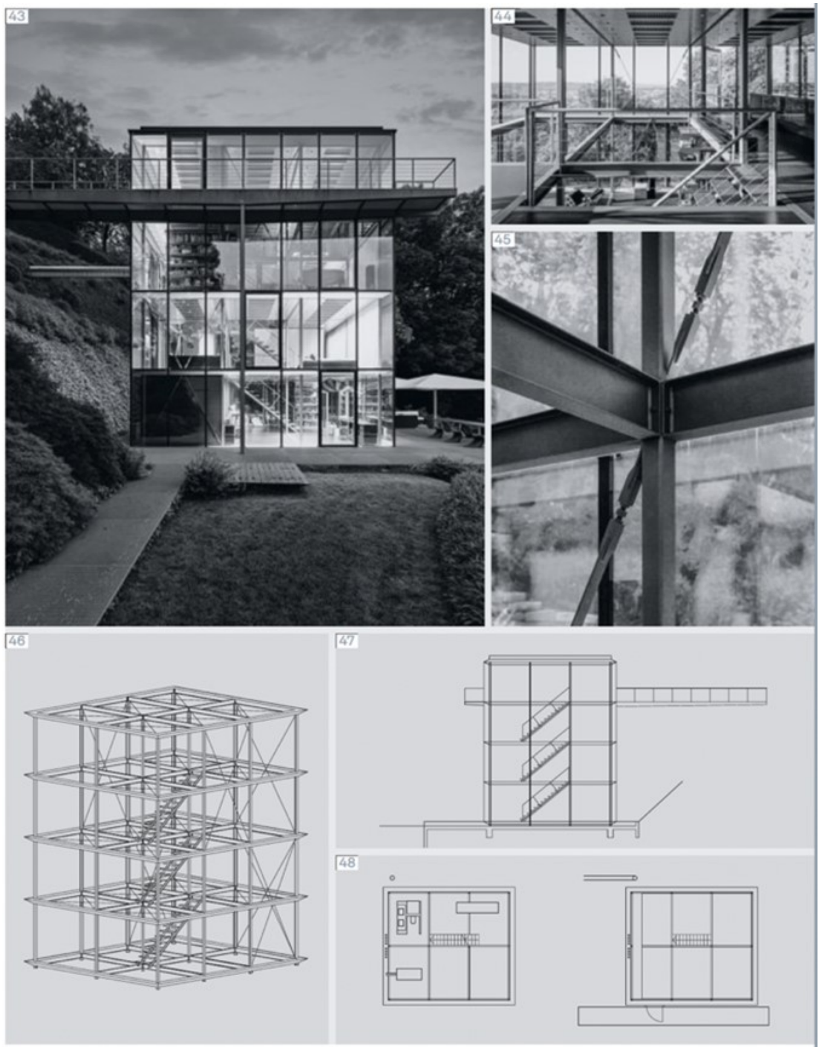


Figure 8: FROM LEFT TO RIGHT: EXTERNAL VIEW; THE OPEN INTERIOR, THE SPACES OF WHICH HAVE NO PARTITION WALLS AND ARE SEPARATED ONLY BY GLASS. CONNECTING JOINTS IN THE PRIMARY STRUCTURE. STRUCTURAL AXONOMETRY. LONGITUDINAL SECTION AND PLANS OF FIRST FLOOR AND TOP FLOOR. ©ROLAND HALBE, ©WERNER SOEBEK

2.2.6 The many routes to circularity

For every architectural assignment, there is more than one appropriate solution—the five projects presented here thus merely outline a range of possible responses.

Studio Albori have adopted a radical and principled stance, namely that absolutely nothing should be thrown away. When thinking about a project, they always start from the position that all or as much of the existing materials as possible should be reused and repaired, thus creating architecture that allows the existing fabric of the building to live on in a new guise.

Both Gilles Perraudin and Seiler Linhart are practising a new form of regionalism, one in which the local area or region is the chief source not just of the raw materials but of the technical Knowhow too. Their use of a limited number of primary materials and their avoidance, wherever possible, of additional processing can also be read as a continuation of traditional local practices.

Lacaton & Vassal's architecture looks beyond a focus on material, stressing the need for flexibility in space plan and usage. They also design spaces that take into account the differing life cycles of various components, clearly separating structure and fitout.

Lastly, Werner Sobek has developed an architectural approach in which concept and detail always go hand in hand. From design idea to detail execution, Sobek assiduously applies the principles of constructional logic and modularity, of assembly and disassembly, carrying them forward into the architectural aesthetic—from micro to macro and back again.

In an increasingly interconnected world in which humanity's impact on nature, and natures on humanity, is becoming more and more severe, it is imperative that we turn our back on today's steroidal architecture, on the constant quest for ever higher standards and ever greater convenience. Instead, we need to focus on going back to a critical examination of spatial requirements, to simpler materials, to less complex HVAC technology. It's no longer enough to build buildings that are net zero in terms of operational energy, we need to adopt a second Net Zero goal—to ensure the construction and future deconstruction of our buildings is powered solely by renewable energy. Perhaps we should look afresh at Semper's Caribbean hut and see its constructional and functional simplicity not as the starting point for architectural evolution but as its ultimate goal!

3. RE-USE: THE K.118 PILOT PROJECT

3.1 A brief History

The Kopfbau 118 in Winterthur stems from the desire to construct a building with only reutilized parts. Due to its radically exceptional character, the K.118 is seen as a manifesto of circular architecture.

The conceptual beginning of the project can be dated back to 1995 when Barbara Buser, together with Klara Klauser, founded the Bauteilborse in Basel, an association with the aim of recovering used building materials, finishing elements, parts of appliances and other pieces of buildings. Once gathered and stored in the "construction components exchange," these materials are offered for sale. The association has grown over time, to the point of creating an online platform for the sale and purchase of materials, a platform that still functions today.

It was during this experience that Barbara Buser, together with Eric Honegger, founded the architecture firm Baubüro in situ in Basel.

Twenty years later Klara Klauser took a position in charge of real estate investments for the Abendrot pension Fund. The fund has recently acquired the Lagerplatz Areal in Winterthur, one of the industrial areas of the foundry of the Sulzer brothers, a company that contributed during the previous century to make the city one of the largest industrial centers in Switzerland.

Abendrot Fund had to make the area profitable, and Klara Klauser thus had a concrete opportunity to demonstrate that the principle of circular architecture could work. The program is simple: offices of varied sizes, shared kitchen and restrooms, a two-story conference room with a balcony, and a first floor with spaces for teamwork.

But the K118 is not just a building for shared offices. It should be the manifestation of the fact that circular architecture can be competitive within a market economy. The building demonstrates the concrete possibility of construction made entirely with reused components, without higher costs with respect to a building made with new materials. Barbara Buser, a consultant of the board of the foundation, was hired for the project, and accepted the challenge indicated by Klara Klauser. The main problem was the fact that making a construction using recycled parts requires an inversion of the design process. An inversion, in the sense that the choice of a construction system, of a detail or a finish as opposed to others, cannot be determined by what is envisioned by the designer, but can only be defined by the availability of components when they are needed. “Form follows availability” is the motto that has accompanied Baubüro in situ during the design of the K118.

The first choice was to conserve the existing building and elevate the volume over it. The new levels, made with a structure in steel dismantled from a distribution center then being demolished in the city of Basel, rest on the old masonry structure. The proportions of the square grid of the structure determine the form of the overhanging volume. These levels are accessed by means of an external staircase, it too in steel taken from a demolished office building in Basel. The landings of the stairs determine the height of the new slabs and the decision to place the staircase on the exterior permits the internal space to have no limitations to its layout. The slabs of Italian granite that clad the restrooms, kitchens and floors of the terraces come from the facing of the same demolished building. The facade is prefabricated by assembling wooden parts and insulating straw panels. The flexibility of this system allows it to adapt to the different windows, recovered from three different buildings. The external cladding is in aluminium sheet taken from the sheds of an abandoned printing plant on the outskirts of the city of Winterthur. The slabs are made by reutilizing sheets of corrugated metal and concrete: the concrete is deployed at an indispensable minimum, only where it is inevitable, to comply with standards of statics, acoustics and fire prevention. The floors are finished with solid wood boards taken from a residential settlement demolished in Winterthur. Even the heating systems have been recovered from abandoned buildings: from the solar panels on the roof to the radiators. The same is true of the sanitary fixtures and components in the bathrooms.

Once finished, the K118 asserts its presence in the Areal in a clear, forceful way. The colour, the overhanging volume, the composition of the various windows are

the elements that set its character, and they are all components that have found a place in the project not due to the compositional or formal choices of the architect, but as a matter of fate. The parts were available at the right time and in the right quantities. The "vernacular" reuse of the materials links back to methods of preindustrial construction before the energy generated by fossil fuels permitted the ubiquity of every material and the possibility of every construction technique. The entire design phase of the K.118 and its construction have been monitored by the Institute of Structural Design (Institut Konstruktives Entwerfen) of the department of Architecture of ZHAW, located just 200 meters from the worksite.
One of the most surprising facts has to do with the calculation of greenhouse gas emissions (CO_2 eq.) caused by the construction of the K.118, as compared with the levels that would be reached to make the same building with new components. The K118 permits savings of almost 60% of CO_2 equal to almost 500 tons. The remaining 40 % can be attributed almost exclusively to the works in concrete, though they have been implemented with a procedure of recycling. Results of this quantitative size, and above all with such an immediate effect, cannot be found in any other work or strategy that is considered "sustainable". Nevertheless, we also must admit that to date there are no infrastructures in the territory such as "materials exchanges" that would be able to support a true expansion of construction with reutilized materials. The idea of transforming the city into a mine of continually available materials -in the logic of "urban mining"- is still limited to small projects, and the management is left almost exclusively up to the individual efforts of individual architects, and some rare, enlightened investors. A strategic catalogue of existing materials in the "urban mine" is still lacking. As are the digital platforms and physical storage facilities that could handle the ongoing sorting, distribution and immediate supply of the required materials.

Like all pilot projects, the K118 does not set out to present itself as a dogmatic solution; the aim is to demonstrate that the reuse of materials is possible. The K118 implies the rediscovery of a vernacular construction process, which although it has always existed can open up new pathways for design, ethics and morals. It can contribute to the debate on the value and meaning of a true circular architecture, which puts the focus on the environment, materials and construction at its center, getting beyond the axioms of a mechanistic civilization still based on the principles of a linear economy.

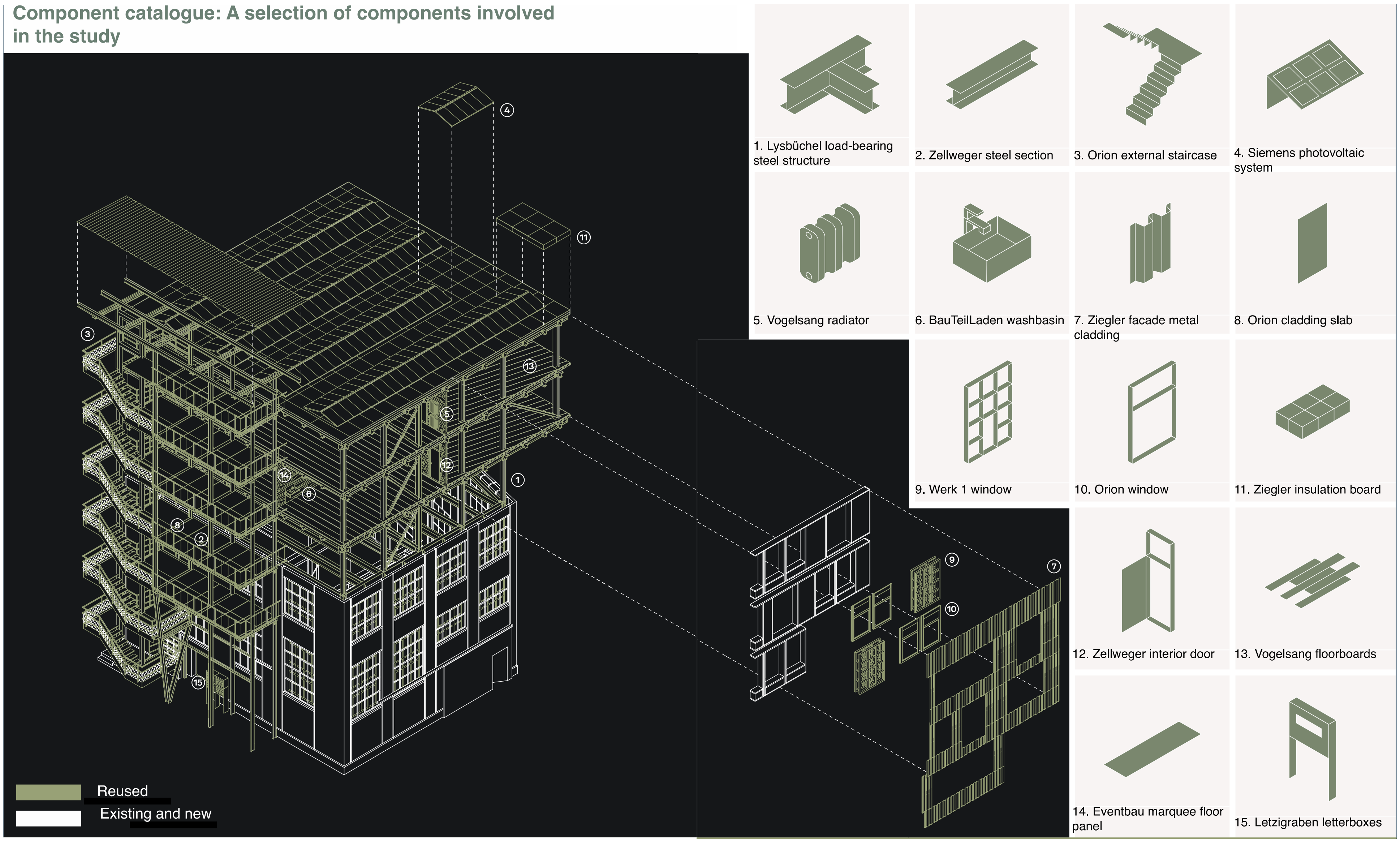
3.2 Design with reuse components

The reuse of building components changes the way we design and construct — both in terms of process and results. Every success in the search for components triggers a chain reaction, which to some extent reverses the traditional design process or provokes surprising about turns. Certain materials, forms, finishes, and connection details are suddenly specified one-to-one with the found component and demand design and constructive responses. But the future reusability of building components also requires a new perspective in the design process that goes beyond the current project.

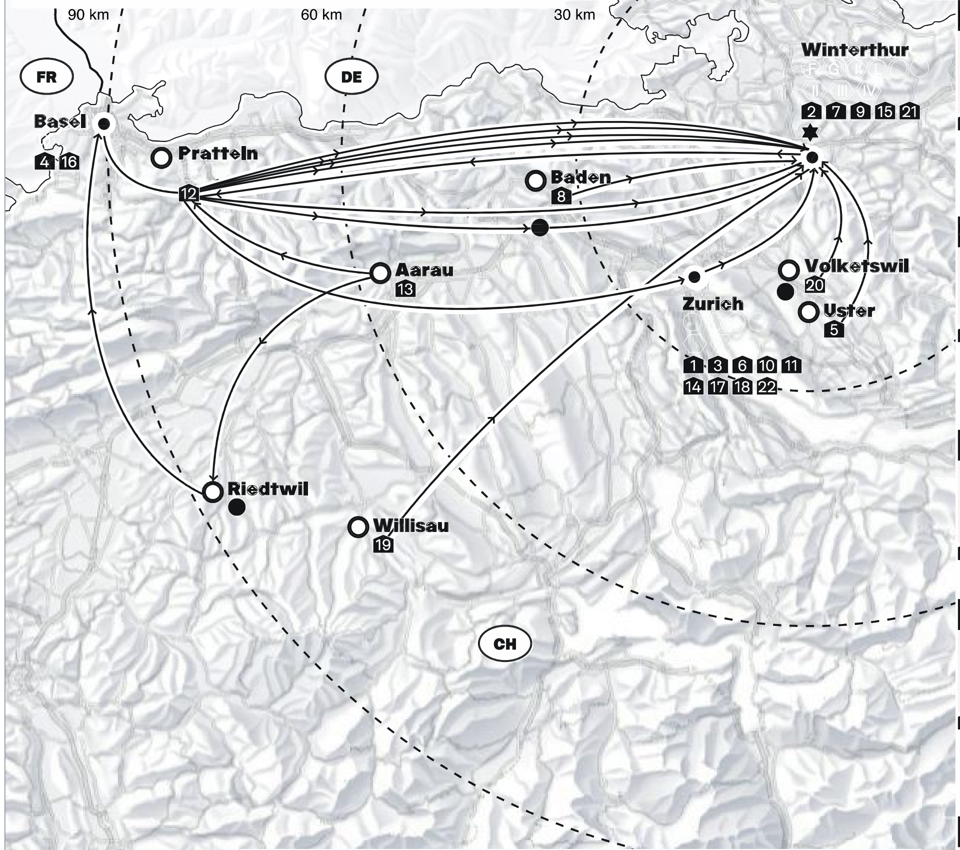
The following graphic retraces the process using the K.118 project as an example. It illustrates the main design steps in relation to the found components recorded in the component map as a quasi-evolutionary development.
The map below shows all demolition sites from which components were collected.

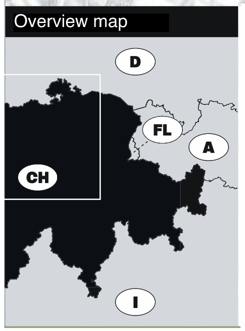
In the next pages.
Figure 9: Component map; ©ZHAW
Figure 9: The axonometry shows how the entire building is completely constructed with reused elements (in green). Even the solar panels on the roof are reused; ©ZHAW
Figure 10: Design and Construction: Process ©ZHAW

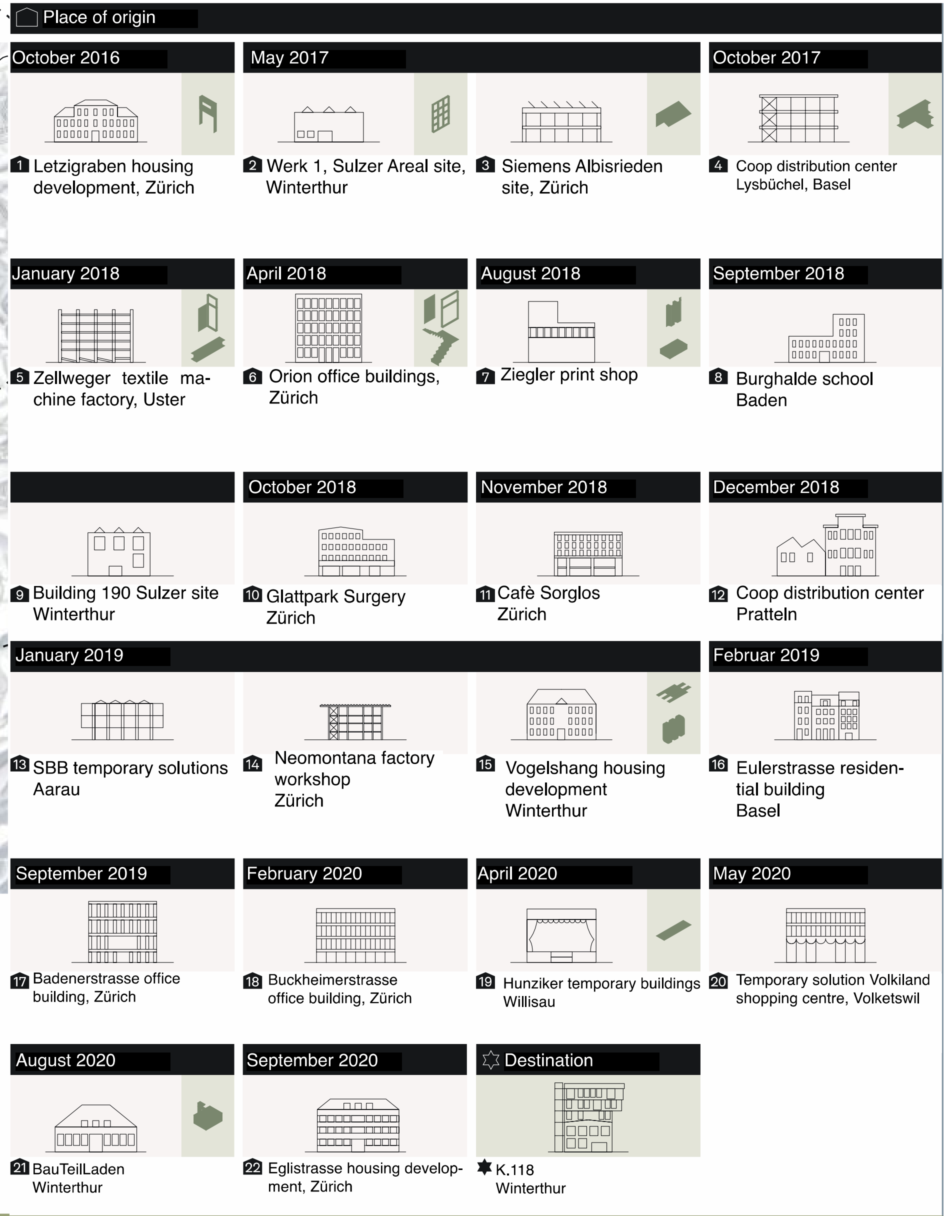
Component catalogue: A selection of components involved in the study



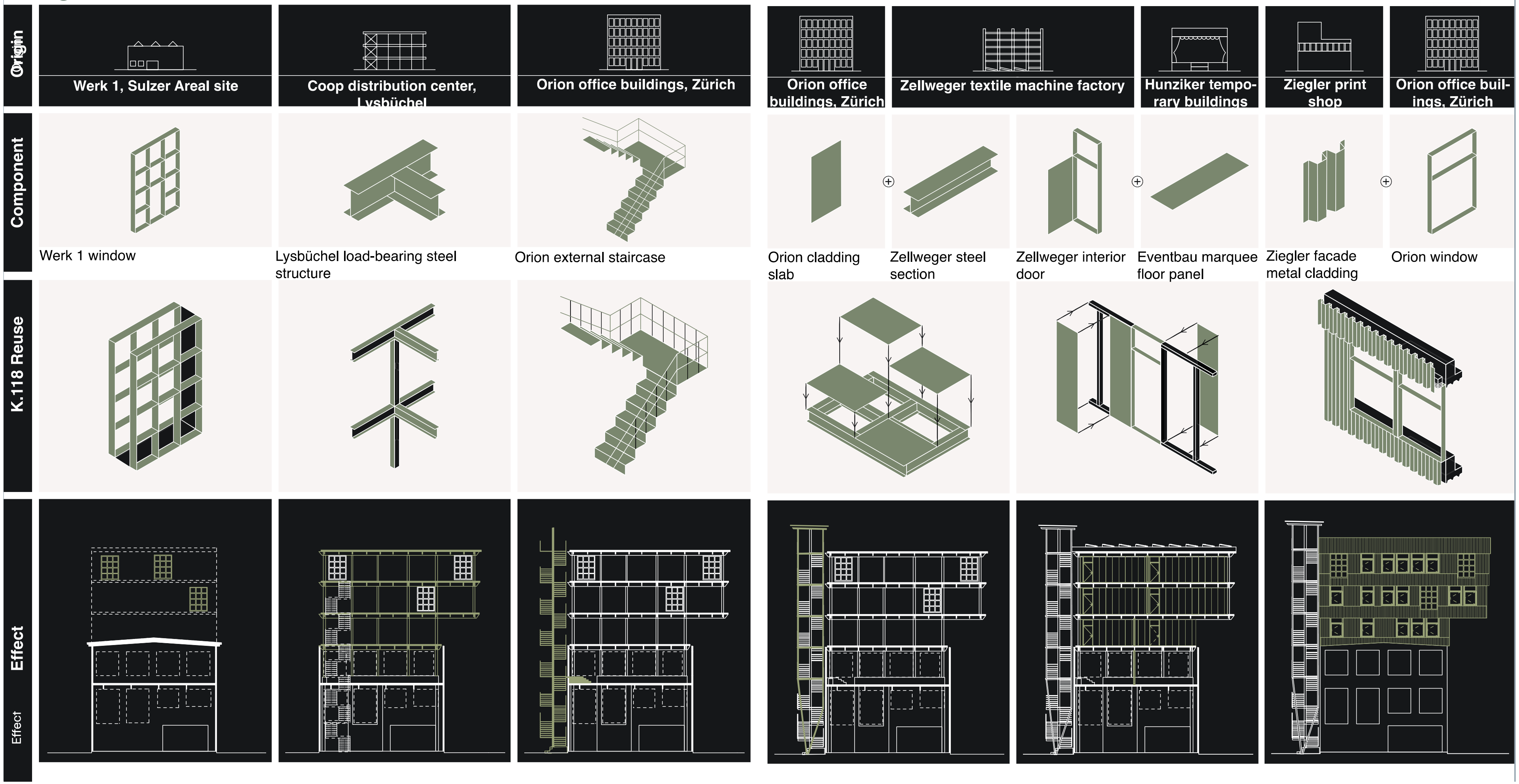
Component map







Design and Construction: Process



This diagram shows how the final design of the building follows the finding of the components: in fact, it is no longer the architect who decides a priori the shape and colors of the building, but reacts to the shapes, sizes and colors of the components he finds on his way: Form follows function. This paradigm shift requires great flexibility and knowledge of the components and materials that are going to be reused.

3.3 Construction organization

The practical application of reuse is probably as old as building itself. Nevertheless — or perhaps precisely because of this — in many ways it challenges the general conditions of our modern construction, focused as it is on standardized and technologized planning and production. As a basic framework for a systematic investigation of these phenomena in the context of this study, and— based on the K.118 case study — specific services and processes of reuse were defined and considered from different points of view. Which stakeholders are involved? What services do they undertake and how do they relate to each other? What consequences can result from liability issues, for example? And which organizational models are conceivable to make the building process more circular? The key findings from this review are illustrated in the following four graphics.

Ten specific services showed in table below can be derived from the K.118 case study that only become necessary as a consequence of reuse (e.g. dismantling and preparation) or need to be reallocated (e.g. transport and storage) on the basis of it, they are:

1. Search
2. Assessment
3. Documentation
4. Acquisition
5. Dismantling
6. Transport (happening two times, from dismantling site to storage space and from storage space to the new construction site)
7. Storage
8. Preparation
9. Reinstallation
10. Maintenance

Each component search triggers a cascade of actions and decisions which can be assigned to these services.

3.4 Cost of 10 components

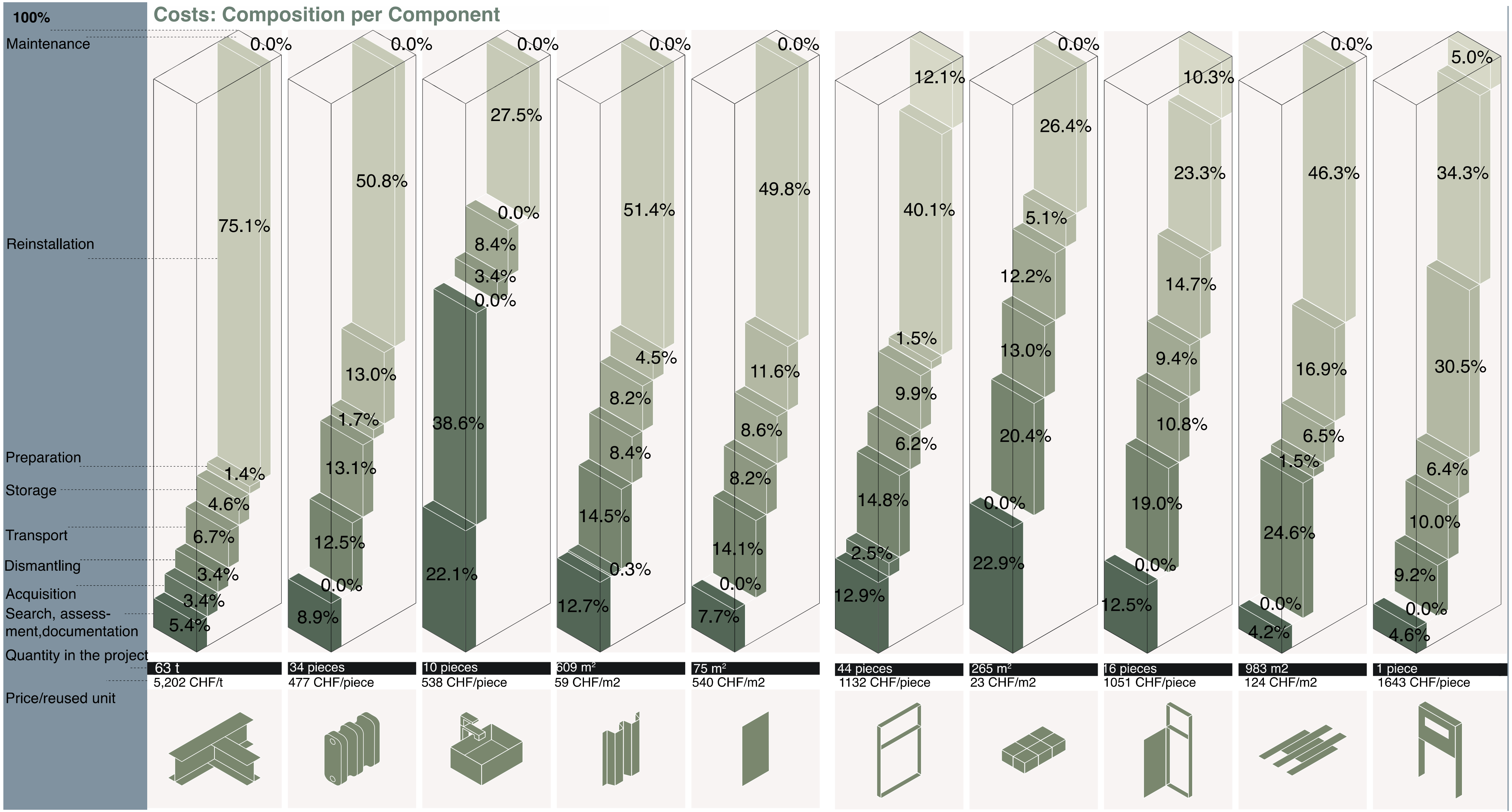
Is it still possible in Switzerland today to build with reused components for the same price as with new ones? In order to get to the bottom of this question, the effective costs at component level were established, based on the construction accounting for K.118, and compared with equivalent new components. Not only is the final price relevant, but also the time when payment is due: while in conventional construction, materials can be ordered according to the construction program of the new building, the availability of used components obeys the logic of demolition sites and the stocks of dealers who have been scarce up to now.

In the first step, the composition per component is investigated using ten components with different manufacturing processes and material properties as examples: what is the effective composition of their costs when all the services and processes relevant to reuse are considered?

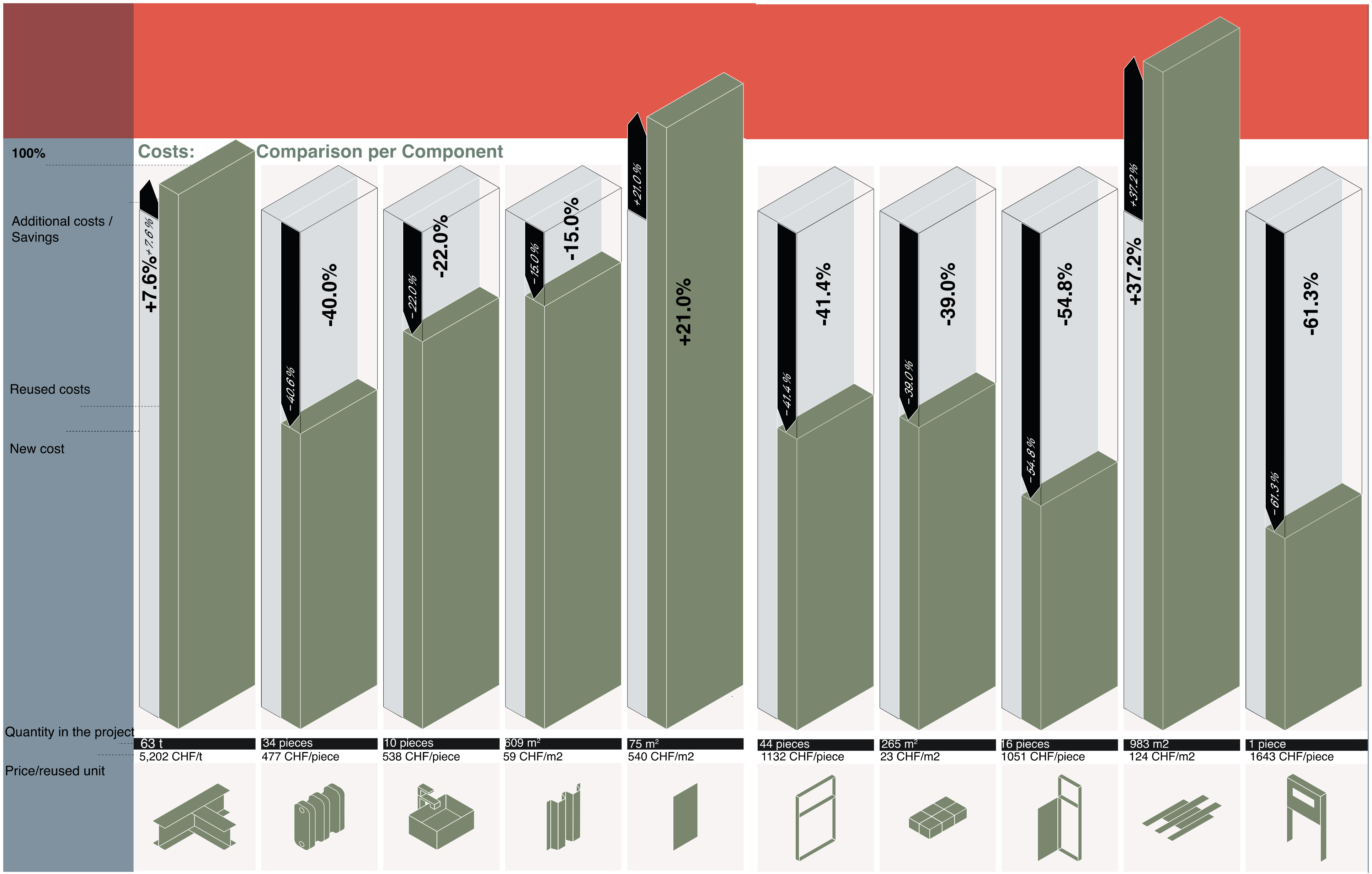
The planning costs directly related to the search and documentation of the components are also recorded here. The actual purchase price — at most, usually the scrap value — is generally negligible. On the other hand, labour costs for dismantling, preparation, and reinstallation are significantly higher in Switzerland, a high wage country. For components subject to mechanical wear (e.g. the Orion window, Zellweger interior doors, Letzigraben letter boxes) special maintenance work and provisions for warranty replacement must also be taken into account. In the case of K.118 they are part of the contracts for work and services.

The next step is the comparison per component with values for equivalent new components. Although they are mostly reinstalled with only minimal preparation, in some cases it was not possible to undercut the price of new components. For example, despite its untreated surface patina, the Lysbüchel loadbearing steel structure, which requires heavy lifting gear for dismantling, transport and reinstallation, turned out slightly more expensive than a new one. From a purely economic point of view, the Vogelsang floorboards were also not 'profitable'. The dismantling, preparation, and reinstallation of the small timber elements require a great deal of expensive manual work. However, had they been made from valuable highgrade timber instead of cheap spruce, the ratio would quickly have looked more favourable. Also relevant is the amount of work stored in the component in terms of embodied craft. Thus, reuse is financially worthwhile, especially for components with complex manufacturing processes, such as doors or windows, provided they are easy to salvage. Considerations such as these need to be taken into account when estimating the costs of reusing components.

In the next pages.
Figure 11: Costs: Coomposition per Component, ©ZHAW
Figure 12: Costs: Comparison per Component, ©ZHAW



Costs: Composition per Component
100%
Maintenance
Reinstallation
Preparation
Storage
Transport
Dismantling
Acquisition
Search, assess-ment,documentation
Quantity in the project
Price/reused unit
0.0% 75.1% 1.4% 4.6% 6.7% 3.4% 3.4% 5.4%
63 t
5,202 CHF/t
0.0% 50.8% 13.0% 1.7% 13.1% 12.5% 0.0% 8.9%
34 pieces
477 CHF/piece
0.0% 27.5% 0.0% 8.4% 3.4% 0.0% 38.6% 22.1%
10 pieces
538 CHF/piece
0.0% 51.4% 4.5% 8.2% 8.4% 14.5% 0.3% 12.7%
609 m^2
59 CHF/m2
0.0% 49.8% 11.6% 8.6% 8.2% 14.1% 0.0% 7.7%
75 m^2
540 CHF/m2
12.1% 40.1% 1.5% 9.9% 6.2% 14.8% 2.5% 12.9%
44 pieces
1132 CHF/piece
0.0% 26.4% 5.1% 12.2% 13.0% 20.4% 0.0% 22.9%
265 m^2
23 CHF/m2
10.3% 23.3% 14.7% 9.4% 10.8% 19.0% 0.0% 12.5%
16 pieces
1051 CHF/piece
0.0% 46.3% 16.9% 6.5% 1.5% 24.6% 0.0% 4.2%
983 m2
124 CHF/m2
5.0% 34.3% 30.5% 6.4% 10.0% 9.2% 0.0% 4.6%
1 piece
1643 CHF/piece


Costs: Comparison per Component
100%
Additional costs / Savings
Reused costs
New cost
Quantity in the project
Price/reused unit
+7.6%
-40.0%
-22.0%
-15.0%
+21.0%
-41.4%
-39.0%
-54.8%
+37.2%
-61.3%
63 t
5,202 CHF/t
34 pieces
477 CHF/piece
10 pieces
538 CHF/piece
609 m²
59 CHF/m2
75 m²
540 CHF/m2
44 pieces
1132 CHF/piece
265 m²
23 CHF/m2
16 pieces
1051 CHF/piece
983 m2
124 CHF/m2
1 piece
1643 CHF/piece

Considered overall, reuse also affects the construction costs and financing of the project: whereas in the conventional design and construction process, only design and approval costs are incurred up to the start of construction, for K.118, component costs of about 11 per cent of the construction costs had already accumulated during this time. The real design effort is also higher as a percentage of the total effort in the early project phases than provided for in the service model of SIA Order 102.2. The effect is only relativized in the implementation phase, when the planning costs exceed that of a pure new build by about 15 per cent, similar to a conversion. In the case of K.118, that amounts to about 2 per cent of the construction costs. The client must therefore invest a considerable amount long before the construction permit is issued - over 60 per cent more than usual by the start of construction. In the end, the question posed at the beginning can nevertheless be answered with 'almost': at the component level, the reused components in the K.118 case study are on average cheaper than new ones. However, in total, additional expenses arise in the planning, and in the case of construction costs, 2–3 per cent savings due to rational construction methods are offset by the subsequent costs of reuse. That has to do not only with individual connection details but also with material residues that are difficult to calculate, and the lack of established processes and markets.

3.5 Greenhouse gas emissions

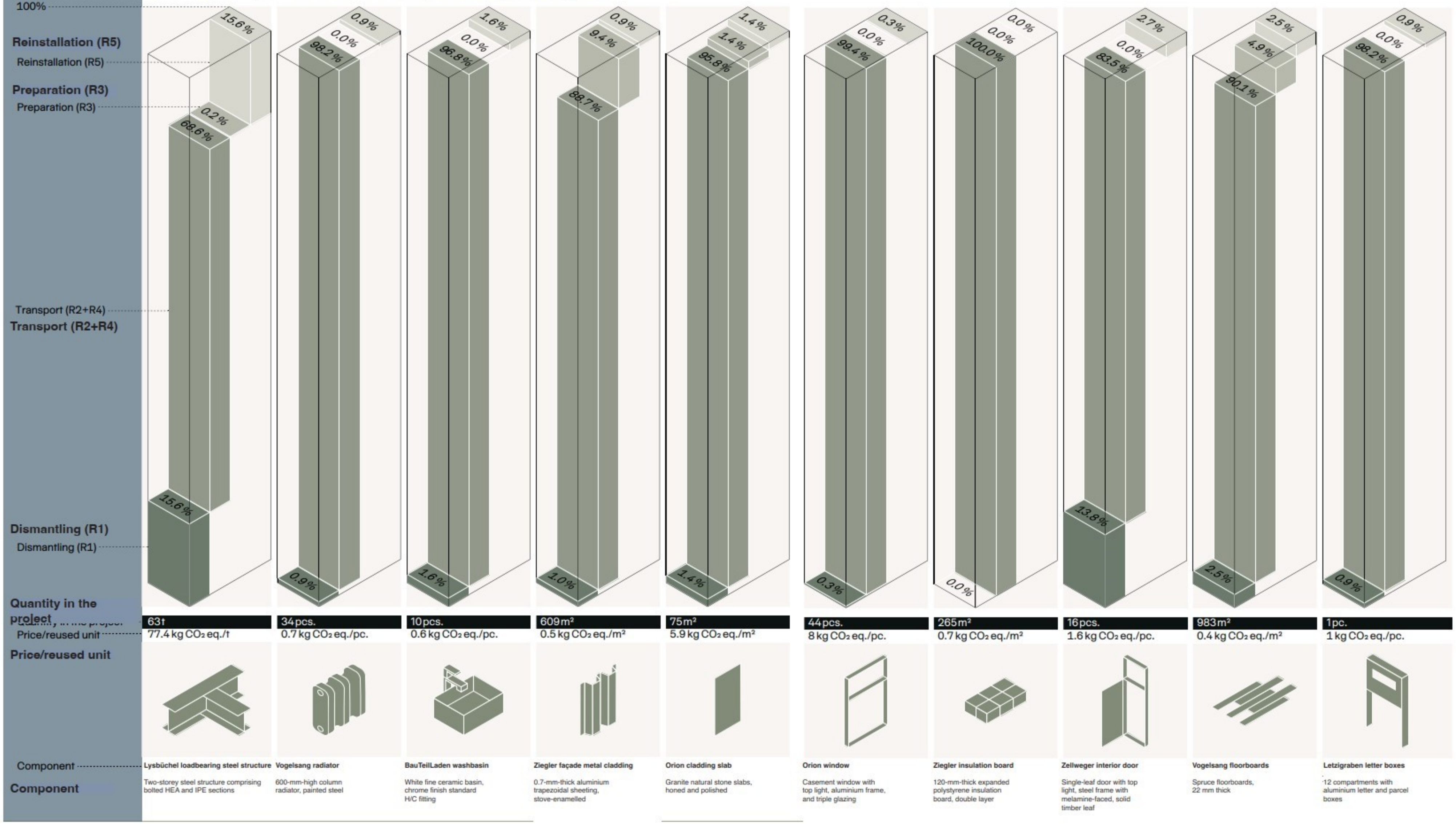
As part of ZHAW's Circular Construction research project, the energy expert Katrin Pfäffli has investigated the energy consumption and greenhouse gas emissions associated with the creation of the K.118 project. Her June 2020 study 'Graue Energie und Treibhausgasemissionen von wiederverwendeten Bauteilen' (Grey energy and greenhouse gas emissions of reused components) serves as the basis for the following investigation, which was supported methodologically by a workshop with the participation of Michael Pöll and Philipp Noger of the City of Zurich's Office for Sustainable Construction.

The following questions are thus of particular importance: what is the composition of greenhouse gas emissions for individual components? How big are the possible savings compared with new components? To what extent can the emission of greenhouse gases from construction be reduced through reuse if this is implemented as consistently as in the present case study? The sources and methodology of the investigation are explained with each graphic.

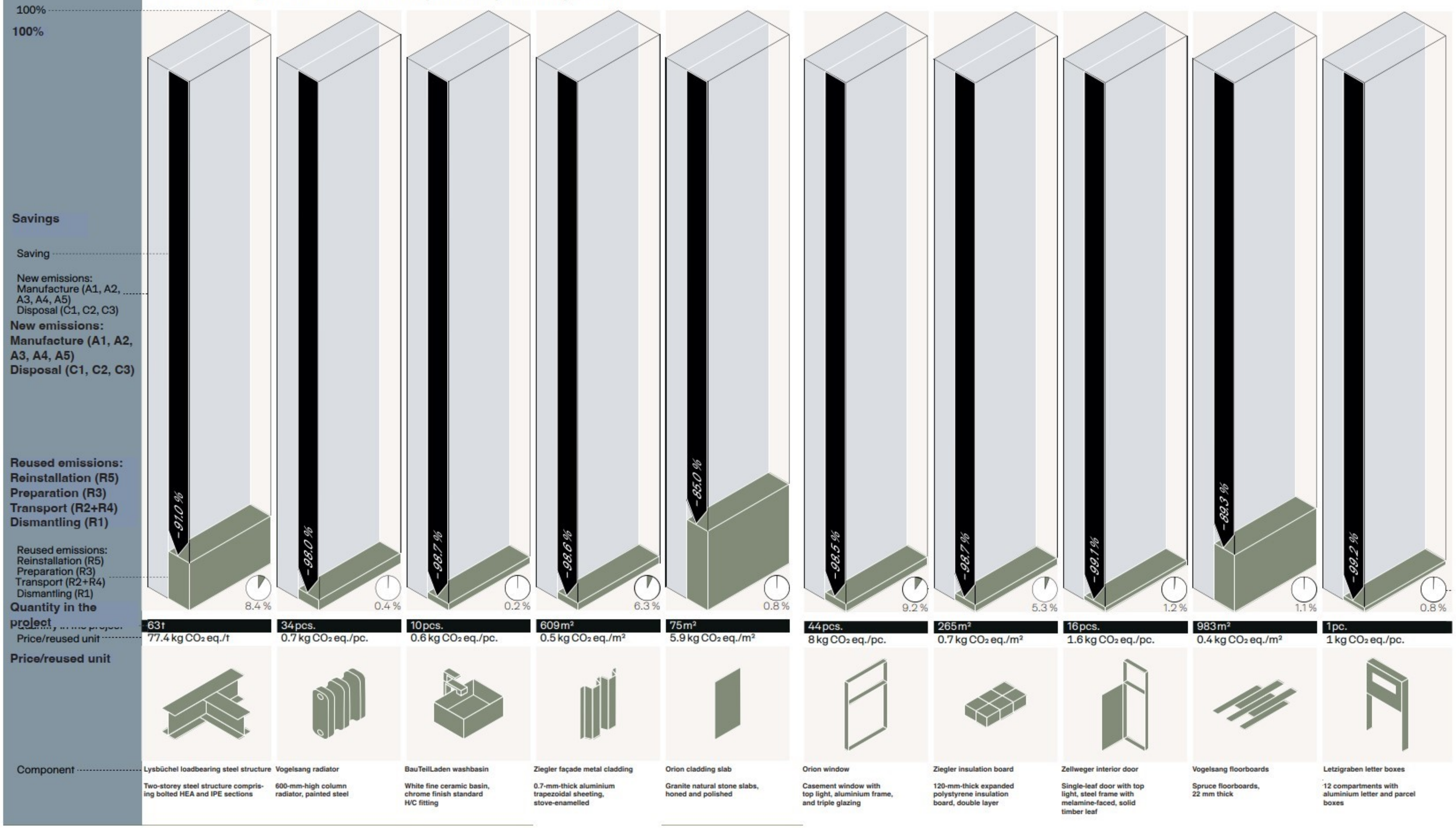
In the first step, the greenhouse gas emissions are analysed analogously to the economic study with regard to their composition per component. In order to provide as realistic a picture as possible, all services and processes of reuse relevant to emissions were taken into account, including dismantling, transport, and preparation. This also includes transport from the interim storage facility to the construction site and reinstallation, processes which are usually neglected in the life cycle assessment according to SIA 2032. A clear picture emerges although all components originate within a maximum radius of 100km, transport is key to the remaining greenhouse gas emissions. Dismantling and reinstallation are then only significant if heavy equipment is used, as in the case of the Lysbüchel loadbearing steel structure. On the other hand, preparation proves to have negligible effects for all the components under consideration.

In the next pages:
Figure 13: Greenhouse gas emissions: Composition per component, ©ZHAW
Figure 14: Greenhouse gas emissions: Composition per component, ©ZHAW

Greenhouse gas emissions: Composition per component



Greenhouse gas emissions: Comparison per component



The potential of reuse becomes obvious with the comparison per component with the same but new parts. Even the transport within the stated radius is comparatively insignificant. Emissions are usually reduced more than 98 per cent, particularly if the manufacture requires thermal processes (e.g. the melting of metal or glass). The balance is somewhat less clear only with components whose handling during reuse requires the costly use of machinery, such as the Lysbüchel loadbearing steel structure, or those made from natural materials, whose manufact e hardly emits any greenhouse gases, e.g. the Vogelsang solid timber floorboards. Here, too, however, the savings are extremely high at about 90 per cent — reused components act as wild cards for the life cycle assessment.

Even if the values from a single case study cannot be generalized, the overall balance of the K.118 case study does indicate the possible potential savings from reuse. Compared with a hypothetical building constructed from the same but new components, a total of 494t CO_2 eq are saved — i.e. about 59 per cent. The reused components are only responsible for about 6t of the remaining 349t of greenhouse gas emissions. If one considers the contributions of the various component groups to the savings, then, as expected, the loadbearing structure, windows and façade turn out to have lucrative potential savings. Overall, however, it is noticeable that the reductions of greenhouse gas emissions are not attributable to a few elements, but that it is the aggregate effect of many different elements that makes the difference.

The enormous potential of reused components for the reduction of greenhouse gases also casts the economic evaluation in a different light: If, when making the comparison per component, a realistic monetary value was attached to the CO_2 eq savings shown, this would also significantly shift the cost per component in favour of reuse.

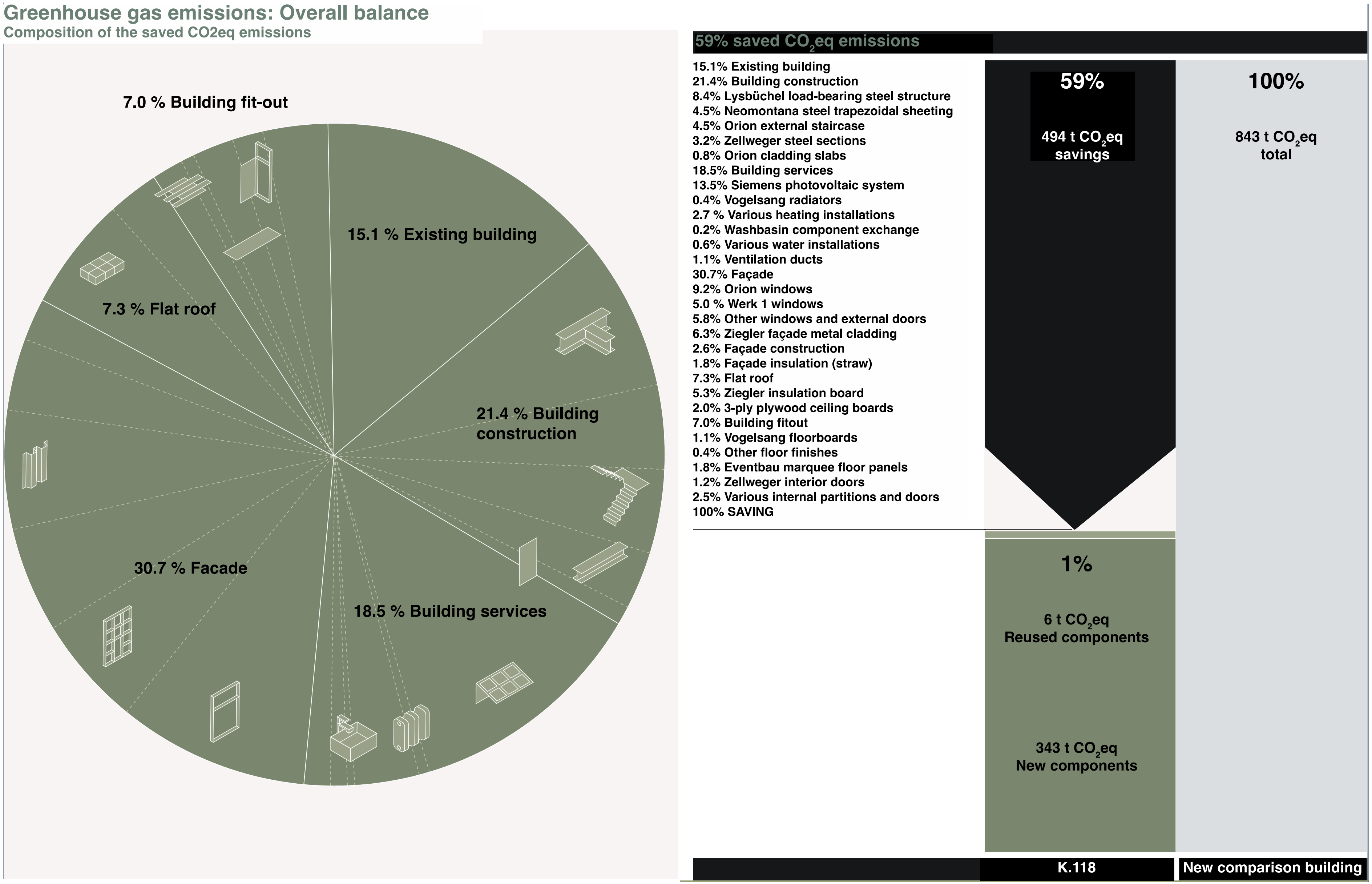
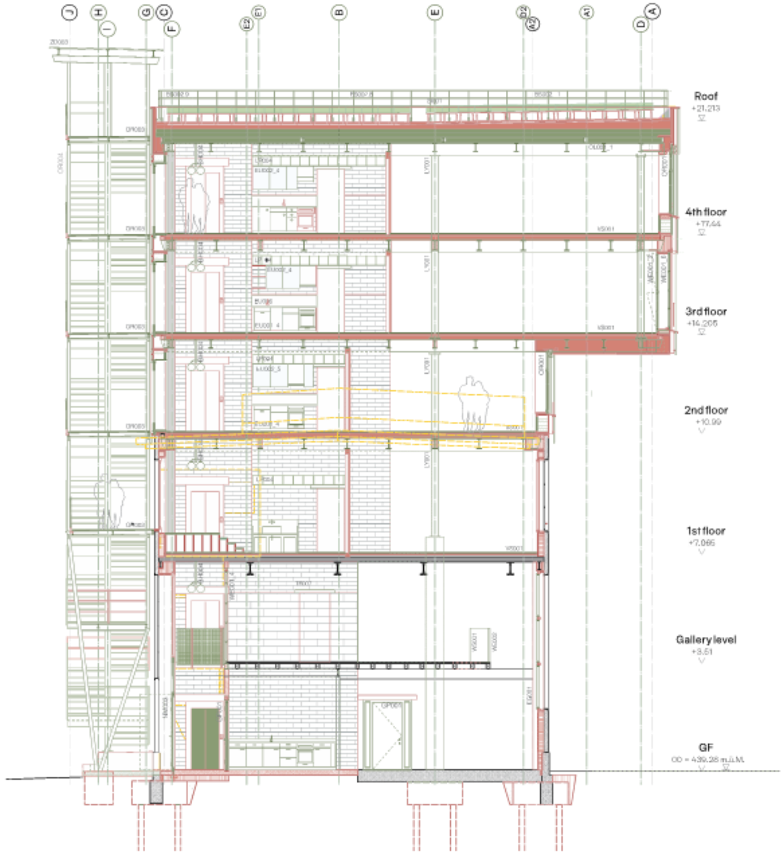


Figure 15: Greenhouse gas emissions: Overall balance, ©ZHAW

3.6 Plans, sections and details of the K118

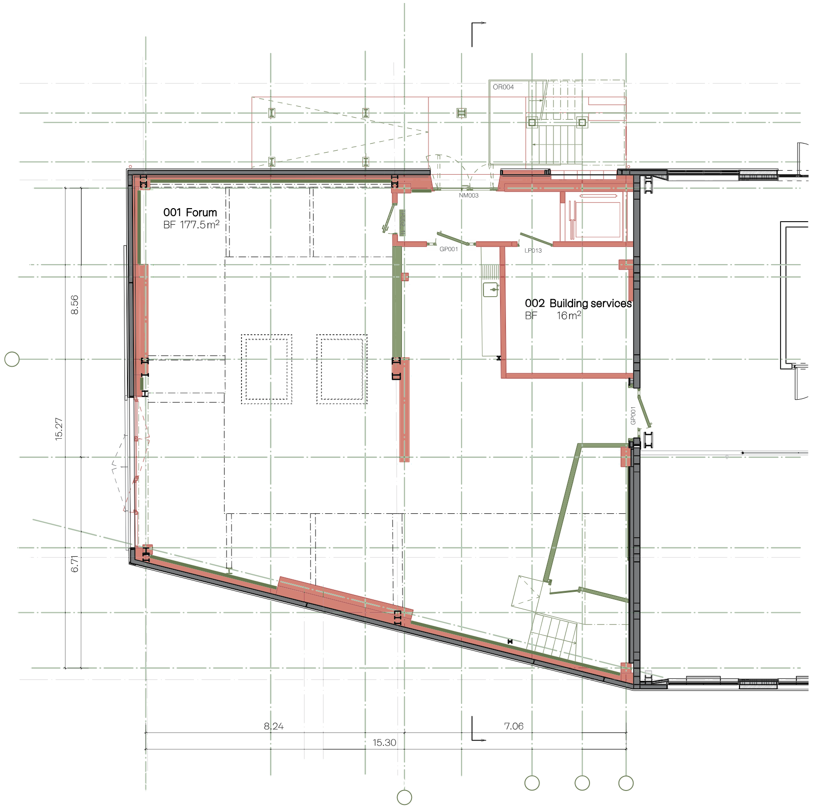


South-west elevation

10m

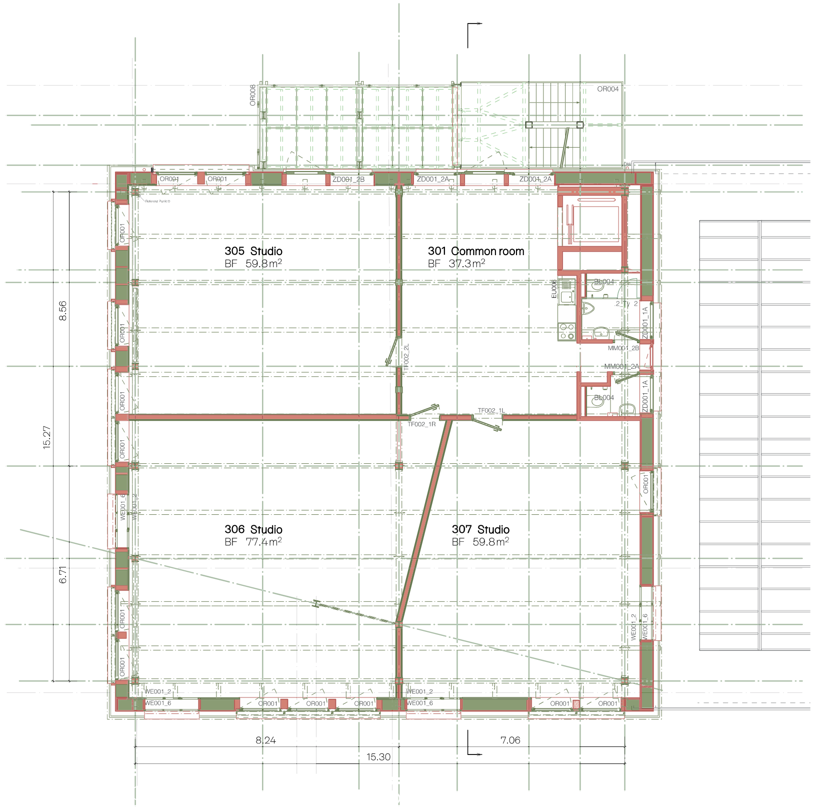
Figure 16: Façade and Section ©Baubüro in situ

New build reused/straw/clay New build unclassified/new
Existing
Demolished
XY000 Component numbers



Ground-floor plan

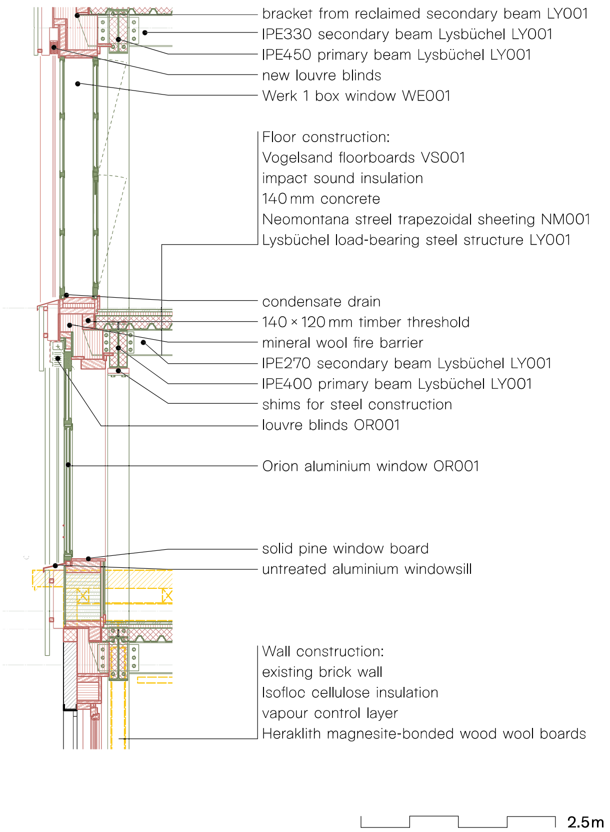
10m

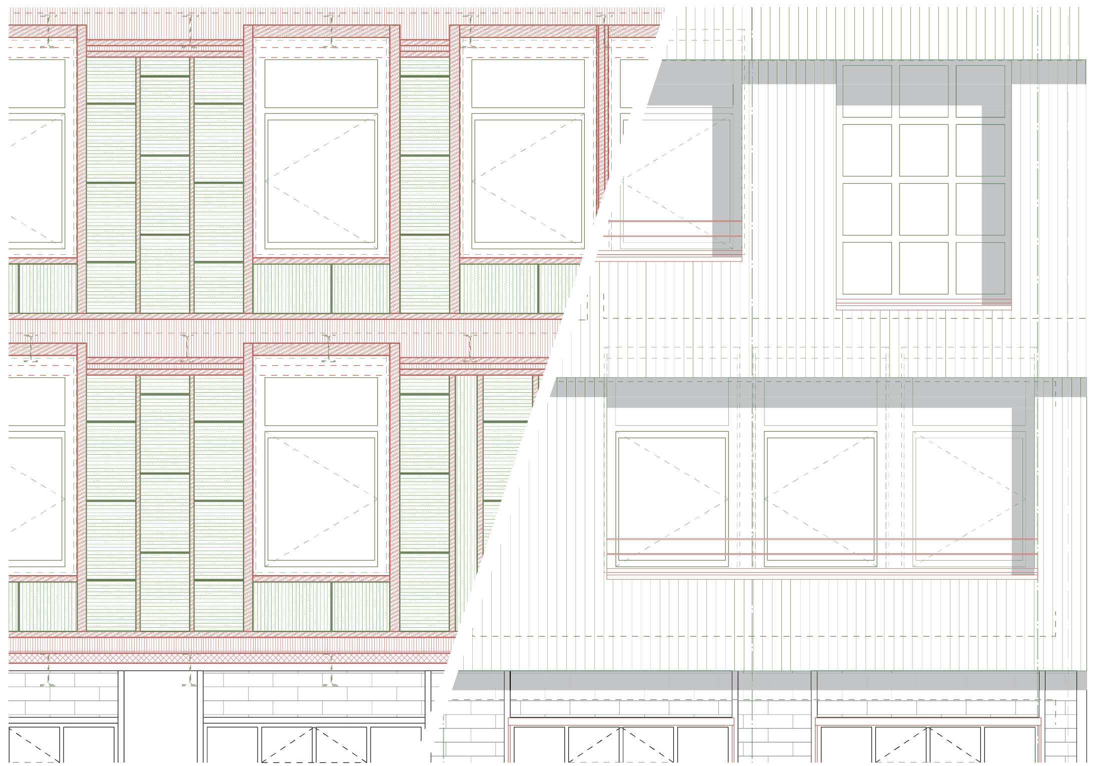


3rd-/4th-floor plan

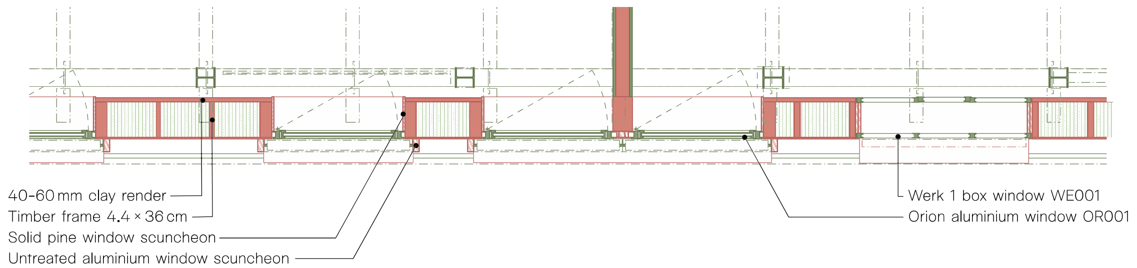
10m

Figure 17: Ground Floor and 3rd and 4th Floor plan ©Baubüro in situ





Façade elevation unclad/clad



Horizontal section through façade

Figure 18: Detail section and floor plan with view of the K118 Façade ©Baubüro in situ

4. DESIGN FOR DISASSEMBLY

4.1 Introduction and Definition

Design for disassembly (DfD) is a practice aimed to facilitate and value the deconstruction processes and procedures. This will be achieved by meticulous consideration from planning and design stage. (Rios, F. C., Chong, W. K., & Grau, D. (2015). Design for disassembly and deconstruction-challenges and opportunities. Procedia engineering, 118, 1296-1304.) DfD enables the disassembly of the buildings and subsequently reusing/recycling the building's components. DfD is one of the fundamental measures in achieving the goal of energy, resource and waste production reduction. (Thormark, C. (2007, September). Motives for design for disassembly in building construction. In International congress sustainable construction, materials and practices challenge of the industry for the new millennium, Lisbon.)

Some of the main principles of DfD can be summarized as follows: 1) through documentation of materials and deconstruction methods; 2) accessible and simple design of connections and joints design. This comprises of use of detachable connections such as bolts, screws, and nail connections instead of welded and chemical connections and incorporating prefabricated and/or modular components 3) separation of non-recyclable, non-reusable and non-disposal items, such as mechanical, electrical and plumbing (MEP) systems; 4) implementing simple building design that enable the standardization of elements and dimensions and 5) reflection of labor practices, productivity and safety in the design [13].(Rios, F. C., Chong, W. K., & Grau, D. (2015). Design for disassembly and deconstruction-challenges and opportunities. Procedia engineering, 118, 1296-1304.)

Some of the examples of DfD approach can be seen in the following projects:

4.1.1 Bridges of Toni el Suizo

Toni Rüttimann is a Swiss bridge builder. In 1987, he travelled to Ecuador to do social work, after the country had been hard hit by an earthquake. The adversities the people faced there encouraged him to help rebuild the destroyed infrastructure.

His designs are a direct product of the materials that were available at no cost in the oil fields of the Ecuadorian jungle: used steel pipes, steel cables, and hardwood, as well as sand and stone contributed by the villagers. Even today, little has changed in the choice of materials, except the steel pipes and cables now come from sponsors in Argentina and Switzerland.

Rüttimann's bridges are suspended cable structures with different spans but always the same components: they consist of bridge pylons, main cables, suspender cables, a bridge deck, and anchorage blocks. Such a design uses materials very efficiently, since all the main elements except the bridge pylon are under tensile loading. The full capacity of the cross section can thus be activated without having to account for reductions linked to stability problems. However, the bridges have no redundancy. If one of the elements fails, the result is a total collapse, which is why the safety factors that Rüttimann uses for the engineering play a central role. They differ according to the bridge element and are dependent on the quality of the source material. The bridge components are stored in different countries and are inspected, assessed, and rated. This data is compiled in a spreadsheet and the safety factors are chosen as a function of the material assessment.

Rüttimann builds his bridges in such a way that they can later be dismantled and then rebuilt elsewhere. Only the juncture points of the pylon segments are welded. The rest of the nodes are made with bolted connections, which enables disassembly into segments of transportable size. It is thus theoretically possible to build a bridge of the same length or less without using additional components.

Figure 19: TRANSFER OF CABLES AND THEIR USE IN THE CONSTRUCTION OF THE BRIDGE. ©VANDERWALM

4.1.2 The Circular Building, London, Arup

As part of the "London Design Festival", taking place from the 17th-25th September 2016, Arup has collaborated with FRENER & REIFER and BAM to create the Circular Building, an installation acting as a circular economy prototype located outside The Building Centre (who also provided support). The partners have teamed up to apply and test circular economy principles in the construction industry by asking the following question: "Can we design a building where, at the end of its life, all its components and materials can be re-used, re-manufactured or re-cycled?" Asking this question profoundly alters design and construction priorities. There needs to be a significant change in thinking about materials and construction process. (https://www.frener-reifer.com/news-en/circular-building-installation-and-exhibition-in-london/)

The installation is an extremely low-waste, self-supporting and demountable structural insulated panel (SIPs) wall system. Clamp connections between the wall and recycled steel frame ensure that both can be repurposed in the future. The cladding and decking are sustainably sourced heat-treated timber that is durable and recyclable.

"The temporary pavilion is constructed and furnished using products that demonstrate how users can reuse and repurpose items," says Nitesh Magdani, Director of Sustainability at BAM. "We hope to inspire companies and individuals to adopt a more flexible approach to spaces, which allows them to easily adapt areas to meet future requirements, and without generating waste."

BAM's supply chain has been responsible for providing many of the items on show in the pavilion, some of which have been chosen to demonstrate the cradle-to-cradle ethos behind the Circular Building. For example, visitors could see:

- Autex – an acoustic fabric that also provides the wall structure and finish. Unlike traditional products, Autex is detachable, enabling people to easily change the look and feel of their space and quickly access services behind the fabric. Made from recycled bottles, it is also insulating and can be used as a pin board.
- Desso – loose lay floor tiles, which have been designed and manufactured using the circular ethos.
- Buzzi Space furniture – which features detachable upholstery and recyclable foam fillings and frames.
- Orange Box's first European accredited cradle-to-cradle task chair, which has components that can be easily replaced, repaired or upcycled.
- A green wall made of demountable troughs that can be easily detached when plants need to be watered or replaced.
- Sustainable timber joists/battens – widely used in the pavilion, Travis Perkins is evaluating how best to recover used materials and maintain value for future uses or resale.

Figure 20: FROM LEFT TO RIGHT: AN INSTALLATION CREATED OUTSIDE THE BUILDING CENTRE FOR THE LONDON DESIGN FESTIVAL 2016. THE STEEL STRUCTURE OF THE CIRCULAR BUILDING. THE INTERIOR SPACE OF THE CIRCULAR BUILDING. EXPLODED AXONOMETRIC VIEW OF THE STRUCTURE AND ELEMENTS OF THE CIRCULAR BUILDING. ©ARUP

4.1.3 House of Switzerland, Zürich, Spillmann Echsle Architekten

The appearance of the House of Switzerland in Zurich, the temporary sporting center of Europe, transformed the new Sechseläuten Square into an attractive and dynamic meeting zone during the home European Championship. The House of Switzerland is a mobile house that uses wood as a material. The expression of this largely standardized kit consisting of 193 elements and 1300 screws, is tectonic. The elements are divided into different basic types: floor, ceiling, roof, and wall elements. In addition, the open spaces of the wall elements have been either glassed, grated, or filled with three- layered wood panels according to use. Four archaic, radially arranged structures connected to each other with metal locks span an inner courtyard. The dimensions of the prefabricated wooden building elements correspond to those of standard transport. The entire kit can be transported in just 14 trucks.

The connections in this building are all demountable, as can be seen in the figures below, allowing for multiple assembly and disassembly of the building in different location. With a construction time of less than two weeks, the individual elements are placed on site on foundations, assembled, fitted together and screwed together.

A house that has gone on tour, mantled and dismantled for the follwoing events:

- House of Switzerland in Sochi (RU), “Olympic Games”, February 7th- 23rd, 2014
- House of Switzerland in Milan (IT), “Giro del Gusto”, from May 1st-10th, 2014
- House of Switzerland in Zürich (CH), European Athletics Championships, from August 12th-17th, 2014

Figure 20: IMAGES FROM THE CONSTRUCTION SITE, SECTION AND PLANS OF THE HOUSE OF SWITZERLAND ©SPILLMANN ECHSLE ARCHITEKTEN

4.2 Teaching Furniture Re-use at ZHAW

4.2.1 Overview

EU member states currently manufacture 28% of furniture sold worldwide, representing a €84 billion p/a market with approximately 1 million European workers. EU member states are also a major consumer of furniture, estimated at €68 billion, which equates to about 10.5 million tonnes of furniture p/a. Total annual waste from the furniture sector, commercial waste from production and disused furniture combined, adds up to 10.8 million tonnes p/a, of which 80%-90% is incinerated or sent to landfill. Only about 10% of waste (materials and disused furniture combined) are recycled. The remanufacturing (refurbishing) of furniture is currently estimated to generate a €300 million turnover with 3400 European workers, equalling to less than 1% of the total furniture industry .

Clearly, this mode of production is not sustainable. In the face of increasingly noticeable, negative effects of climate change, and the scarcity of primary material resources (wood), the furniture industry, like many other branches of industry, is under pressure to rapidly transition to more sustainable modes of production. Furniture manufacturing companies, most of them SMEs, are faced with the complex challenge to develop and implement new business strategies, while regulatory frameworks still incentivise linear take-make-waste business models. The European Furniture Industries Confederation therefore proposes a gradual, step-by-step transition to a circular economy, accompanied by changes in regulation policy, to ensure economic viability at all stages of the process.

On the level of EU policy making, the problem is recognised: "The only solution for fighting climate change and the overburdening of Earth's natural resources is a quick transition from the linear flow of materials and energy towards a circular model.". A number of initiatives is under way to ban harmful manufacturing practices and enable and promote circular business models. As an example, implemented already in 2018, an EU guideline specifies that new products will need to be easily repairable, implying their circular construction and design. As of 2026, furnishings for new public buildings will be required to consist of at least 35% of pre-existing, remanufactured materials and products.

The necessity for change towards sustainable, future-proof business models has been emerging for several decades and a number of pioneering furniture companies have experimented and implemented new business models early on, which are both sustainable and economically successful. For example, Steelcase, the world's largest furniture manufacturer in the office sector, have received their first full Cradle-2-Cradle certification for an office chair and are continuing to integrate circularity principles fully into their business strategy. Requirements for Cradle-2-Cradle certification are Design for Disassembly, Full Circularity of Components and Materials, and abandonment of environmentally harmful materials and processes, among others. Swiss furniture manufacturer Girsberger, on the other hand, offer an extensive and very successful refurbishing and remanufacturing scheme for used furniture from the office and object sector (commendably, the programme is not limited to their own products).

Figure 21: REFURBISHED EASY CHAIR BY GIRSBERGER ©HTTPS://GIRSBERGER.COM/DE/LOESUNGEN/REMANUFACTURING/

4.2.2 Case Study

The transition to sustainability and circularity in manufacturing and product development is a complex matter, because it involves several interconnected subject areas: regulatory aspects, questions of business model generation, production technologies and new modes of consumption, as outlined above. For designers and architects, at the core of the challenge is the use of existing, pre-used materials and components and their transformation into new, functional and desirable objects. Naturally, these new products need to be constructed for circularity and easily dissamblable.

To familiarise students with the challenges ahead, we run an elective design course which explores how waste material can be transformed into new furniture, by using digital fabrication tools . In its first edition 2022, "Parametric Off-Cut Furniture", funded by ZHAW's "Digital Futures Fund", students were asked to source off-cut materials from a skip on a building site. After analysing a specific living situation, they devised a multifunctional side table for the home. By using the innovative Shaper CNC, a hybrid, hand-held CNC-router they were quickly able to prototype their designs. Particular attention was given to the development of joints and connections which do not require glue or additional fasteners and can therefore easily be taken apart again. The precision of the digital machining enabled students to easily fabricate very precise joints, even without prior knowledge of woodworking techniques. This empowering experience in turn inspired a great sense of motivation.

In the second edition of the course, "Open-Source Design", the brief was to design a seating occasion for three people, thus integrating questions of structural load bearing, statics and ergonomics. The range of available manufacturing technologies was opened to include 3D-printing, laser cutting and regular CNC machining. Materials still had to be re-used, but now also included cardboard, cement and building components. While students evaluated the project to be much more difficult than the first edition, due to the increased complexity of the brief, the results were promising: ten teams of 2-3 students successfully produced seating furniture prototypes which met structural criteria.

An underlying theme when working with digital CAD and computer-controlled fabrication processes is the inherent variability of the design. While virtual, designs can easily be adapted and changed, both on a macro scale to "accustom" for varying needs, e.g. seating heights in chairs, as well as on a micro scale to integrate material tolerances (of re-used material). In the current semester, with the project "Variable Objects", we investigate possibilities of variable designs in terms of functionality, design and construction. Of particular interest are proportional systems such as Le Corbusier's "Modulor", conceived to ensure high quality in varying scales.

In the context of our School for Architecture, Design and Civil Engineering, naturally, the aim is to design and build a larger spatial structure with students, a "Circular Off-Cut Pavilion". We just received funding from the University's Sustainable Impact Program for a pilot course next spring, currently named "Spatial System", where the concepts of the first two courses will be developed into a larger structure with wall panels and overhead components.

We are observing that running these hands-on, design-and-build studios which give students an opportunity to experiment, learn and interact with principles of Re-Use, Circularity and Disassembly in a workshop environment are a very effective way for the principles to be properly understood and internalised, thus enabling our future practioners to apply them creatively in their architectural practice. Furthermore, the resulting furniture prototypes communicate very effectively our group's core mission, how Digital Fabrication in combination with reclaimed materials can be utilised to produce high quality and fully circular products and components.

Figure 22: STUDENT PROJECTS FROM LEFT TO RIGHT. "BRIBBON", PARAMETRIC OFF-CUT FURNITURE, STUDENTS FIONA HUBLER, SIMONE MAHLER. "BRIBBON", DETAIL, PARAMETRIC OFF-CUT FURNITURE, STUDENTS FIONA HUBLER, SIMONE MAHLER. "SCHALTABLE", PARAMETRIC OFF-CUT FURNITURE, STUDENTS FERDINAND MATTHIAS, ENDRIT MEMETI. SAFE DIGITAL FABRICATION WITH THE SHAPER CNC, PARAMETRIC OFF-CUT FURNITURE, SINA ELMER, ZHAW WORKSHOP STAFF. ENTHUSIASTIC STUDENTS WITH PRECISE PRESS-FIT JOINT, PARAMETRIC OFF-CUT FURNITURE, STUDENTS ABIDIN MEMETI, MANUEL JECK. RAW MATERIAL FROM A BUILDING SKIP, PARAMETRIC OFF-CUT FURNITURE. "GRID FUSION", BENCH MADE FROM RECYCLED VENTING DUCT GRID WITH 3D-PRINTED CONNECTOR, DETAIL, OPEN SOURCE DESIGN, STUDENTS DOMINIK METTLER, SIMON OTT. "SCHWALBENECK", FURNITURE SYSTEM WITH PARTIAL MACHINING AND 3D-PRINTED CONNECTOR, OPEN SOURCE DESIGN, STUDENTS YANOSH SIMENIC, TIL STEIGER ©ZHAW

5. REPORT ABOUT TRIP TO DEMO PROJECT FIELD

From October 16th to October 26th, the Swiss delegation did partake in a collaborative journey to China as part of the Sino-Swiss Zero Emission Building Project. This initiative is a step towards building a climate-neutral future, providing Swiss innovation to Chinese partners to foster sustainable building practices.
The delegation commenced their journey in Beijing. Here, they participated in the Sino-Swiss Industry-University-Research Institute Collaboration Forum on Zero Emission Building and engage in technical exchanges at the DP Beijing site. The ZHAW provided knowledge and expertise on Zero Emission Design (ZED), Design for Disassembly and Reuse (DfD/reuse). After the lectures the partners participated in various workshops, for example a workshop about reuse in construction. After sessions in Beijing, the team traveled to Shanghai where they conducted technical exchanges and site visits with the DP Shanghai team.

The journey did then lead to Wuxi, where the delegation visited the DP Wuxi project site and engaged in workshops centered around ZED and DfD/reuse concepts, before returning to Shanghai.

As the trip concluded the members of the delegation departed from Shanghai to Zurich, marking the end of the exchange that promises to pave the way for a sustainable and eco-friendly future in building practices.

Figure 23: THE SWISS DELEGATION IN BEJING, OCTOBER 2023

5.1 Impressions of the built Environment

China could be summaries as a country of striking contrast. Between the poles of ancient tradition and state of the art modern technology. China's cities are a mix of historical structures, such as temples and palaces, alongside contemporary skyscrapers and urban developments.

China is home to a wealth of historical architecture, like the Great Wall, Forbidden City (which we were able to visit), and numerous ancient temples. These structures are emblematic of China’s rich cultural history and architectural heritage. Contrasting the ancient architecture is the modern development. In the last decades, China has experienced a construction boom, resulting in modern skylines dominated by skyscrapers. Cities like Shanghai and Shenzhen are notable for their unique rapid development. Rapid urbanization in China has led to the development of sprawling urban areas. Megacities have expanded with new residential, commercial, and industrial zones, often blending traditional styles with modern influences. What is impressive coming from a European background is the sheer number of buildings of the same type lined up next to each other within the neighborhood.

Figure 24: SNAPSHOT FROM BEJING. ©ADRIAN KIESEL

5.1.1 Infrastructure Growth

China has invested heavily in infrastructure, including the world's largest network of high-speed trains, expansive highways, and significant renewable energy projects. There is an increasing focus on sustainable development in response to environmental concerns. However, issues like urban sprawl and air pollution remain challenges. What we noticed is that the emphases of the sustainable development in China lays on the reduction of the operational carbon with no regard to the embodied carbon. This is a major issue that needs to be addressed. Despite modernization, traditional aspects like local markets, street food, and historic neighborhoods offer a deep sense of China's cultural richness.

Differences compared to European cities that stood out on our journey are the following:

- European cities often focus more on preserving historical architecture, whereas Chinese cities exhibit a stronger blend of historic preservation.
- European cities tend to have more consistent urban planning reflecting their longer histories, while Chinese cities can sometimes feel more haphazard due to rapid growth and development.
- European architecture is characterized by a variety of historical styles like Gothic, Renaissance, and Baroque, while Chinese architecture blends ancient styles with cutting-edge modern and post-modern designs. There is no red line connecting modern architecture to the ancient building traditions.
- European cities often integrate green spaces into urban planning more seamlessly, while in China, the integration of such spaces is a more recent development and varies greatly between cities.
- In summary, visiting China's built environment offers a window into a society and political system which is at once rooted in history yet driving towards the future presenting a striking contrast to the more historically consistent European urban landscapes.

5.2 Workshop 18. October 2023

5.2.1 Lecture

Within the role in the Sino-Swiss Industry-University-Research Institute Collaboration on Zero Emission Building the ZHAW gave a lecture and held a workshop on the topic of embodied carbon. The presentation explores the innovative concept of Design for Disassembly (DfD) and the Reuse of building components as a crucial role in China's evolving built environment to lower the embodied carbon emissions. This approach, pivotal in the transition towards sustainable urban development, aligns with China's growing focus on environmental stewardship amidst its urbanization and infrastructural expansion. As China's cities witness unprecedented growth, integrating DfD principles offers a path to reduce environmental impact. If building components can withstand more than one lifecycle of a building, its sustainability increases. To reach that goal buildings need to be constructed in such a way, so that its' components can be easily harvested.

5.2.2 Design Principles in Action

Through case studies and examples, we showcase successful implementations of DfD and ReUse in Switzerland's building environment (for example the K118 building by Insitu). These examples illustrate the feasibility and benefits of designing buildings with the end-of-life phase in mind, promoting material reuse and recycling. Those principles are then applied the partner projects in China. Please have a look in the section of the Final Report about the design suggestions about Reuse and Design for Disassembly for the Demo Projects in Shanghai and Shaanxi.

Our presentation aims to inspire architects, urban planners, and policymakers in China and beyond, advocating for a built environment that is not only aesthetically and culturally rich but also sustainable and forward-thinking, thanks to the principles of Design for Disassembly and Reuse.

Our input aligns with the broader themes of sustainability and modernization in China's built environment, highlighting the critical role of innovative design practices in shaping the future of urban development.

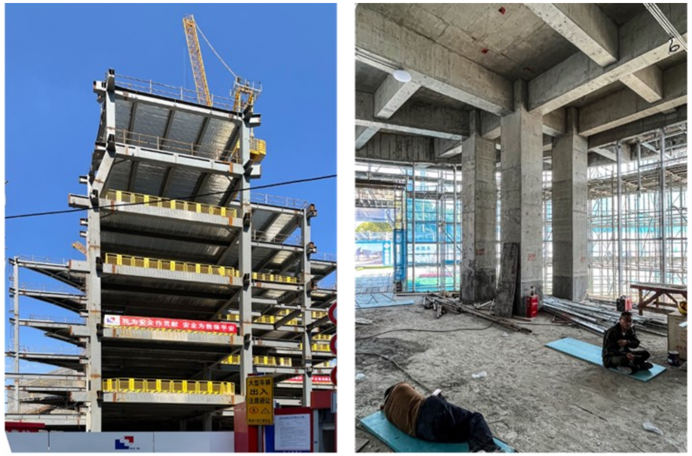


Figure 25: Construction site, Demo Project, ©ADRIAN KIESEL

5.2.3 Site Visits

Bejing

The capital of China is the city where Chinese history and contemporary life meet. It is home to some of the country's most treasured historical sites, including the Forbidden City and the Temple of Heaven. Beijing's urban landscape is a tapestry of old hutong alleys and imposing modern architecture, reflective of its status as the political and cultural heart of China. Located in this urban fabric is the site of the first case study building. In this project the ZHAW has no mandate but is still providing knowledge to the architects while on site. A significant emphasis was placed on implementing a system to measure and control energy consumption, distinguishing between heating, cooling, water, lift, and ventilation. In general, it seems like smart design decisions were carried out. For the planers it seems important to also visualize the generation of energy and the smart management of the building to its visitors. It is interesting that high-tech architecture is a symbol of progress. We would advise monitoring embodied carbon emissions during the design phase and a shift towards low-tech, high-yield interventions instead of high-tech solutions that tend tobe more carbon-intensive and require frequent repairs.

Figure 26: Beijing Demo Project on site, ©ADRIAN KIESEL

Short introduction about the Beijing DP

In March 2022, the “Beijing Fangshan China Construction First Building (Group) · Xuefu Yinyue Zero Carbon House Project” was selected as one of the 1st batch Demonstration Projects of Sino-Swiss ZEB Project. This project is a ministerial-level international cooperation project initiated by the Chinese Ministry of Housing and Urban-Rural Development and the Swiss Agency for Development and Cooperation. The project commenced in May 2021 and, after more than two years of joint efforts by Sino-Swiss teams, was officially completed with its construction on September 27th 2023 and achievement of ZEB goal.

- Investor: C-Land real estate
- Planning team: SUP Atelier of THAD(Architect) + CABR (Energy Consulting) EE
- Sino-Swiss ZEB consulting team: Intep, Skat, CABR, Low-Tech, UAD, HSLU, EMPA, ZHAW etc.
- More details please see Summarizing Report for Sino-Swiss ZEB Demo Project “Gongchen Community Center in Fangshan District, Beijing”

Figure 27: Beijing Demo Project ©Atelier SUP

Shanghai

Shanghai stands as a symbol of China's rapid modernization and global influence. The metropolis is characterized by its iconic skyline, featuring architectural features like the Shanghai Tower and the Oriental Pearl Tower. Shanghai is a mix of cultures and styles, from the historic Bund with its colonial era buildings to the ultra-modern Pudong district. It’s also Chinas window to the west and its economical capital.

The Shanghai project is part of the ZHAW mandate. Here the focus is on Reuse of the interior elements of the exhibition hall, which is currently under construction. The visit is divided into two parts. Firstly, the building site is to be explored, the second part of the day will be shaped by the lecture of the ZHAW regarding DfD and Reuse.

Short introduction of Shanghai DP

Figure 28: Shangai Demo Project on site, ©Sino-Swiss ZEB Project

In April 2023, the project "Public and Residential Building District, Jiading, Shanghai" was selected as one of the 2nd batch Demonstration Projects of Sino-Swiss ZEB Project. This project is a ministerial-level international cooperation project initiated by the Chinese Ministry of Housing and Urban-Rural Development and the Swiss Agency for Development and Cooperation. The project commenced in May 2023 and, after around 1 year of joint efforts by Sino-Swiss teams, is expected officially completed with its construction in May 2024.

Figure 29: Construction site of Wuxi Demo Project and workshop on site, ©ADRIAN KIESEL

- Investor: Shanghai Jia Future Property Co., Ltd
- Constructor: Shanghai Jia Future Property Co.,Ltd
- Planning team: East China Architectural Design &Research Institute Co.,Ltd
- Local ZEB consulting team: East China Architectural Design &Research Institute Co.,Ltd
- Sino-Swiss ZEB consulting team: Intep-skat, CABR low-tech, UAD, HSLU, EMPA, ZHAW etc.

- Location: Shanghai (Climate zone hot summer cold winter)
- Building use: Market, Exhibition Hall
- Structural system
  - Market: Steel frame and wood mixed structure system
  - Exhibition hall: Concrete structure
- Area
  - Total construction area: 9566.8 m2 total
  - Building energy reference area:
    - Market hall: 3446.5m2
    - Exhibition hall 2804.9m2
- Investment costs: ca. 70 million RMB

Figure 30:: Shanghai Demo Project ©XXXX

During our exploration of the building site a common theme starts to emerge. It is state of the art construction practice to use concrete wherever possible. The entire structure of the building is made up out of reinforced concrete. Due to the fact that the structure is already built it is recommended to leave the structure raw and to forgo a carbon intense finish or and decoration. Within this concrete shell temporary exhibition walls and panels can be placed. Those should either be built in a way so that they can easily be taken apart in the future or be built out of sustainable material like wood. All wiring like network cable and power cords can and should be reused. It is recommended to install used wires instead of new ones. In addition, all lamps and lightening objects should be reused and not new. That way we hope the building will work as a strong structure with temporary exhibitions that can be assembled and disassembled without wasting resources.

Wuxi

It is a city located 135 kilometers to the northwest of downtown Shanghai. It is a smaller, more traditional city compared to the bustling metropolises of Beijing and Shanghai. Wuxi is celebrated for its picturesque landscapes, including the famous Lake Tai, and its rich cultural heritage, evident in its ancient temples and gardens. Simultaneously, it has emerged as a hub for high-tech industries, especially in sectors like solar technology and software development.

Short introduction of Wuxi DP

In this project the ZHAW has no mandate but is still providing knowledge to the architects while on site. The visit is divided into two parts. Firstly, the building site is to be explored, the second part of the day will be shaped by a lecture regarding the topric of DfD and Reuse by the ZHAW and a lecture by the FHNW.
In March 2022, the "Wuxi Shangxian Lake Low-Carbon Digital Industrial Park" was selected as one of the 2nd batch Demonstration Projects of Sino-Swiss ZEB Project. This project is a ministerial-level international cooperation project initiated by the Chinese Ministry of Housing and Urban-Rural Development and the Swiss Agency for Development and Cooperation. The project commenced in Jun. 2022 and is planned to be completed with its construction in Nov.2024.

- Investor: Wuxi Taihu New City Urban Development Co.
- Planning team: China Academy of Building and Research (CABR)

- Sino-Swiss ZEB consulting team: Intep-skat, CABR low-tech, UAD, HSLU, EMPA, ZHAW etc.
- Location: Wuxi, Jiangsu, China (Hot Summer Cold Winter; Solar Resource Area IV)
- Area
  - Total planned land area 96657.4 m2
  - Total construction area of 210980 m2
- Demonstration Building: Mix functions with office, conference, exhibition, education
- Building Size: 210980m2
- Building Height:
  - 1# (1- 3 floors above ground);
  - 2# (7 floors above ground);
  - 3-6# (5 floors above ground);
  - 7-10（2- 3 floors above ground）
- Phase I: ground floor B1+ second floor B2
- Phase II: ground floor B1
- Investment costs: ca. 2’170’622’600 RMB total

Figure 31: Wuxi Demo Project ©Wuxi DP

After starting the tour through the building site, the sheer amount of concrete used becomes apparent. Positive is the use of thermal energy to heat the building and the incorporation of large areas for photovoltaic.
In the afternoon the ZHAW held a lecture on DfD and Reuse for the planner team. Principles of sustainability and embodied carbon were communicated and discussed. The strategy of the project team for this building complex is to minimize operational carbon with no regard to embodied carbon. An approach that should be change to cooperate both.

5.3 Initiating Step 2 – Reuse Game & Education

5.3.1 Reuse Game and embodied carbon demonstration

In an engaging and educational reuse game designed for Chinese urban planners, architects, and university representatives, participants embark on a hands-on journey towards sustainable urban development. This interactive game challenges players to rethink traditional construction methods by focusing on material reuse, DfD and CO2 emission reduction.

5.3.2 Game Mechanics

Players aim to construct a building using primarily reused materials. The challenge lies in the limited availability of these materials, compelling participants to make strategic decisions about incorporating new, higher CO2 emission materials.

Participants start with a budget and can buy reusable building parts in a monopoly style way. The game simulates the real-world scarcity and cost implications of sustainable materials, pushing players to think critically about resource allocation. Each building component, whether reused or new, carries a specific CO2 emission value, a disassembly score, and an allocated cost. Players must try to maximize the CO2 reduction within their allocated budged, striving to minimize their environmental impact.

Players within a team are encouraged to discuss and debate their strategies for balancing budget constraints with the goal of achieving the lowest possible CO2 emissions. This aspect of the game reflects the collaborative nature of real-world sustainable urban development.

Throughout the game, players are introduced to concepts like embodied carbon, lifecycle analysis, and the environmental benefits of reusing materials. The game serves as a practical demonstration of these principles in action.

5.3.3 Outcomes

The game raises awareness among participants about the challenges and opportunities in sustainable building practices, especially in the context of China's rapidly modernizing cities.

By simulating the decision-making process in urban development, the game provides valuable insights into how sustainability can be integrated into actual architectural and urban planning projects.

The game inspires creative thinking and innovative solutions, encouraging participants to explore alternative materials and construction methods that are both cost-effective and environmentally friendly.

5.3.4 Conclusion

The Reuse Game serves as a powerful tool for educating and engaging key stakeholders in China's built environment. By simulating the complexities of sustainable development within the building with reuse materials and building DfD, it fosters a deeper understanding of the importance of material reuse and the impact of construction practices on carbon emissions, paving the way for a more sustainable future in urban design and architecture.

5.4 Future Education

The reuse game has significant potential as an educational tool for university students, particularly in architecture, urban planning, and environmental studies programs. By incorporating this game into the university curriculum, students can gain practical insights into sustainable building practices from an early stage, fostering a bottom-up approach to sustainability in the built environment.

The game offers an engaging and interactive method of learning that complements traditional lectures and textbooks. It provides a hands-on experience in understanding the complexities of sustainable building practices. By assigning CO_2 emission values to different building materials, the game educates students about the environmental impact of construction choices. It emphasizes the importance of considering the carbon footprint in architectural and urban design decisions. Students learn to balance financial constraints with environmental objectives. This reflects real-world scenarios where budget limitations often impact material choices, teaching students to find innovative solutions within these constraints.

Because of the streamlined chinese education system it becomes more and more difficult for the students to think outside the box. Within the frameworks of the game students are challenged to think differently and develop strategies to minimize CO_2 emissions while dealing with material limitations. This fosters problem solving skills crucial for addressing real-world sustainability challenges. In addition, the game raises awareness about the principles of design for disassembly, reuse, and emission in construction, tackling the embodied carbon of a building. This knowledge is vital for students who will be future architects and planners, shaping the built environment.

The game can be integrated into a wide range of courses as a practical module, allowing students to apply theoretical knowledge in a simulated environment. It is especially effective if played multiple times. After each time the consequences of the decision should be reflected and discussed. Learnings can then immediately be applied within the next round, making it easier to understand the difficult thought process behind it. The gamification of learning offers an effective alternative to the sometimes-monotone approach of frontal lectures. Universities can organize workshops or seminars where the game is a central activity, supplemented by guest lectures from professionals in sustainable architecture and urban planning.

In addition, Students can be encouraged to modify or expand the game as part of their projects or research, exploring new ways to incorporate additional sustainability factors or urban planning challenges and adding more layers of complicity as their level of understanding increses.

5.4.1 Impact

By introducing this game in university settings, students are not just learning about sustainability in theory but are actively engaging with its challenges and solutions. This experiential learning approach ensures that when these students enter the professional world, they are equipped with a practical understanding of sustainable practices, ready to implement a bottom-up approach to sustainability in the built environment. This early exposure can inspire a new generation of architects and urban planners to prioritize eco-friendly practices in their careers, contributing significantly to the global goal of sustainable development.

5.5 Conclusion

Figure 32: Workshop with all Demo Project at CABR office in Beijing, ©ADRIAN KIESEL

The Sino-Swiss Zero Emission Building Project, supported by the recent Swiss delegation's visit to China, has marked a significant contribution towards sustainable building practices. The journey, covering Beijing, Shanghai, and Wuxi, has not only provided technical exchanges and workshops but also highlighted key areas of learning and adaptation for Swiss and Chinese architects and planners. In addition to foster professional relations, the participants were able to connect on a personal level, elevating the relationship of the different parties.

The project's success in promoting Design for Disassembly and reuse in construction exemplifies how Swiss innovation can contribute positively to global sustainable building practices. The implemented strategies, from advocating for the reuse of building materials to the intelligent design of new structures, demonstrate a commitment to reducing the environmental impact of construction.

Furthermore, the interactive, hands-on reuse game developed for educational purposes underscores the project's innovative approach to raising awareness and educating future architects and urban planners. The game effectively communicates the importance of sustainable practices and the impact of construction choices on the environment.

From the dense urban fabric of China's rapidly developing cities, Swiss architects can glean valuable insights into integrating modern technology with traditional building practices. The Chinese approach to urbanization, characterized by a blend of ancient and contemporary architecture, offers lessons in balancing historical preservation with innovative development. Moreover, the emphasis on high-tech solutions and sustainable urban planning in China presents a model for Swiss architects to explore low-tech, high-yield interventions, reducing both operational and embodied carbon emissions in construction.

In essence, the Sino-Swiss Zero Emission Building Project is a beacon of progress, signaling a promising future for the building industry. It exemplifies how international collaboration and knowledge exchange can lead to more environmentally conscious and sustainable construction practices.

6. CIRCULAR CONSTRUCTION

6.1 Shanghai Marketplace and Exhibition Space DP Project

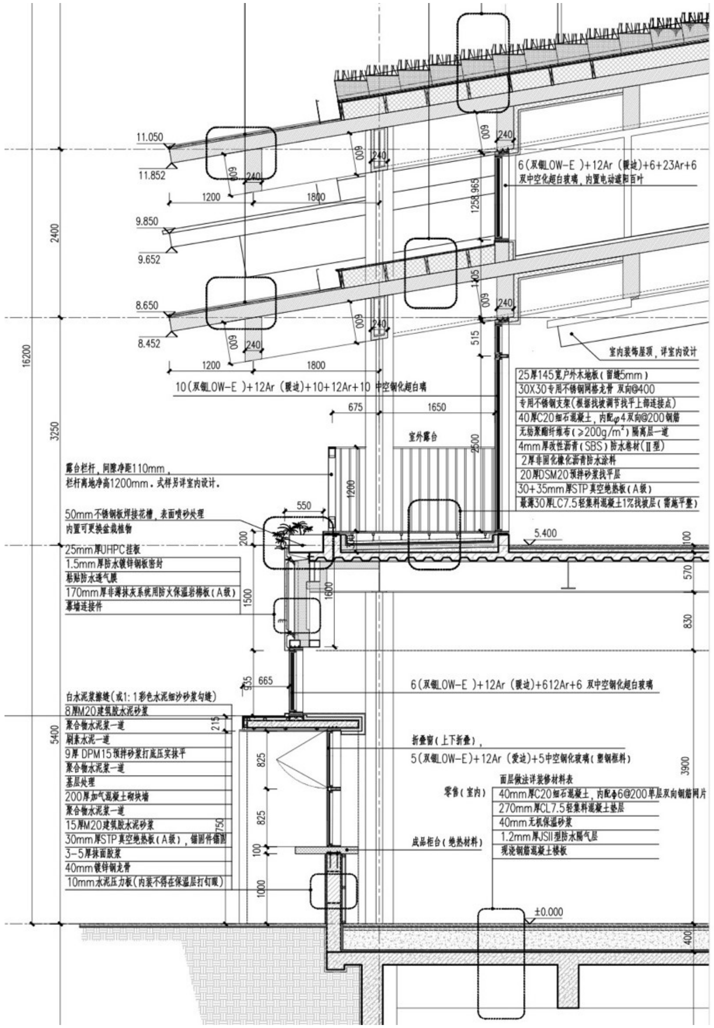


Figure 33: A DETAIL SECTION OF THE MARKETPLACE ALREADY BUILT AND A SECTION OF THE EXHIBITION SPACE

6.1.1 Impact

As Swiss team we analysed two building situated in Shanghai: the Market Place and the Exhibition Hall. The two projects are in distinct phases: the Marketplace is built and already in use. The Exhibition Hall is in the construction phase: at the moment of the visit of Adrian Kiesel (20. October 2023) the main concrete structure was already erected.

6.1.2 Main structure of the two Buildings

The market has a steel structure covered with fireproof wood paneling. The primary roof structure is also steel with only the secondary structure made of wood. The underground floor is with reinforced concrete. The Exhibition Hall, on the other hand, has a completely reinforced concrete structure poured on site. The green façade, which in some images in the presentation was supposed to build a vertical garden like a "carpet covering much of the design, has disappeared from the final execution.

<u>Use of reinforced concrete</u>

In the Marketplace the underground construction which includes Foundations, Slabs and Walls is realised in a standard way in reinforced concrete. In the Exhibitions spaces, all the floors with primary structure and decks are realised with reinforced concrete. Reinforced concrete with steel rods is the most used building material in the world. More than the concrete, the steel rode inside it are the major cause of greenhouse gas emissions.

<u>Load-bearing and roof structure</u>

The primary load-bearing structure of the Marketplace building is built with steel columns and beams elements. The roof construction has also a primary structure of steel beams, covered with wooden elements because of fire protection. The final result hides completely the steel structure hinting at a wooden structure. The decks are built with corrugated metal sheet and concrete poured on site. For the façade there is an extensive use of glass windows.

The roof construction seems to be planned with timber laminated elements. During the visit of Adrian Kiesel was clarified that also the roof construction is in steel covered with wooden anti-incendiary elements.

6.1.3 Suggestions

These comments and suggestions take their cue from precise issues and details of one of the specific case studies but can also be considered as general suggestions for both DP Projects.

Structural bamboo elements instead of steel rods

Figure 34: CONSTRUCTION PHASE OF THE UNDERGROUND LEVEL OF THE HOUSE K IN ALPNACH, SWITZERLAND. ©RASMUS NORLANDER

In the Case-Study Haus K in Alpnach the entire walls of the underground floor were planned and built with bamboos elements replacing the steel rods. This construction solution had been proposed by the client, who at the same time is also the Kung construction company specializing in wooden constructions. The client's willingness to experiment with this construction method relieved the engineer and architect of the possible responsibilities arising from the non-perfect execution of the building.

To date there are few studied cases in the Western world of concrete construction with Bamboo reinforcement. The most credited scientific literature is that of Khosrow Ghavami, one of the first engineers to publish research on the use of structural Bamboo:

- Ghavami, Khosrow. (2005). Bamboo as reinforcement in structural concrete elements. Cement and Concrete Composites. 27. 637-649. 10.1016/j.cemconcomp.2004.06.002.
- Khosrow Ghavami, Romildo D. Toledo Filho, Normando P. Barbosa,
- Behaviour of composite soil reinforced with natural fibres, Cement and Concrete Composites, Volume 21, Issue 1, 1999, Pages 39-48, ISSN 0958-9465
- In the Future Cities Laboratories ETH in Singapore directed by Prof. Dirk Hebel and Dr. Alireza Javadian there is research going on about structural bamboos. More can be read in these papers:
- Hebel, Dirk E., Heisel, Felix, Javadian, Alireza, Müller, Philipp, Lee, Simon, Aigner, Nikita and Schlesier, Karsten. "Constructing with Engineered Bamboo". Cultivated Building Materials: Industrialized Natural Resources for Architecture and Construction, Berlin, Boston: Birkhäuser, 2017, pp. 58-71. https://doi.org/10.1515/9783035608922-007
- Javadian, A.; Smith, I.F.C.; Hebel, D.E. Application of Sustainable Bamboo-Based Composite Reinforcement in Structural-Concrete Beams: Design and Evaluation. Materials 2020, 13, 696. https://doi.org/10.3390/ma13030696
- Maier, M.; Javadian, A.; Saeidi, N.; Unluer, C.; Taylor, H.K.; Ostertag, C.P. Mechanical Properties and Flexural Behavior of Sustainable Bamboo Fiber-

Reinforced Mortar. Appl. Sci. 2020, 10, 6587. https://doi.org/10.3390/app10186587

Reuse of Steel elements (comparison with grey energy emissions with wood structure)

In any case, it would be interesting to consider reusing steel elements for primary structure if it possible. In fact, according to the KBOB Table in Switzerland from 01.2022, a reuse steel structure with elements coming from a Radius of 300 km, would be more sustainable than a new structure with glue laminated timber elements.

According to KBOB Table:

Laminated timber beam A1-A2-A3 Phases	**Reuse Steel element K.118 R1-R2-R3 Phases**
0.287 Kg CO_2 eq	**0.026 Kg CO_2 eq**
from Table KBOB 01.2022	As a reference taken a kg of an HEA 220 beam disassembled in Basel, prepared in Pratteln and brought to the new site in Winterthur ready for assembly (100 km distance)
Element name in German: Brettschichtholz	

Figure 35: KBOB Table comparison between elements. © ZHAW

Re-Use of interiors partitions for the Exhibition space

In the building Exhibition Space, the focus is on the planning of exhibition spaces and related systems of partitions, lighting, and furniture.
In one of the interviews with the Exhibition Space planners, the Swiss team was asked to advise on the construction with reused elements of the interior partitions for temporary exhibitions. All separating walls between spaces, and walls against concrete bearing walls can be made of lightweight material that can be disassembled and reused over time.

Figure 36: ON THIS EXHIBITION FLOOR LAYOUT SUBMITTED ON 11. OCTOBER 2023, THE SWISS TEAM IS ASKED TO GIVE ADVICE ON THE POSSIBLE REUSE OF COMPONENTS. RENDERINGS OF THE EXHIBITIONS. THE STRUCTURE OF THE INTERNAL PARTITIONS COULD BE PLANNED AS WOODEN STUD CONSTRUCTION WITH COUPLED WOODEN FRAMES. ©DEMO PROJECT SHANGAI

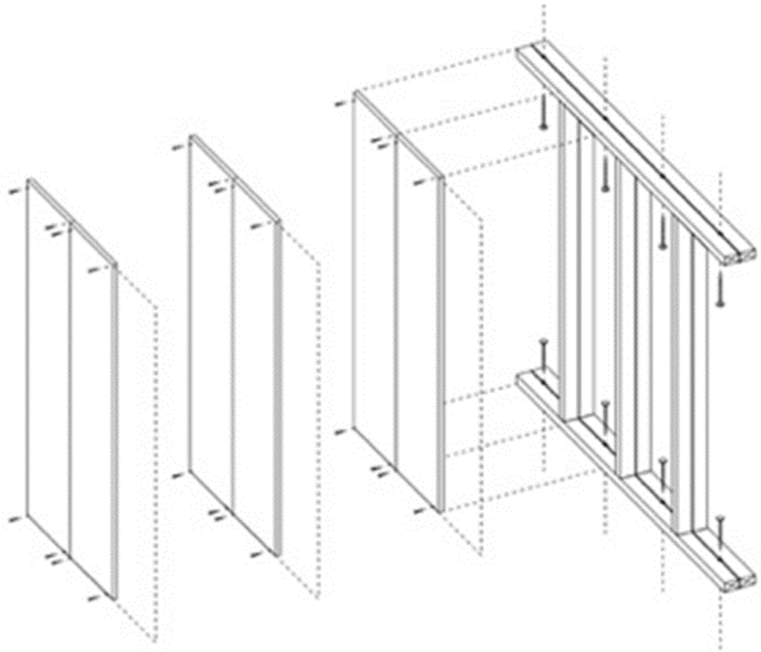


Figure 37: EXAMPLE OF WOODEN STUD CONSTRUCTION WITH COUPLED WOODEN FRAMES. THAT CAN BE DISASSEMBLED AND REUSED OVER TIME. ©ZHAW

Between them could be also planned a rubber strip for sound insulation if the partition needs to be placed between rooms with different functions and sound requirements. The rubber strip is also placed in contact with the floor and ceiling. The structure is than screwed into the floor and the ceiling or it can be connected to the side walls with spacers such as metal or wooden profiles. After the structure is solid, the finishing plates are screwed into the wooden stud construction.

Here are listed 3 possible finishing elements with the calculation (following the swiss KBOB standards, table 01.2022) of their grey emission:

- Finishing element as light fiber-glass concrete element: 1.04 Kg CO2 eq
- Finishing element as Mirror Stainless Steel plate: 333 Kg CO2 eq
- Finishing element in 3-layer panel wood: 0.471 Kg CO2 eq

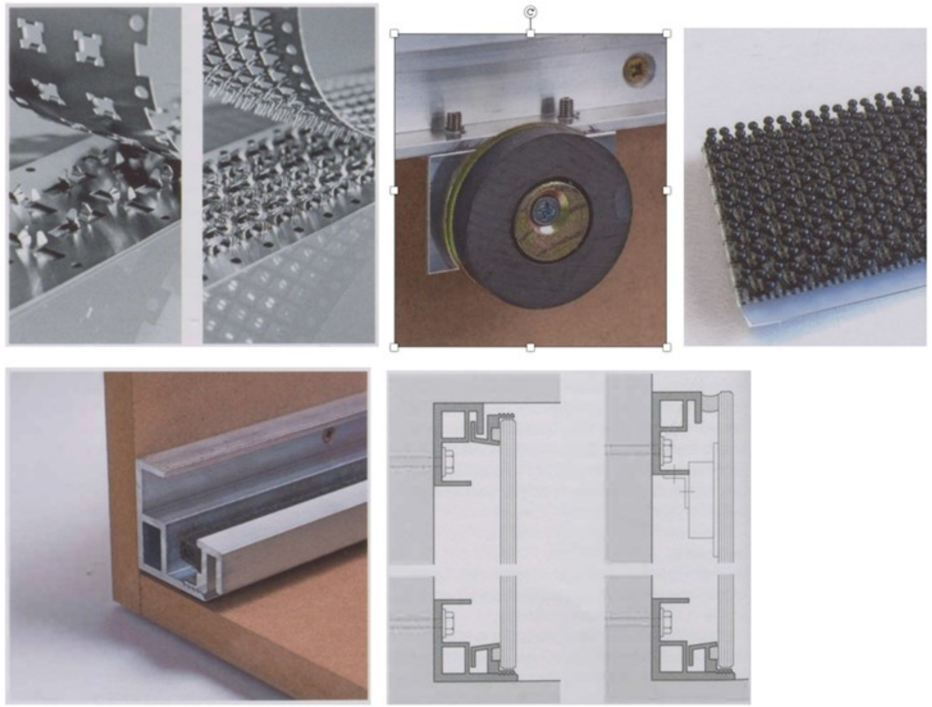


Figure 38: EXAMPLES OF CONNECTION SYSTEMS. ©DETAIL

- The finishing plats are attached to the structure with click-clack system, Magnets System, quick release fastening systems (Velcro type). The wooden stud structure can be built with Wooden dowels. ©Detail
- Metal hook and loop straps for particularly high demands on hook and loop connections: as hook-and-loop system or as a snap fastener ©Detail
- Fixing system for wall glazing in wet areas: for hanging or by means of magnet
- Magnetic fastening system for wall glazing in wet areas ©Detail

- Climbing fastener: For higher retention forces, the hook strap or both elements can be designed as a so-called mushroom head strap. ©Detail

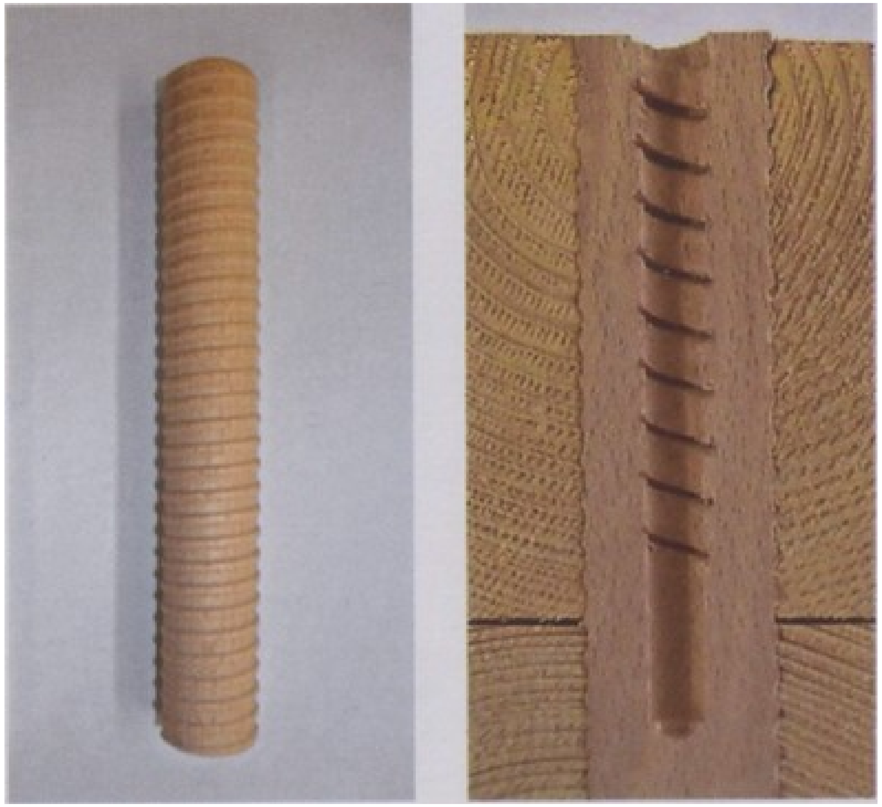


Figure 39: Detachability obsolete - Fasteners for the rigid construction method: Wood screw und Wooden dowel ©Detail, ©DETAIL

6.1.4 Possibile types of internal partitions

<u>K118</u>

In K118 the interior partitions are made with reused wooden frames. The rock-wool insulation, used for noise protection, is also reused.

Figure 40: K.118, WNTERTHUR, INTERNAL PARTITION CONSTRUCTION © BAUBÜRO IN SITU

The internal structure consists of two coupled frames between which there is a rubber strip for sound insulation between rooms. This is also placed in contact with the floor and ceiling. In the K118, the wood planking is achieved with reused three-layer board that were used as stage floor.

TRANSA, Office space designed by Baubüro in situ, Zürich

Another possibile solution could be a wooden stud construction developed for the project of the Office of Transa in Zürich, a renovation planned by the Architecture Office Baubüro in situ, the same of K118 Building in Switzerland. Here the existing suspended acoustic ceiling made of fiberboard are cutted into panels and they are stacked in a wooden stud construction made of reused battens to form interior walls. The same it is done with removed chipboards. Vertical uprights are screwed onto the structure so as to lock the fill material and make the construction stable.

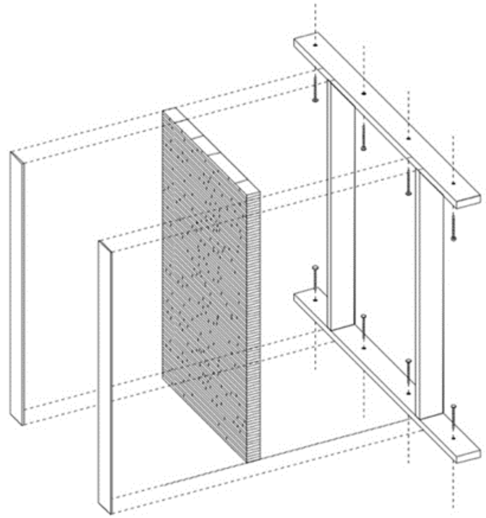


Figure 41: The existing suspended acoustic ceiling made of fiberboard cutted into panels has a real low emission of greenhouse gases as 0.001 Kg CO2 eq, © ZHAW

Figure 42: THE COMPLETED OFFICE SPACE OF TRANSA IN ZÜRICH, PLANNED BY BAUBÜRO IN SITU ©IN SITU

UNIT SPRINT and UMAR in EMPA NEST

In the Unit Sprint in NEST from EMPA (the Swiss Federal Laboratories for Materials Testing and Research) in Dübendorf, designed by Baubüro in situ the interior walls are designed, according to the principle of Design for Disassembly, in two ways. The first, demountable interior wall system consists of folded or layered carpet tiles, the second of stacked books or magazines.

The permanent partition walls of the office units are made from sections of material from the standard timber module construction. These sections (pieces of Fermacell panels and 3-layer panels) represent a constant material flow in today's construction industry, which can be accessed at any time. The wall system developed by Baubüro in situ meets the current fire protection and sound insulation requirements and the interior wall can be produced by the meter, so to speak. The load-bearing timber construction of the office units is made from sawn beams from a dismantled roof structure.

The modules are assembled in a wooden workshop and brought in the construction site to be inserted in the existing primary construction in reinforced concrete.

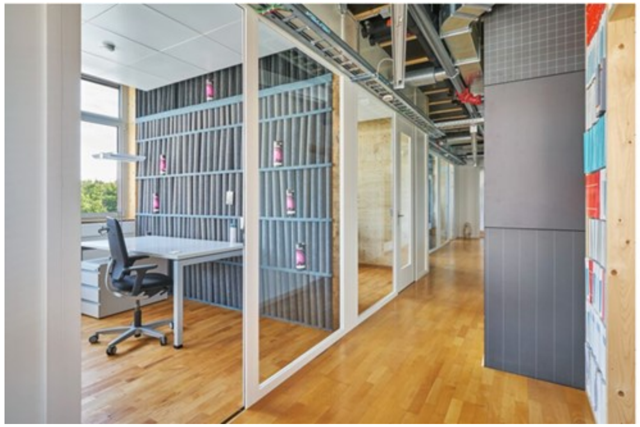


Figure 43: UNIT SPRINT: THE PARTITIONS ARE FILLED WITH REUSED PIECES OF OLD CARPET. ©IN SITU

In the Urban Mining and Recycling (UMAR) Experimental Unit designed by Werner Soebek, D. Hebel and F. Heisel the supporting structure and large parts of the façade consist of untreated wood, a material that can be reused or composted after the building is dismantled. The façade also includes aluminium and copper, two types of metal that can be separated out cleanly, melted down and recycled. The interior of the unit contains an extremely diverse range of serially manufactured building products whose various constituent materials can be separated out and sorted before being introduced back into their respective materials cycles without leaving behind any residue or waste. Among the technologies used here are cultivated mycelium boards, innovative recycled bricks, repurposed insulation materials, leased floor coverings and a multifunctional solar thermal installation.

In this unit an internal partition is designed with a wooden frame and steel rods screwed onto the horizontal uprights. Into this steel rods can be inserted different kind of materials such as recycled bricks, recycled paper plates or magazines, wooden elements, etc.

The stones produced especially for UMAR have holes and are simply threaded onto steel rods from above. They can also be wedged into each other by a tongue and groove system and are thereby activated as a wall plate. The system now makes it easy to change the bricks by pulling them back up and reusing them in other places. Also, the metal rods can be reused or recycled.

The stones are produced by the company StoneCycling, a young startup from Amsterdam, which returns mineral rubble back into the technical cycle.

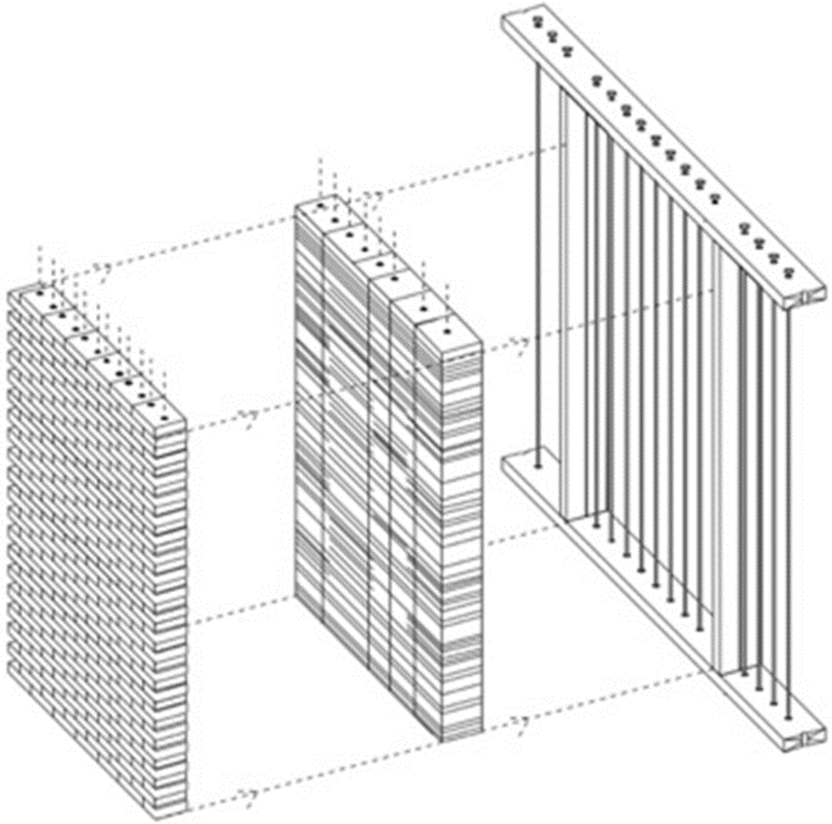


Figure 44: Finishing element as recycled Brics Stonecycling. The bricks have holes and are simply threaded onto steel rods from above. ©ZHAW

- This kind of wall partition can have a grey gas emission of ca. 0.050 Kg CO2 eq. ©ZHAW
- Finishing element as reused magazines. The Magazines have holes and are simply threaded onto steel rods from above. ©ZHAW
- This kind of wall partition can have a grey gas emission of 0.001 Kg CO2 eq. ©ZHAW

Figure 45: Built example of a movable wall partition with recycled Brics Stonecycling © BEYOND WALL SYSTEM

Another possible demountable solution given from Stonecycling for the finishing of interior partition is the Beyond Wall System.

The thin brick plates composed with recycled materials have a joint on the inside that can slide on metal rails screwed to the wall support, which can be made of wood.

These tiles then can be grouted with a removable mortar or be left with the joint exposed.

- StoneCycling – Beyond Wall System ©
- WasteBasedSlips® and BioBasedTiles®

Figure 46: A detail image of the anchoring system of the Beyond Wall System © BEYOND WALL SYSTEM

K118 Lamps designed by ZHAW Students

Another example of furniture constructed from reused materials can be found on the Ground Floor of K118: 6 Lamps reusing broken neon fluorescent tubes designed by the master student of Department of Architecture of ZHAW following the course of Constructive Research IKE ZHAW. This use broken neon tubes that are no longer usable. These become the case, the new lighting body of the lamp. The 32 neon tubes are held together by two metal discs (these are new) that also support the new LED light inside.

Figure 47: Axonometry of the Lamp and the end result in the entrance of the K118 © ZHAW

German Pavillion, Venice Biennale

Curators: ARCH+ / SUMMACUMFEMMER / BÜRO JULIANE GREB
Made entirely using leftover material from the Biennale Arte 2022, which left behind hundreds of tons of trash, the pavilion will become a productive infrastructure, promoting principles of reuse and circular construction in tandem with architecture's social responsibility. By squatting the German pavilion through a series of maintenance works, the contribution renders visible processes of spatial and social care work typically hidden from the public eye. The project demonstrates that ecological sustainability is inextricably linked to the social question.

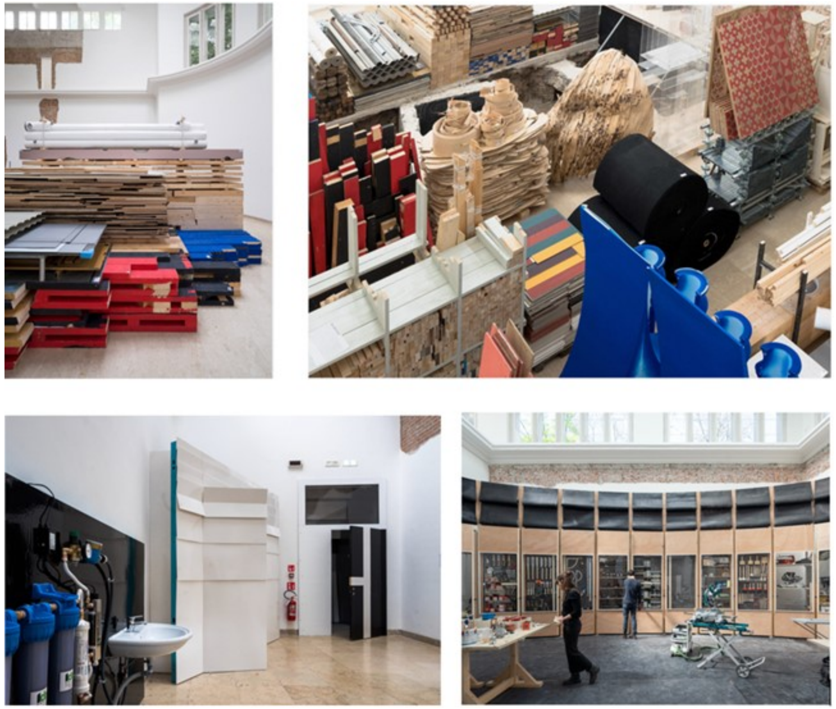


Figure 48: GERMAN PAVILLION ©ARCH+

Palais de Tokyo, Paris, Lacaton & Vassal

Maintain as much as possible! The approach taken to space in this project enable very flexible management of the different areas of the facility and its rich programs, all offered in a skilfully organized series of rooms, spaces, and time frames for various uses; all within a container as vast as possible. Though open, it can easily be temporarily partitioned and reconfigured into an immense space or divided into smaller spaces.

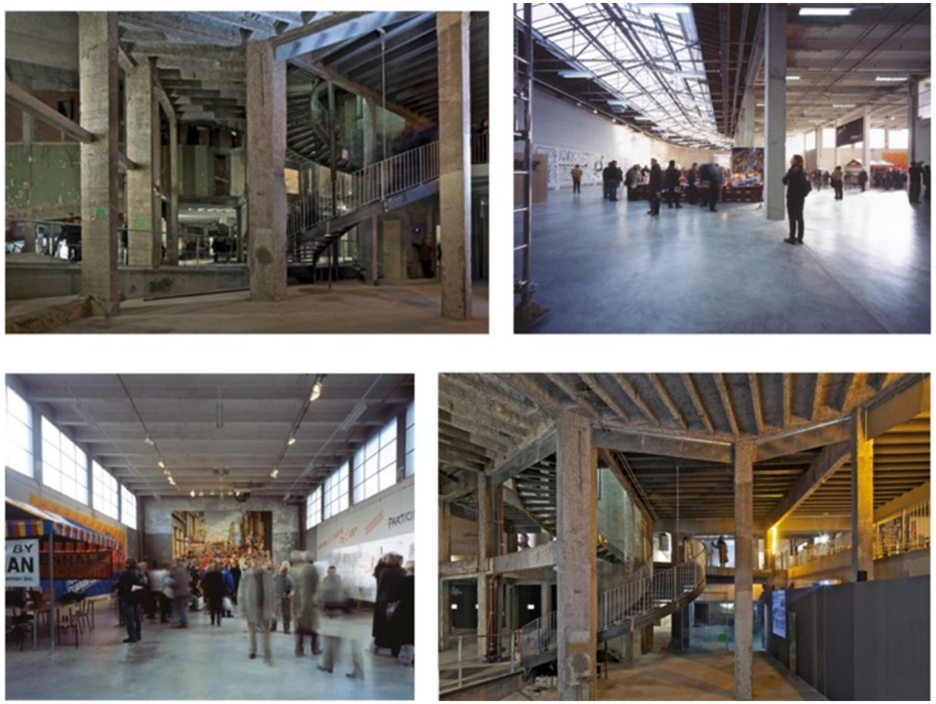


Figure 49: PALAIS DE TOKYO. ©LACATON&VASSAL

6.2 Shaanxi Bee Museum DP Project

6.2.1 About the project

- Investor and Constructor: Liuba Yunmu Rural Tourism Development Co., LTD
- Planning team: Architectural design and Research Institute, XAUAT
- Local ZEB consulting team: Xi'an University of Architecture and Technology, CABR
- Sino-Swiss ZEB consulting team： Intep-Skat, CABR, Low-tech, UAD, HSLU, EMPA, etc.
- Location: Liuba County, Hanzhong City, Shaanxi Province (Climate zone cold area)
- Building use: comprehensive building integrating popular science research, interactive experience, bee culture display and bee product sales
- Structural system: steel structure
- Area
  - Planned land area: 4674.1 m2
  - Total construction area: 1530.55 m2 t
  - Building energy reference area: 1404.3 m2
- Investment costs: ca. 22 million RMB

6.2.2 Existing Situation

The following is an analysis of the key themes found in the museum project in Shaanxi.

Repetition in Plan

There is a strong emphasis on having repetition in the building's design, leading to the creation of modular structures. By adopting modular design principles, the pre-fabrication of building components is enabled, which not only enhances construction efficiency but also lays the foundation for future disassembly. The modularity of the structure allows for easy assembly and, critically, disassembly when the building reaches the end of its lifecycle.

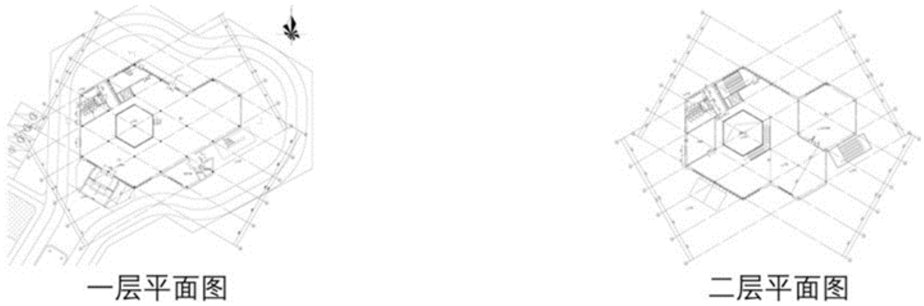


Figure 50: PLAN OF SHAANXI PROJECT IS A HIGHLY GRID-BASED AND HAS A MODULAR PLAN. Left: 1st floor, Right: 2nd floor @DEMO PROJECT SHAANXI

Auxiliary Ceiling

Incorporating an auxiliary ceiling system for the placement of pipelines is a strategic choice enabling easy access for maintenance, repair, and eventual changes to the building's utilities. This aligns perfectly with the system separation principle of the circular economy, where materials and components are kept in optimal use for as long as possible, reducing waste and promoting sustainability.

Open and Flexible Floor Plan

The open and free floor plan of the project, enhances the building's flexibility and adaptability, not only caters to the current function of the building but also future proofs it by allowing for repurposing and reconfiguration for different uses.

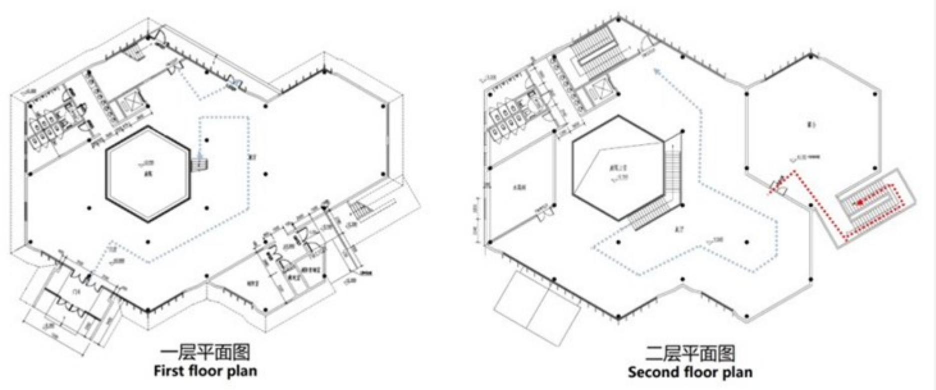


Figure 51: OPEN PLAN OF SHAANXI PROJECT THAT FACILITATES LATER CHANGE OF FUNCTIONALITY IF NEEDED. @DEMO PROJECT SHAANXI

Environmentally Conscious Building Insulation

In the realm of insulation materials, the rockwool has been chosen, a material known for its lower environmental impact compared to polystyrene foam which helps with increasing the sustainability aspect of the building. However, it can be further improved through implementation of even more sustainable materials such as straws.

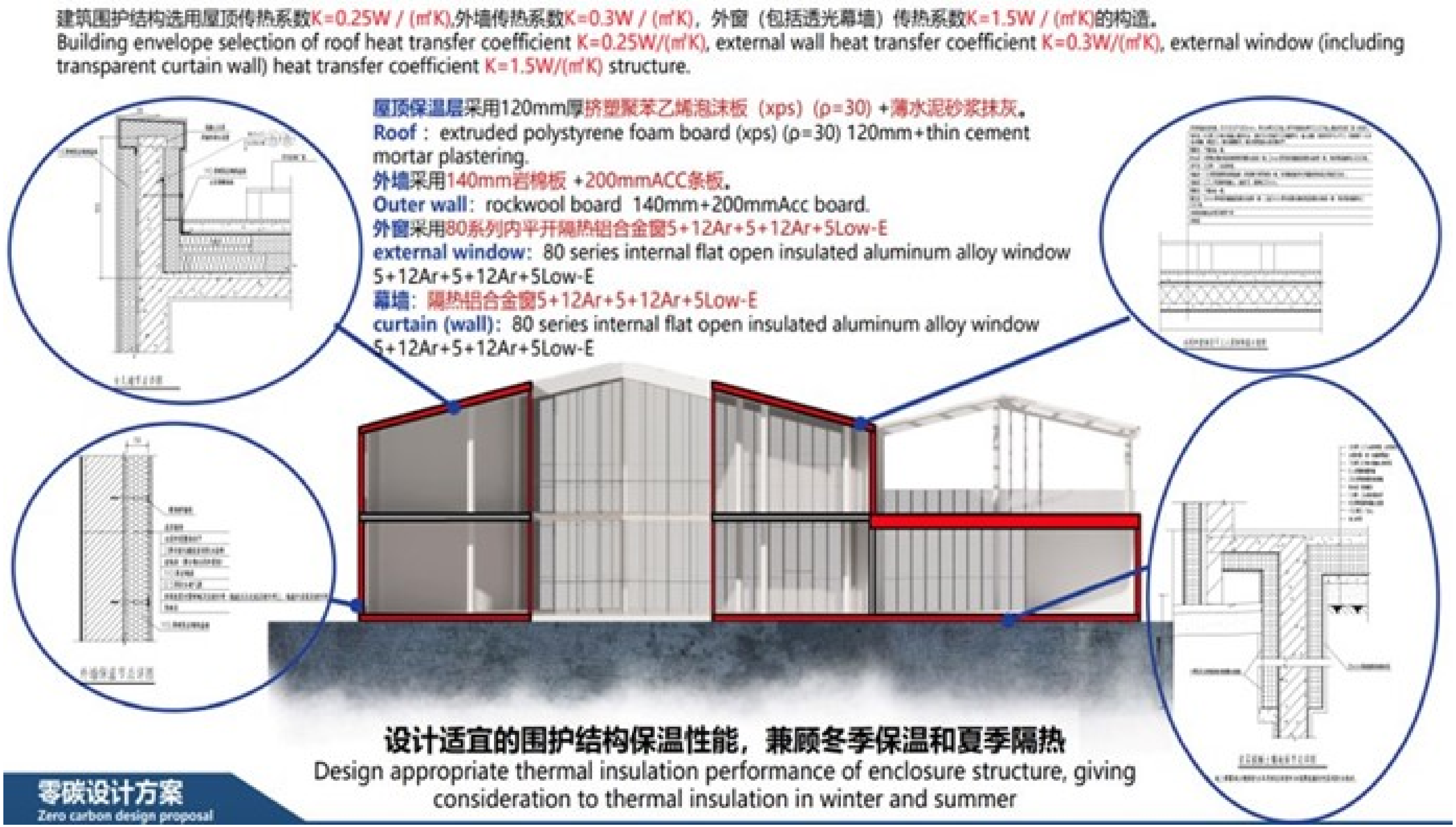


Figure 52: DETAILING AND EXPLANATION OF THE INSULATIONS AND THE UTILIZED MATERIALS FOR THIS PURPOSE

6.2.3 Suggestions

Structural Material Selection

One of the primary considerations in achieving sustainability and circular economy within this project is the choice of materials. Steel production is associated with substantial CO2 emissions. There are two possible routes for the choice of material, I) the project stays with its current proposed steel beams and concrete slabs ii) the project turns into a different material with lower CO2 emission such as wooden structure.

Wooden Structure

Given the spans of the building, approximately 6.2 meters, there is an opportunity to opt for wooden structures. Wood is renowned for its significantly lower CO2 emissions in comparison to steel and concrete, therefore making it a suitable option for enhancing the sustainability aspect of the project.

Solid Wood Ceiling

Another approach could be to use the Cross-laminated timber ceilings for this project. Cross-laminated timber, often abbreviated as CLT, is a versatile building material consisting of multiple layers of wooden boards. Typically, it consists of three to nine layers. These layers of wood are arranged so that they run in the longitudinal direction of the panel, as roof and ceiling structures. The board layers are usually connected to one another by gluing (approx. 1% glue content). There is also research and development in the area of connection techniques, such as dowelling and nailing with hardwood elements. In order to transmit horizontal forces, the CLT wall and ceiling elements are usually connected to one another using cross connected screw connections or threaded rods. Recently, these screws have increasingly been replaced by high-strength elements made of beech or birch plywood, which are reminiscent of traditional dovetail connections and connect the panels firmly and securely.

Over time, more and more dowels have been used as the connection method. Rod dowels made of beech are heated and driven into the pre-drilled slats made of softwood with a wood moisture content of 6%. There they reach the equilibrium humidity of 12%, whereby they swell significantly and form an irreversible bond with the slats. In another process, hardwood nails made of beech and oak are driven into the slats using compressed air. The high press-in pressure causes a high temperature, which irreversibly bonds the nail and lamella, similar to wood welding.

Cross-laminated timber panels can transfer forces in two directions, unlike traditional timber board ceilings where this can only be done in one direction. Some manufacturers use this property to create cavities by leaving out certain boards or inserting layers of beams. These cavities can be used for installations and improve the efficiency of the elements as well as the building physics properties, depending on which filling material is used. In addition, due to its natural structure, the wood for cross-laminated timber panels contains numerous air pockets that offer improved thermal protection. The solid structure of cross-laminated timber panels also gives them a high level of fire resistance, even without treatment, which meets increased fire protection requirements through additional cladding or encapsulation. In the event of a fire, the outer layer of wood, efficiently putting out the fire and protecting the inner layers of boards. This allows the inner board layers to maintain their structural integrity for several hours even in a very severe fire. The massiveness also increases sound insulation compared to other wooden ceiling constructions.

Although the mechanical processing and drying of the sawn wood is energy-intensive, the most recent developments that use nails and dowels made of wood eliminate the need for adhesive. The use of untreated wood, the absence of glue and the high mass of the wood create a comfortable and biologically favourable indoor climate. The wood used should come from local softwoods and is therefore a renewable resource.

At the end of use, cross-laminated timber can be recycled materially or thermally. The panels are cut into smaller pieces and can then be reused as a secondary structure. The disposal options for BSH include reuse (with non-destructive dismantling), incineration in suitable combustion systems and further processing into wood-based materials.

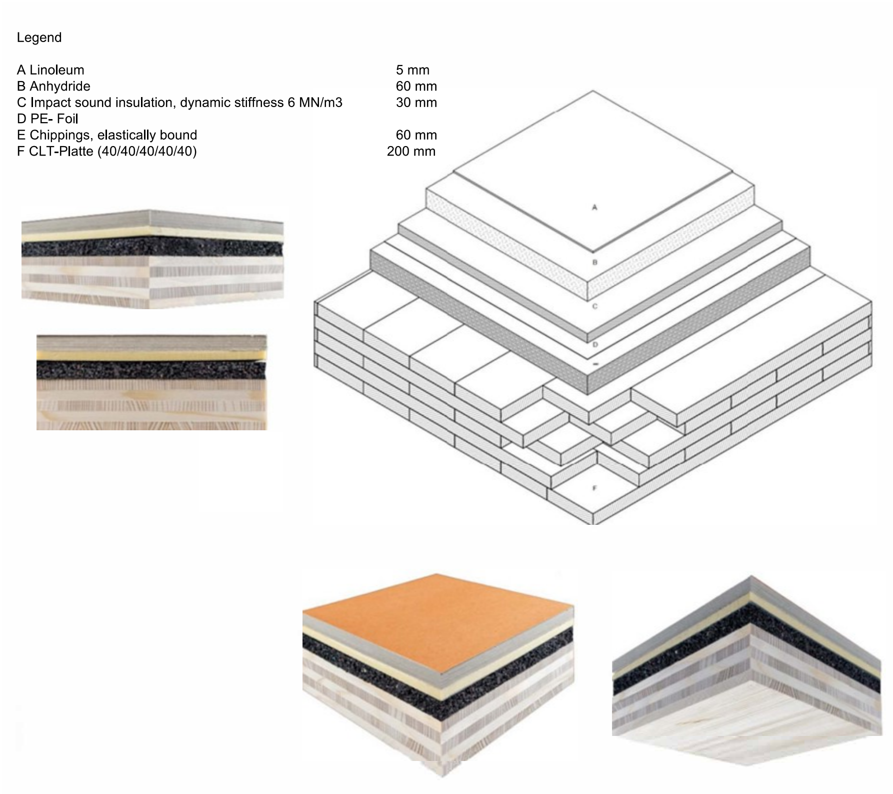


Figure 53: CLT CROSS-LAMINATED TIMBER CONSTRUCTION SYSTEM ©ZHAW

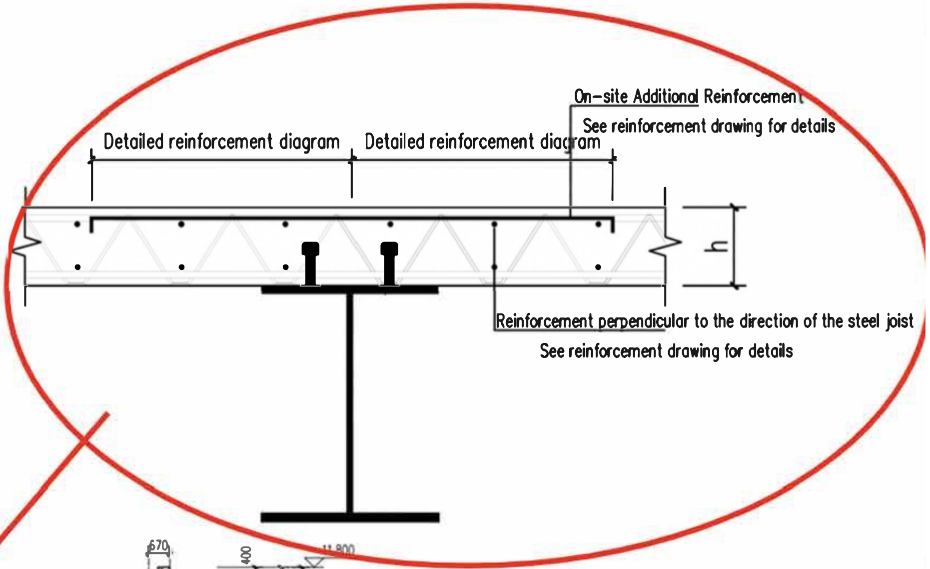
Staying with the current structural system of concrete slabs and steel beams

In the case of the project staying with the current structural system of concrete slabs and steel beams, there are few issues that needs to be addressed to improve the Sustainability aspect of this system. The predominant use of conventional steel beam requires the use of fire resistance coating which this material is not fully environmentally friendly. Furthermore, with the current proposed detail of the construction of the slabs, as seen in the figure below, after the life cycle of the buildings, due to connections not being designed for the disassembly process, the separation of the concrete from steel beams is not possible efficiently. Due to reasons above, the current construction technique of the project does not align with our sustainability goals due to its high carbon footprint and lack of DfD feature.

Conventional Construction Approach

Challenges

- Not easy to disassemble
- Requires fire resistance coating --> not environmentally friendly
- Requires cold formed steel deck --> its production process has high CO_2 emission---> not environmentally friendly



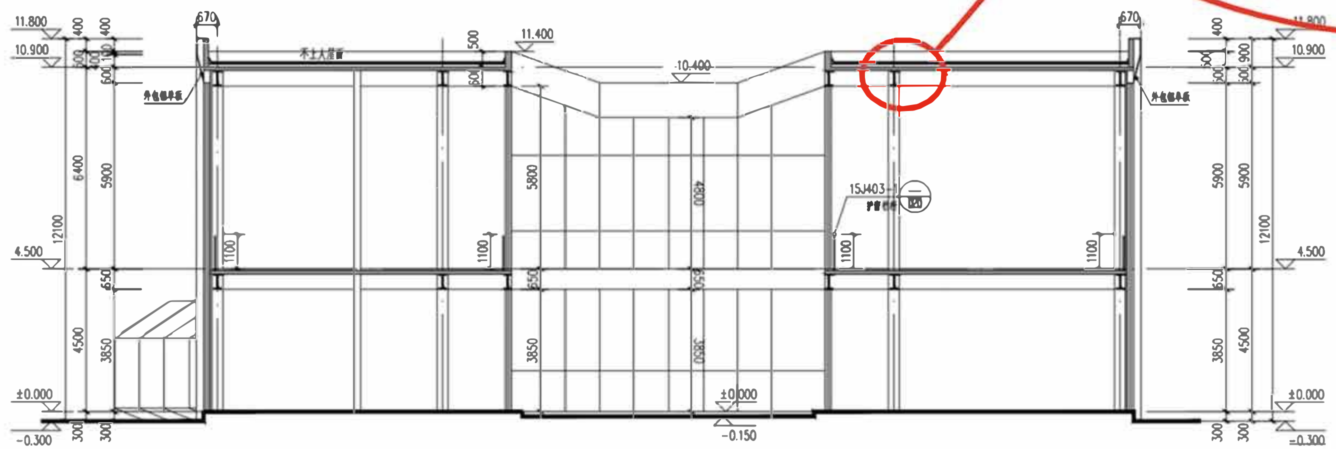
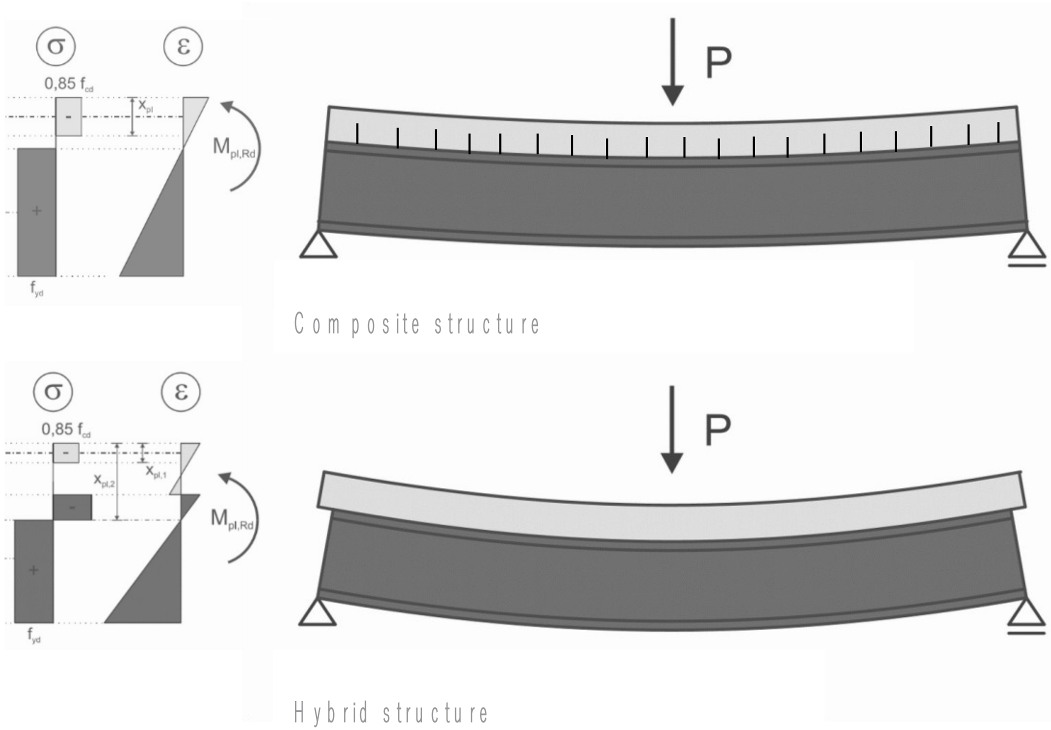


Figure 54: CURRENT DETAIL OF THE CONNECTION BETWEEN CONCRETE SLAB AND STEEL BEAM. ©DEMO PROJECT SHAANXI

Concrete-Steel Connection Method

In order to make sure we're in line with the principle of DfD the connections of concrete and steel will be required to be through demountable shear connectors. In general, if we have two separate materials, steel and concrete, which are not connected together, this will result in the appearance of tension and compression in both of the elements. However, if they are properly connected and the composite action is developed between them, in the case of concrete slab and steel beams, the tension will develop in the steel beam and the compression develops in the concrete section which results in much more efficient transformation of forces within the elements, resulting in smaller cross-sections and therefore higher functional and sustainability efficiency.

Materialeffizienz:



Composite structure	Hybrid structure
– Different building materials are combined.	– Different building materials are combined.
– The building materials are connected in a shear-resistant manner using composite materials.	– No shear connectors
– The composite joint is form-fitting and force-fitting.	– The composite joint is only form-fitting.
– There is an exchange of forces between the different building materials.	– There is no exchange of forces between the different building materials.
– Joint load-bearing effect Composite behaviour	– Independent load-bearing effect

DEFORMATION CAPACITY AND DUCTILITY OF SHEAR CONNECTORS

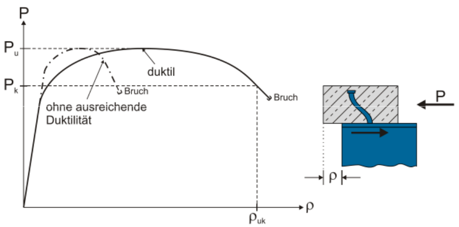
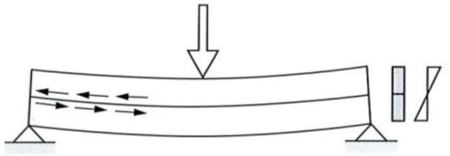


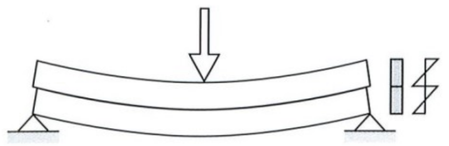
Figure 55: Difference between a composite and hybrid structure ©ZHAW



$$W = \frac{1}{6}\,b(2h)^2 = \frac{2}{3}\,bh^2$$

$$I = \frac{1}{12}\,b(2h)^3 = \frac{4}{6}\,bh^3$$

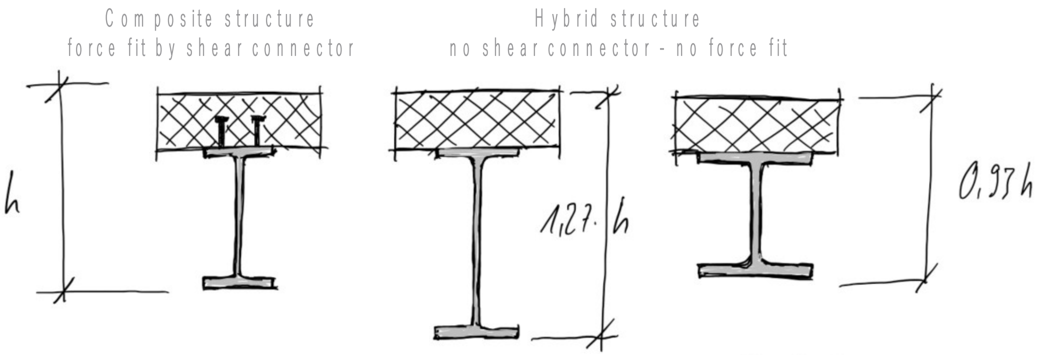
Composite structure



$$W = 2\frac{1}{6}\,bh^2 = \frac{1}{3}\,bh^2$$

$$I = 2\frac{1}{12}\,bh^3 = \frac{1}{6}\,bh^3$$

Hybrid structure



section	IPE 400 66,3 kg/m'	IPE 550 106 kg/m'	HEB 360 142 kg/m'
resistance to bending	100 %	100 %	100 %
dead weight	100 %	159 %	214 %
component height	100 %	127 %	93 %
stiffness	100 %	72 %	46 %
deformation	100 %	139 %	217 %
			Limited in height

Figure 56: Structural deformations in composite and hybrid structures ©ZHAW

Thus, to have an efficient transfer of the loads yet featuring DfD, the following demountable connection method for the concrete and steel elements with through bolts have been investigated by the researchers as seen in the figure below.

Prefab concrete slabs

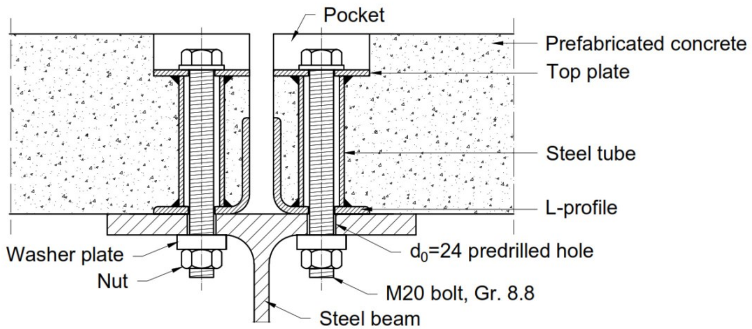


Figure 3.1 Layout of the shear connection system P3

Onsite concrete slabs

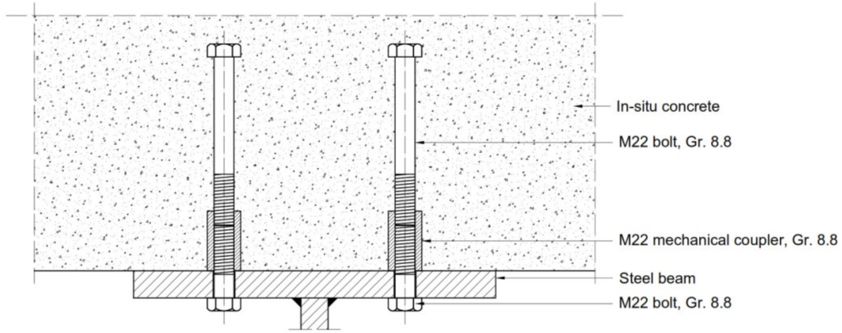
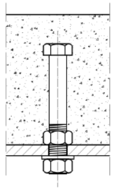
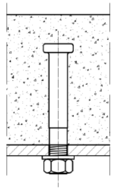
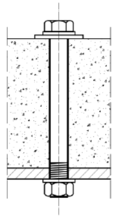
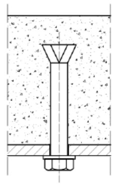


Figure 3.3 Layout of the shear connection system tested by Yang et al. [60]

Figure 57: DEMOUNTABLE SHEAR CONNECTIONS. ©YANG ET AL.

Table 2.1 Demountable shear connections overview

Shear connection	Image	Advantages	Disadvantages
Encased bolts		- Similar to the traditional solution. - High strength. - Possible use of pretensioning.	- Lower stiffness than welded studs. - The end of the bolt protrudes from the slab when removed. - The bolt is not replaceable. - Reuse of the slab is questionable. - Prefabrication is complicated.
Threaded studs		- Similar to the traditional solution. - Relatively low cost.	- Lower stiffness than welded studs. - When removed the end of the bolt protrudes. - The stud is not replaceable. - Reuse of the slab is questionable. - Prefabrication is complicated.
Through bolts		- The bolt is replaceable. - Relatively high strength. - No protruding parts from the slab when removed. - Provides access from the top.	- Lower stiffness than welded studs. - Loss of pretension due to creep and shrinkage. - Special attention is required for tolerances.
Anchor bolts and blind bolts		- No problems with tolerances. - Works with prefabrication and with in-situ concrete as well.	- Drilling in the concrete is necessary when prefabricated. - Lower stiffness than welded studs. - Relatively low strength.

L'UNIVERSITÉ DU LUXEMBOURG

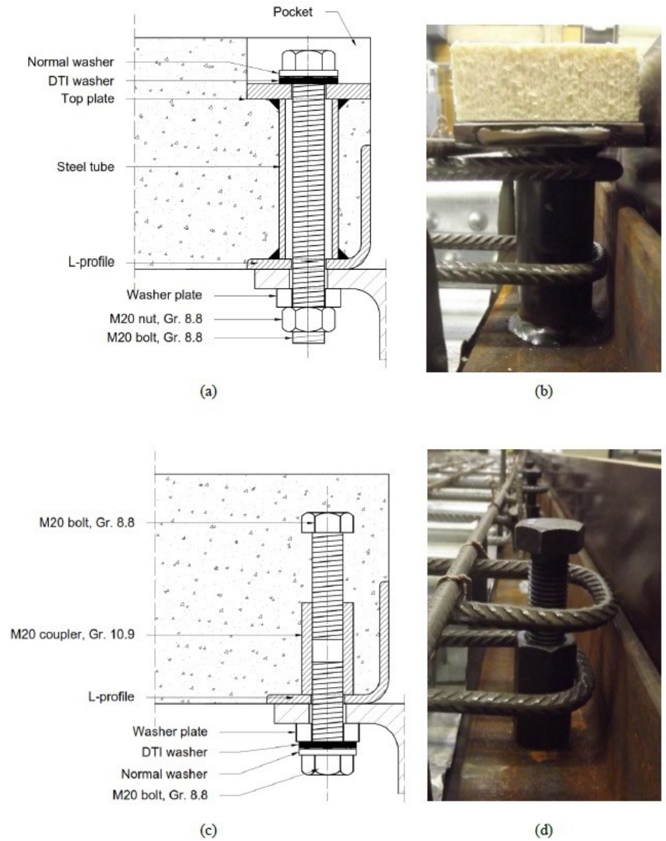


Figure 5.8 Shear connector systems applied in the beam tests: (a) and (b) System P3.3 in beam B7, (c) and (d) System P15.1 in beam B8

Reduktion Ressourcenverbrauch

Figure 58: DEMOUNTABLE SHEAR CONNECTIONS. ©KOZMA

The possible suggested demountable connection is explained in more details in the following sections:

Through Bolts (for prefabricated concrete)

Though bolt shear connectors are constructed by placing structural bolts into predrilled holes in the flange before casting concrete. Figure below shows an example of such connection method. Through bolts shear connectors, arranging bolts as a group in several rows, can be applied in prefabricated steel–concrete composite beams. Through-bolt shear connections offer a sustainable and disassemble solution that supports the circular economy by enabling material reuse, reducing waste, and promoting long-term structural adaptability.

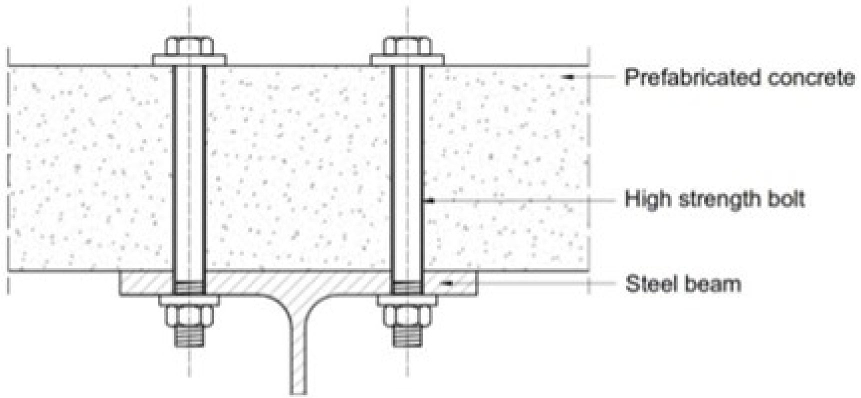


Figure 59: THROUGH BOLT: DETACHABLE CONNECTION FOR STEEL AND PRE-CAST CONCRETE ELEMENTS. ADAPTED FROM KOZMA, A. (2020). DEMOUNTABLE COMPOSITE BEAMS: ANALYTICAL CALCULATION APPROACHES FOR SHEAR CONNECTIONS WITH MULTILINEAR LOAD-SLIP BEHAVIOUR (DOCTORAL DISSERTATION, UNIVERSITY OF LUXEMBOURG, LUXEMBOURG). ©KOZMA

Prefabricated Concrete Slabs

Furthermore, in the project's current method of steel profile and the concrete slab, with on-site concrete pouring, a cold-form steel decks are required for pouring of the concrete (working as the concrete's formwork) which the production of these metal cold-form steel decks, has a CO_2 intensive process. Therefore, if the demountable construction method of the through bolt is chosen as the construction method, this corrugated metal sheet can be avoided as the concrete can be then prefabricated and assembled on site. It's crucial to note that post-construction, both methods of cast on-site and pre-fabrication yield the same whole-life emissions, encompassing the production phase of the elements. To enhance sustainability, whether through the reuse of cold-formed steel decks or the prefabrication of slabs, efforts to reduce whole-life emissions are pivotal. The emphasis remains on minimizing the environmental impact throughout the production process, with each approach offering its unique benefits in achieving this goal.

Graph below compares the CO_2 emission of the conventional and current method of concrete and steel beams with the method which does not require this cold formed steel deck for the construction of the concrete slab. Through this approach, about 300 kg of CO_2 can be saved in comparison to the conventional method of using cold-formed steel.

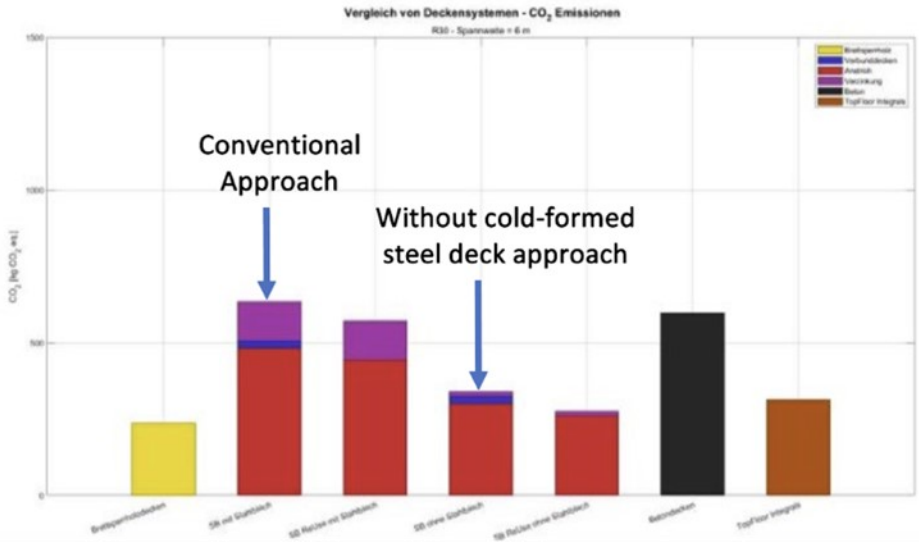


Figure 60: AMOUNT OF CO2 EMISSION (KG) FOR EACH METHOD OF CONSTRUCTION ©ZHAW

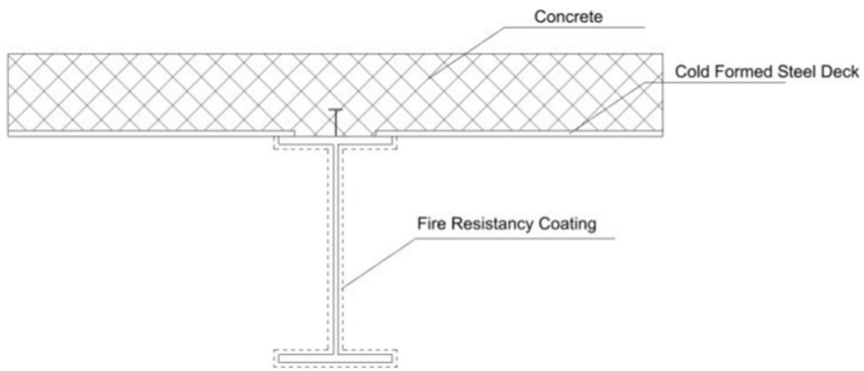


Figure 61: THE COMMON CONSTRUCTION DETAIL OF CONCRETE AND STEEL BEAM WITH COLD FORM STEEL DECK AS THE FORMWORK OF THE CONCRETE AND NECESSITY OF HAVING A FIRE-RESISTANT COATING FOR THE STEEL. ©ZHAW

Stahlkammer Method

Moreover, as mentioned earlier, in the conventional method, as presented in the graph below, the steel profiles need to be coated with fire-resistance material, which are often not environmentally friendly, and therefore not suitable for the scope of the project.

In order to avoid this matter, the hybrid system of Steel and Cleancrete© is suggested instead. As shown in Figure below, this system consists of steel C-profiles and the environmentally friendly “Cleancrete©”. This is a cement-free concrete that consists of clay-containing soil or excavated material, water and the natural additive Oxacrete©. Furthermore, Cleancrete© is a resource-saving and sustainable alternative to cement-based concrete where high compressive strength is not required. The Oxacrete© admixture is 100% cement-free. As The creation of cement is the most carbon-intensive portion of the concrete process, hence, by reducing the cement content of the mix, the CO2 footprint of it will be significantly lower compared to conventional building materials. It also uses up-cycled excavation materials further enhancing its sustainability potentials. The CO2 consumption of Cleancrete© is reduced by 90% compared to concrete due to use of much less cement which is replaced by rammed earth. In addition, the exposed connections integrated in the design of the Stahlkammer system, ensures easy access for maintenance and potential disassembly.

Although a small amount of fire-resistant coating may still be necessary for parts not covered in the Stahlkammer method, the overall requirement is considerably less than in conventional methods.

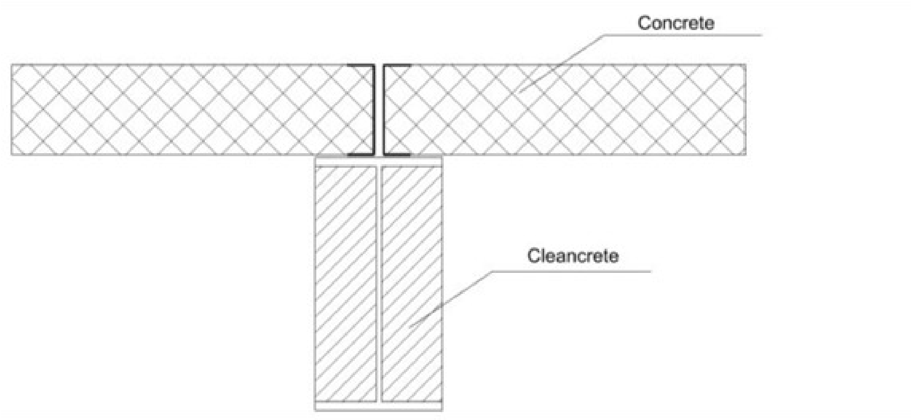


Figure 62: THE PROPOSED CONSTRUCTION SYSTEM OF CONCRETE SLAB AND STEEL BEAMS, WITH DETACHABLE CONNECTIONS AND CLEANCRETE© INSTEAD OF THE FIRE COATING. ©ZHAW

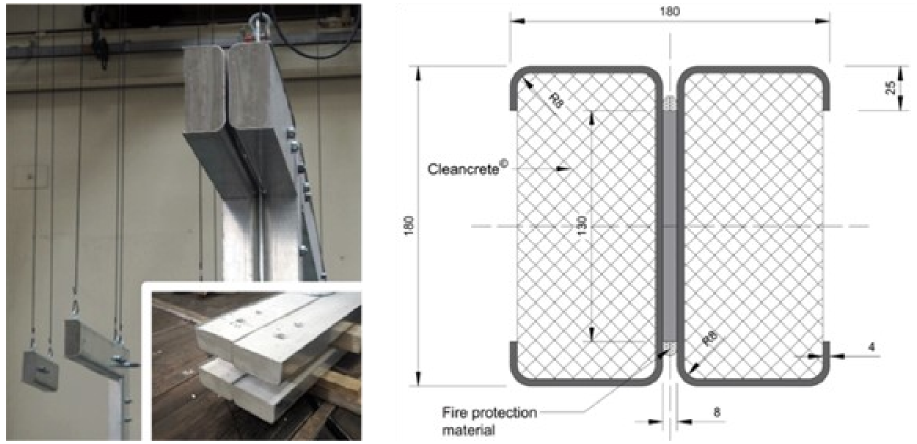


Figure 63: MORE DETAIL ON THE STAHLKAMMER SYSTEM: HYBRID SYSTEM OF CONCRETE AND CLEANCRETE© WHICH ALLOWS BOTH FOR DESIGN FOR DISASSEMBLY AFTER THE LIFE OF THE BUILDING AND PROVIDES THE REQUIRED FIRE-RESISTANCE. ©ZHAW

Wooden Façade with Straw Insulation

Based on the meetings that the Swiss team had with the Shaanxi Project team, the demo project team have shown interest in the implementation of the idea of using environmentally friendly straw as the façade insulation along with reused wooden façade element, similar to the K118 project (shown in figures below).

Figure 68: K118 PROJECT, RE-USED WOODEN FAÇADE SYSTEM WITH STRAW INSULATORS. @IN SITU

Below the proposed façade design for the Bee Museum in Shaanxi is confronted and replaced with a Façade using Strow as main insulation.

- Thermal conductivity of Rockwool 160 mm is 0.037 W/mK
- Thermal conductivity of Pressed Strow Bales 360 mm is 0.043 W/mK

Although the thermal conductivity of straw insulation is slightly worse than Rockwool insulation, the entire stratigraphy of the planned façade system must be considered to determine whether it is feasible to use the 360 mm thickness of straw compared to the 160 mm thickness of Rockwool. With a few precautions and adjustments, it may be possible to use pressed straw as insulation instead of the Rockwool panels on the presented construction of the Museum in ACC panels.

However, the final outer layer of the façade must then be developed by applying a Gypsum fibreboard - or in general a solid layer that meets Chinese fire protection standards and protects and encloses the insulation with straw. This final layer, in addition to being the fire-proof protection, is essential as the support for the ventilated facade. This needs a metal or wood substrate attached to the gypsum board, a space to allow ventilation, and then the final layer that makes up the facade which can be a wide variety of materials such as wood, steel or aluminium sheets, glass cement, glass, etc.

Even more sensible in terms of sustainability and grey energy consumption would be the use of timber-framed façades and insulation with pressed straw bales as planned and realised in the K118 building.

We would like to point out that these comments are based on Swiss standards and knowledge and must be verified by specific design against Chinese standards and norms.

Below are listed the requirements for the use of strow insulation for a tender call in Switzerland:

- Cereals: spelt, rye, wheat, triticale, barley, no oats
- Colour and smell: (golden) yellow and fresh, no smell of mould
- Threshing: as long as possible, as few damaged straws as possible
- When shaking: no small cutting or chopping of the straw
- Geometry: edges straight, surfaces even, surfaces at right angles to each other. It should be as cuboidal as possible
- Bale density: approx. 100 kg/m3; it must not be possible to push the outstretched hand between the straw layers, or only with difficulty.
- Integrated bulk density: 100 ± 15 kg/m3
- Format: maximum approx. 50cm/80cm, mostly approx. 36cm/50cm

Furthermore:

- Twine constriction at the ends as little as possible deep in the straw
- Stalk orientation predominantly transverse to the constriction
- Infestation percentage as low as possible
- No fungal infestation (grey straw)

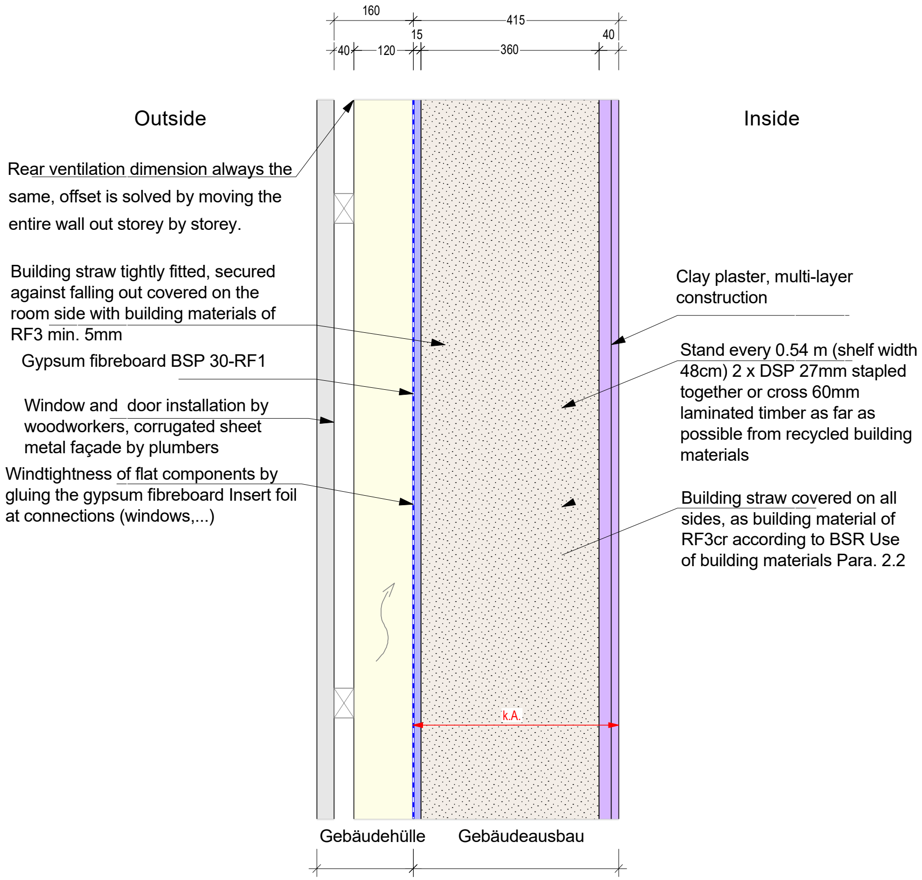


Figure 64: DETAIL SECTION OF THE K118 FAÇADE IN WINTERTHUR © IN SITU

Connection Facade - Slab – Beam

For the construction detail of the desired wooden façade of the client to the concrete slab and steel beam, the Circular House from Graser Troxsler Architekten presents a nice demountable solution, demonstrated in Figures below.

Connection Facade - Slab – Beam

For the construction detail of the desired wooden façade of the client to the concrete slab and steel beam, the Circular House from Graser Troxsler Architekten presents a nice demountable solution, demonstrated in Figures below.

Figure 65: HERBSTWEG PROJECT, STEEL STRUCTURE WITH WOODEN FAÇADE WITH DISASSEMBLABLE CONNECTION. @GRASER TROXLER

Figure 66: FAÇADE DETAIL OF HERBSTWEG PROJECT, STEEL STRUCTURE WITH WOODEN FAÇADE WITH DISASSEMBLABLE CONNECTION. @ZHAW

6.2.4 Proposed Approach

Based on the current desire of the client, in order to facilitate the system of concrete slab, steel beams and wooden façade, the suggestion is to follow a novel approach, benefitting from different ideas mentioned above, that allow for having such system considering design for disassembly, circular construction and more sustainable a method.

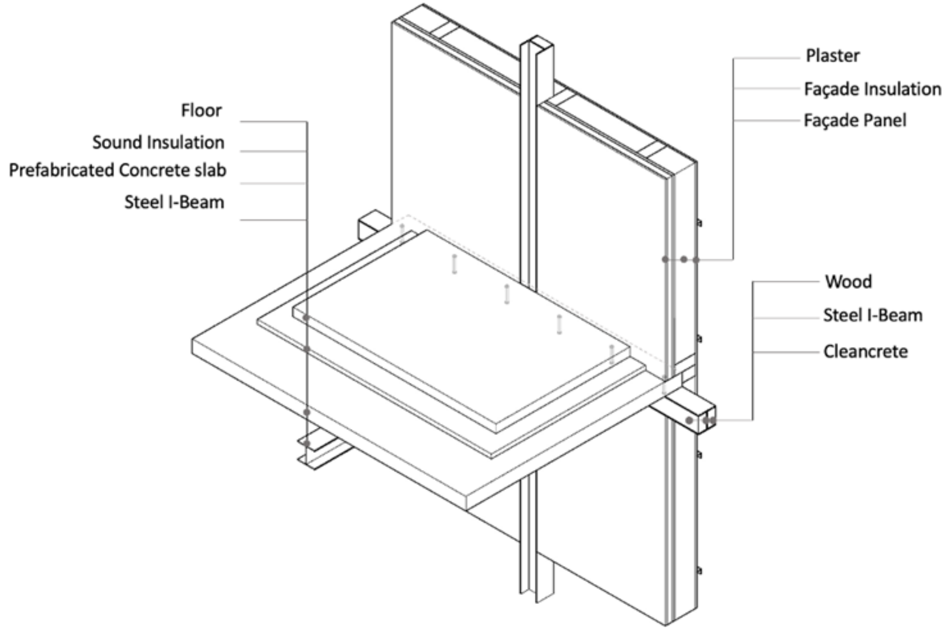


Figure 67: AXONOMETRIC VIEW OF PROPOSED APPROACH. ©ZHAW

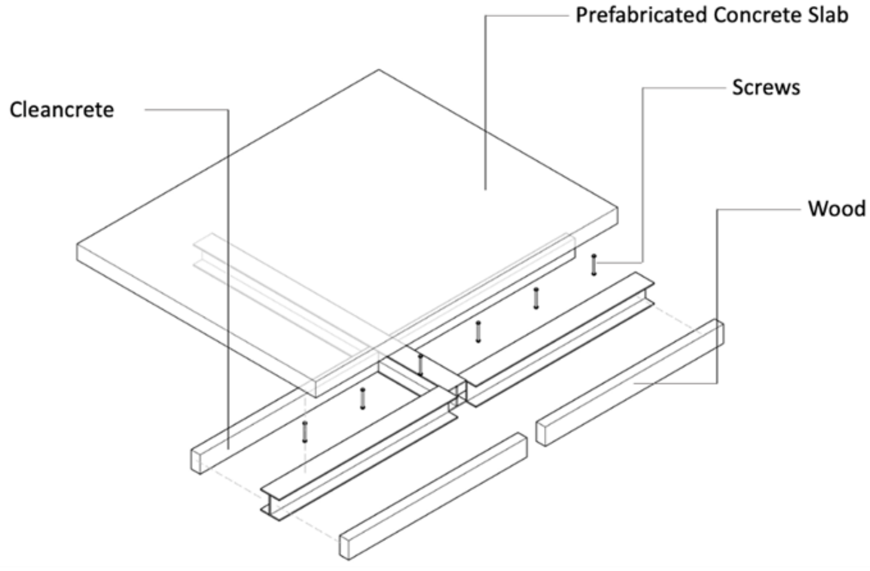


Figure 68: AXONOMETRIC VIEW OF THE PROPOSED DISASSEMBLE CONCRETE FLOOR-STEEL STRUCTURE APPROACH. @ZHAW

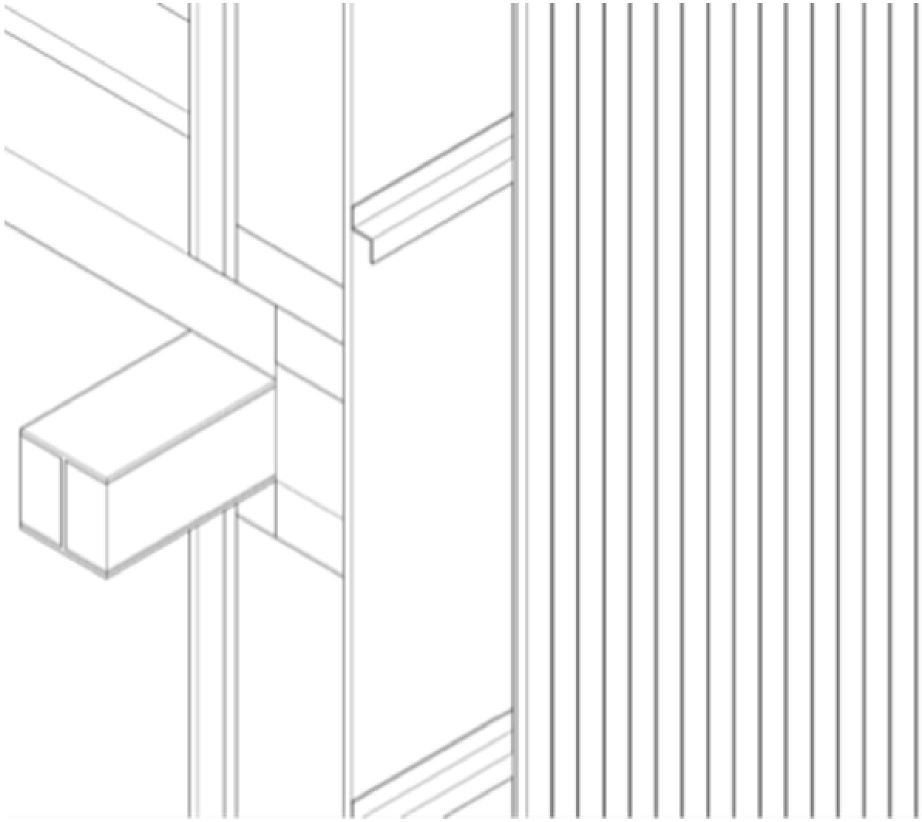


Figure 69: PROPOSED CONNECTION DETAIL FOR THE STEEL STRUCTURE WITH CONCRETE SLAB AND WITH WOODEN FAÇADE. @ZHAW

Utilizing Reused Steel for the Open Terrace Roof

The design of the open terrace roof presents an opportunity to showcase sustainability by utilizing reused steel. Reusing steel components not only extends the lifecycle of these materials but also reduces the energy-intensive process of steel production.

Dimensional Design Considerations for Recycled Materials

Incorporating recycled materials is an essential step in promoting sustainability. However, it is crucial that the dimensions of these materials are carefully considered during the building's design phase.

Optimizing Concrete Slabs Geometry

In cases where concrete slabs are necessary, we recommend optimizing their geometry following principles such as "Block's Research Group work." This approach focuses on minimizing material usage while maximizing structural efficiency, thereby reducing the environmental impact of concrete usage.

Annex

A1. TERMINOLOGY

In the current discourse, the terminology of circular construction is heavily influenced by its origins in waste management. In various linguistic regions and contexts, certain terms have become established to designate the strategies of circular construction. However, these are not used uniformly. The following is a summary of some of them, without claiming to be exhaustive.

- In the Dutch parliament in 1979, Ad Lansink formulated a hierarchy of waste handling measures ('Lansink's ladder') aimed at reducing waste, which attracted a great deal of international attention. Reduce, Reuse, Recycle, Incinerate with energy recovery, Incinerate, send to Landfill.
- Since then, the waste hierarchy has been continuously refined and adapted in line with new technical possibilities. For example, in 2000, the Technical University of Delft differentiated the hierarchy for the construction industry, known as the 'Delft ladder': Prevention, Object renovation, Element reuse, Material reuse, Useful application, Immobilisation with useful application, Immobilisation, Incineration with energy recovery, Incineration, Landfill — see C. F. Hendriks, Nationaal congres Bouw- en Sloopafval, kwaliteit in de keten (Rotterdam: Nederlands studiecentrum, 2000); B. J. H. te Dorsthorst, T. Kowalczyk, C. F. Hendriks, and J. Kristinsson, 'From Grave to Cradle: Reincarnation of Building Materials', in Proceedings of International Conference on Sustainable Building 2000 (Maastricht, 2000).
- In the English-language technical literature, the term reuse or re-use subsequently established itself in construction for the reutilization of components, irrespective of their function on the new site, as distinct from recycling, which merely describes the recovery of materials — see Bill Addis, Building with Reclaimed Components and Materials: A Design Handbook for Reuse and Recycling (New York: Routledge, 2006); Duncan Baker-Brown,The Re-use Atlas: A Designer's Guide towards a Circular Economy (London: RIBA Publishing, 2017).
- In the French-language technical literature, the term recyclage is used analogously to the English recycling for the recycling of building materials with loss of form. On the other hand, réutilisation (reuse with retention of form and the same function) and réemploi (reuse with retention of form for another function) are differentiated. The term récupération is used as an umbrella term for the reuse of obsolete building fabric — see Jean-Marc Huygen, La poubelle et l'architecte: Vers le réemploi des matériaux (Arles: Actes Sud, 2008); Julien Choppin and Nicola Delon (eds.), Matière grise: Matériaux/réemploi/architecture (Paris: Edition du Pavillon de l'Arsenal, 2014); Michaël Ghyoot, Lionel Devlieger, Lionel Billiet, and André Warnier, Déconstruction et réemploi: Comment faire circuler les éléments de construction (Lausanne: EPFL Press, 2018).
- However, in two more recent German-language publications, the term recycling is used in its original sense as meaning the recycling of building materials and components back into the materials cycle. If this involves a loss of form, the term Verwertung is used, with a differentiation made between Wiederverwertung (same production process) and Weiterverwertung (another production process with inferior results). Similarly, the term Wiederverwendung is defined as reuse for the same purpose, while Weiterverwendung denotes reuse for another, inferior purpose. At the same time, the terms upcycling and downcycling are used to describe the quality gradient between the materials' previous and subsequent usage or further processing. On the other hand, there is no neutral, non-judgemental umbrella term for the reuse of building components with retention of form — see Annette Hillebrandt, Petra Riegler-Floors, Anja Rosen, and Johanna Seggewies, Atlas Recycling: Gebäude als Materialressource (Munich: Detail, 2018); Daniel Stockhammer (ed.),Upcycling: Wieder- und Weiterverwendung als Gestaltungsprinzip in der Architektur (Zurich: Triest, 2020).
- For the title of the German pavilion of the 13th International Architecture Exhibition in Venice 2012, the curator, Muck Petzet, borrowed the terms Reduce Reuse Recycle from the waste management industry, linking them with architectural and urban planning strategies. As a result, the buzzwords gained considerable prominence, but their meanings also shifted. Reduce was used to describe a strategy of sufficiency; reuse included all forms of conversion and additions to existing buildings; and recycling was applied as an umbrella term for the reuse of materials and components in another locality — see Muck Petzet and Florian Heilmeyer (eds.), Reduce, Reuse, Recycle: Architecture as Resource; German Pavilion, 13th International

Architecture Exhibition, La Biennale di Venezia 2012 (Ostfildern: Hatje Cantz, 2012).

- In addition to the purely material-centric ecological-economic assessment and naming of circular processes, the reuse of building materials and components has long been a focus of research in the history of art and architecture. In the German-speaking discourse, the term spolia (Lat. 'spoils' = repurposed building fragments) has come to the fore, as it is closely linked to the origin and significance of building components.

Various distinctions are drawn in the technical literature, depending on the places of origin and use. The term Wiederverwendung is employed as a neutral umbrella term for the reuse of building materials. This also brings the architectural historical discourse and the current debate closer together — see Stefan Altekamp, Carmen Marcks-Jacobs, and Peter Seiler (eds.), Perspektiven der Spolienforschung 1. Spoliierung und Transposition, Berlin: De Gruyter, 2013; Hans-Rudolf Meier,Spolien: Phänomene der Wiederverwendung in der Architektur (Berlin: Jovis, 2020).

The Research on circular construction in the ZHAW takes up this idea and uses the term Wiederverwendung in a similar way to the English term Reuse (or Re-use): as an umbrella term for the reuse of dismantled components, independent of changes of use, quality standards, or its implicit meaning. This establishes a name for the reuse of building components without having to make an a priori judgement, which a differentiation of context would require (parity in terms of economy, environmental impact, design, cultural significance), and, as the K 118 case study has shown, it is almost impossible in practice, as building components usually fulfil several functions.

A2. LITERATURE

- C. F. Hendriks, Nationaal congres Bouw- en Sloopafval, kwaliteit in de keten (Rotterdam: Nederlands studiecentrum, 2000)
- B. J. H. te Dorsthorst, T. Kowalczyk, C. F. Hendriks, and J. Kristinsson, 'From Grave to Cradle: Reincarnation of Building Materials', in Proceedings of International Conference on Sustainable Building 2000 (Maastricht, 2000).
- Bill Addis, Building with Reclaimed Components and Materials: A Design Handbook for Reuse and Recycling (New York: Routledge, 2006)
- Duncan Baker-Brown,The Re-use Atlas: A Designer's Guide towards a Circular Economy (London: RIBA Publishing, 2017)
- Jean-Marc Huygen, La poubelle et l'architecte: Vers le réemploi des matériaux (Arles: Actes Sud, 2008)
- Julien Choppin and Nicola Delon (eds.), Matière grise: Matériaux / réemploi / architecture (Paris: Edition du Pavillon de l'Arsenal, 2014)
- Michaël Ghyoot, Lionel Devlieger, Lionel Billiet, and André Warnier, Déconstruction et réemploi: Comment faire circuler les éléments de construction (Lausanne: EPFL Press, 2018)
- Annette Hillebrandt, Petra Riegler-Floors, Anja Rosen, and Johanna Seggewies, Atlas Recycling: Gebäude als Materialressource (Munich: Detail, 2018)
- Daniel Stockhammer (ed.), Upcycling: Wieder- und Weiterverwendung als Gestaltungsprinzip in der Architektur (Zurich: Triest, 2020).
- Muck Petzet and Florian Heilmeyer (eds.), Reduce, Reuse, Recycle: Architecture as Resource; German Pavilion, 13th International Architecture Exhibition, La Biennale di Venezia 2012 (Ostfildern: Hatje Cantz, 2012)
- Stefan Altekamp, Carmen Marcks-Jacobs, and Peter Seiler (eds.), Perspektiven der Spolienforschung 1. Spoliierung und Transposition, Berlin: De Gruyter, 2013
- Hans-Rudolf Meier, Spolien: Phänomene der Wiederverwendung in der Architektur (Berlin: Jovis, 2020)
- Guido Brandi, Baubüro in situ – K.118 – Kopfbau Halle 118, Winterthur, Switzerland; Architettura circolare / Circular architecture, Casabella 939, Novembre 2022, Mondadori, 2022
- Rios, F. C., Chong, W. K., & Grau, D. (2015). Design for disassembly and deconstruction-challenges and opportunities. Procedia engineering, 118, 1296-1304.
- Thormark, C. (2007, September). Motives for design for disassembly in building construction. In International congress sustainable construction, materials and practices challenge of the industry for the new millennium, Lisbon.
- Rios, F. C., Chong, W. K., & Grau, D. (2015). Design for disassembly and deconstruction-challenges and opportunities. Procedia engineering, 118, 1296-1304.
- Circular Construction, Re-Use and Design for Disassembly in the Swiss Furniture Industry and in teaching BA-Architecture Students at ZHAW
- https://circulareconomy.europa.eu/platform/sites/default/files/circular-economy-in-the-furniture-industry.pdf
- https://www.ellenmacarthurfoundation.org/what-is-the-linear-economy
- https://www.pusch.ch/fileadmin/kundendaten/de/Unternehmen/Furniture_Industry_And_Circular_Economy_Policy_Paper_EFIC.pdf
- https://www.eesc.europa.eu/en/our-work/opinions-information-reports/opinions/european-furniture-industry-its-recovery-towards-innovative-green-and-circular-economy
- https://www.europarl.europa.eu/RegData/etudes/BRIE/2019/640158/EPRS_BRI(2019)640158_EN.pdf
- https://www.clubofrome.org/history/
- https://www.steelcase.com/eu-de/produkte/arbeitsstuhle/ara/
- https://c2ccertified.org/
- https://girsberger.com/de/loesungen/remanufacturing/
- Case Study: Teaching principles of Circular Construction, Re-Use and Design for Disassembly to BA Architecture students by using furniture as a didactic object
- https://www.zhaw.ch/de/archbau/institute/zbp/lehre/lehrprojekte-dtef/
- https://www.shapertools.com/

Design for Disassembly

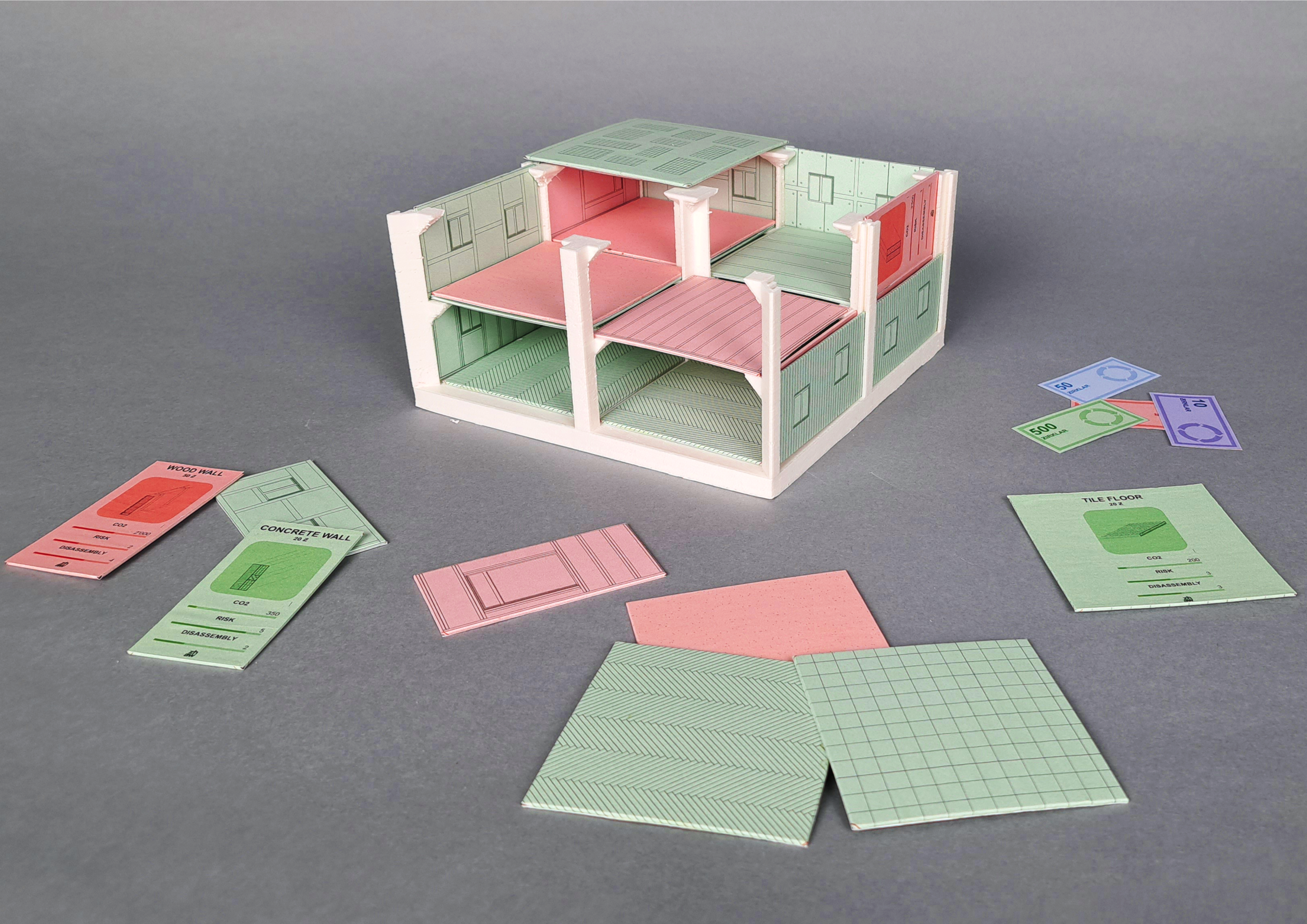
- Rios, F. C., Chong, W. K., & Grau, D. (2015). Design for disassembly and deconstruction-challenges and opportunities. Procedia engineering, 118, 1296-1304.
- Thormark, C. (2007, September). Motives for design for disassembly in building construction. In International congress sustainable construction, materials and practices challenge of the industry for the new millennium, Lisbon.
- https://www.bam.co.uk/media-centre/news-details/bam-opens-circular-building-at-london-design-festival
- https://www.frener-reifer.com/news-en/circular-building-installation-and-exhibition-in-london/
- https://emphase.ch/house-of-switzerland/
- https://www.spillmannechsle.ch/?p=2753&lang=de
- Wieser, C. (Ed.). (2017). House of Switzerland: a dictionary of elements. Park Books.
- Analysis of the Shaanxi Project
- Kozma, A. (2020). Demountable Composite Beams: Analytical calculation approaches for shear connections with multilinear load-slip behaviour (Doctoral dissertation, University of Luxembourg, Luxembourg).

A3. Grossary

DP	Demonstration Project
HVAC	Heating, Ventilation, and Air-conditioning
SDC	Swiss Agency for Development and Coordination
Mohurd	Ministry of Housing and Urban-Rural Development
ZEB	Zero Emission Buildings
Intep	Integrale Plannung GmbH
Skat	Skat Consulting Ltd.
CABR	China Academy of Building Research
UAD	Architectural Design & Research Institute of Zhejiang University
SUP	SUP Atelier of THAD (The Architecture Design and Research Institute of Tsinghua University Co., Ltd.)
HSLU	Lucerne University of Applied Sciences and Arts
Low-Tech	Low-Tech Lab GmbH
FHNW	University of Applied Sciences Northwestern Switzerland
ZHAW	Zurich University of Applied Science
Willers	Willers Jobst Engineering AG
DfD	Design for Disassembly

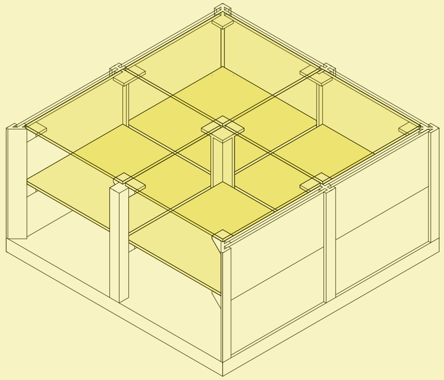
A4. Reuse Game Guide

REUSE GAME
再利用游戏

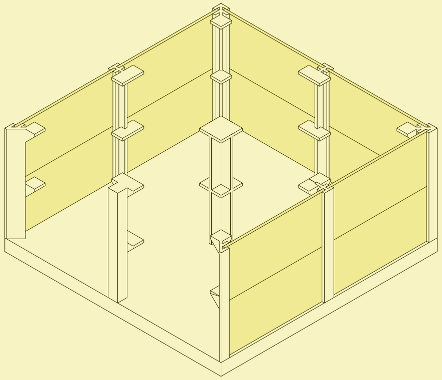


WOOD WALL
CO2
RISK
DISASSEMBLY
CONCRETE WALL
20 Z
CO2
350
RISK
5
DISASSEMBLY
2
TILE FLOOR
20 Z
CO2
200
RISK
3
DISASSEMBLY
3
50
ZIRKLAR
500
ZIRKLAR
10
ZIRKLAR

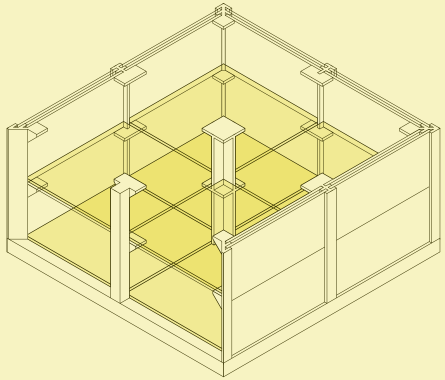
TO BUILD THE EXTENSION, YOU WILL NEED
要建造这个扩展部分，你需要



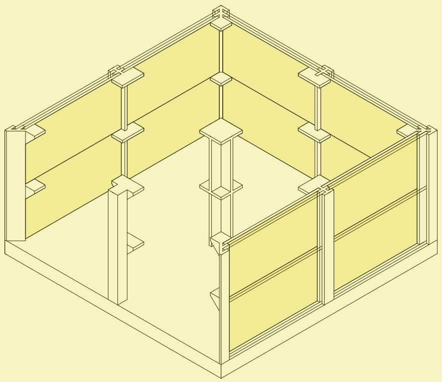
8 SLAB ELEMENTS
8个板块



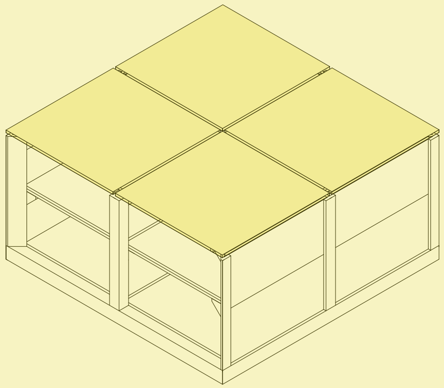
12 FACADE ELEMENTS
12个立面



8 FLOORING ELEMENTS
8个地板



12 WALL STRUCTURE ELEMENTS
12个墙面结构



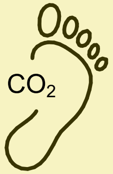
4 ROOF ELEMENTS
4个屋顶

RULES 规则

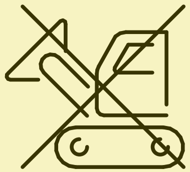
NEW
新部件

REUSED
再利用部件

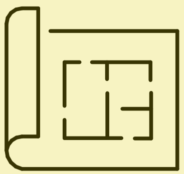
THE COMPONENTS CAN BE NEW OR REUSED
部件可以是新的也可以再利用



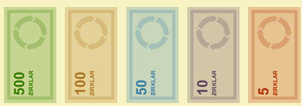
THE BUILDING MUST BE LOW IN CO2
建筑必须低碳



... BUT ALSO EASY TO DISMANTLE
同时也要容易拆解



... AND BE AESTHETICALLY AND STRUCTURALLY FEASIBLE
并且在美学和结构上是可行的

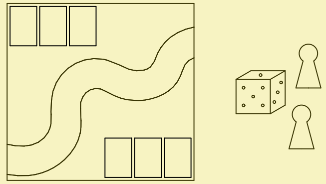


1x 6x 11x 10x 10x

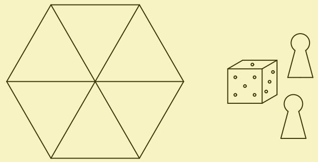
YOU HAVE A MAXIMUM BUDGET OF 1600 Ƶ
你最多有1600Z的预算

GAME SETTING 游戏设置

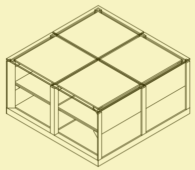
1: COMPONENT HUNTING
部件搜寻



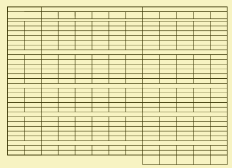
2: COMPONENT TESTING
部件测试



3: PROJECT DESIGN
工程设计



4: EVALUATION AND DISCUSSION
评估和讨论



1: THE HUNT
搜寻

MATERIAL:

1 game board "Components hunting"

1 token per team and 1 dice

1600 Zirkulars per Team

The Bank of reused materials

材料：

1个游戏棋盘——“材料搜寻”游戏

每队1个棋子和1个骰子

每队1600个Zirkulars

再利用材料银行

1. Each team rolls the dice and the team with the highest total starts the game.

2. The first team places its token on the "START" square, rolls the die and moves its token forward as many squares as the die indicates.

3. On each square, the team receives a card referring to the category it has just landed on. The team can choose to buy all, some or none of the materials on offer.

4. The second team can then roll the die.

5. The first team to land on or pass through the "FINISH" square gets the bonus card and stops playing. The other team can continue until it is their turn to finish.

1. 每个团队都要掷骰子，总点数最高的团队开始游戏。

2. 第一队将棋子放在“开始”方格上，掷骰子，然后将棋子向前移动到骰子所示的方格数上。

3. 在每个方格上，该队伍将收到一张与其刚刚着陆的类别有关的卡片。队伍可以选择购买该方块上提供的所有、一些或者没有材料。

4. 第二队可以开始掷骰子

5. 第一个着陆或通过“终点”方格的队伍将获得奖励卡并停止游戏。其他队伍可以继续进行，直到轮到他们结束。

SEARCH

Finding materials is a challenging task for architects. They must engage with various sources, including contacting multiple dealers (such as businesses and companies specializing in used building components, including industries undergoing changes or demolitions). Additionally, they often utilize intermediaries like online consulting platforms and companies that facilitate connections between buyers and property owners, such as Ricardo and Salza. Architects also conduct individual research efforts, which involve scouting demolition sites and establishing direct contact with property owners.

ASSESSMENT

Once the components have been found, the architects have to sort out very systematically what can be used and what cannot. There are several criteria for this. It has to be logistically feasible, so it has to be easy to transport, dismantle and store. There are, of course, architectural criteria, such as colours, geometry and proportions. Technical criteria are also very important: the objects have to be suitable in terms of structure, building physics and fire protection. Also if a component costs more to re-use, the client won't like it. And finally, you have to calculate whether it's worth the cost in ecological terms. Although you can cross almost the whole of Europe with a reused component and still be better off in terms of CO_2 emissions, that may not be the case if you have to cross an entire ocean, for example.

寻找

寻找建筑部件是建筑师面临的一项具有挑战性的任务。他们必须与各种资源互动，包括联系多个经销商（如专门从事二手建筑材料的企业和公司，包括正在发生变化或拆除的行业）。此外，他们经常利用在线咨询平台和促进买卖双方联系的公司，如Ricardo和Salza等中介机构。建筑师还进行个体研究工作，包括寻找拆迁场地并与房地产所有者直接联系。

评估

一旦找到了这些组件，建筑师们必须非常系统地整理出什么可以使用，什么不能使用，这有几条准则。它必须在运输上是可行的，因此在运输、拆卸和存储方面必须简便。当然，还有建筑标准，如颜色、几何和比例。技术标准也非常重要：物体在结构、建筑物理和防火方面必须合适。另外，如果重新使用某个组件的成本更高，客户可能不会喜欢。最后，你必须计算在生态方面是否值得成本。比如，尽管你可以将一个再利用的组件运过整个欧洲并且在二氧化碳排放方面仍然更有利，但如果你需要穿越整个海洋，情况可能就不同。

DOCUMENTATION

An essential phase in the process is thorough documentation of all the components. The individuals responsible for this task, often referred to as "hunters," must first identify the manufacturer to obtain relevant documentation. Subsequently, they compile this documentation and generate CAD drawings, occasionally including 3D models. These collected pieces of information are then used to create a comprehensive passport for the located materials.

记录

该过程中一个重要的阶段是对所有组件进行彻底的文档记录。负责这项任务的个人通常被称为“猎手”，他们必须首先确定制造商以获取相关文档。随后，他们整理这些文档并生成CAD图纸，有时包括3D模型。这些收集到的信息会被用来为定位到的材料创建一份全面的档案。

DISMANTLING

The dismantling phase is of extreme importance, although it can pose significant challenges. There are instances where architects wish to rescue components in excellent or near-new condition, but are unable to do so due to strong adhesion that makes removal without damage impossible. Demolition is usually carried out by either a specialist company or a demolition contractor.

拆解

拆解阶段非常重要，尽管可能存在一些重大挑战。有时建筑师希望拯救处于极好或几乎全新状态的组件，但由于坚固的粘附使得部件在拆除时会产生损坏。拆除工作通常是由专业公司或拆迁承包商进行。

2: THE TESTING
测试

MATERIAL:

1 game board
"Components testing"

1 token per team and 1 dice

The money left over

材料：

1个游戏棋盘“零部件测试”

每队1个棋子和1个骰子

剩下的钱

1. Each team in turn throws the dice once.

2. The number on the die equals the corresponding box

3. The teams have to do what is written in this box

1、每队轮流掷一次骰子

2、骰子上的数字对应相应的方格。

3、队伍必须按照方格上写的内容执行

TRANSPORT

The cost of transporting components is a significant factor in the project budget. You need to coordinate the transfer of the components from the mine to storage, possibly to a repair facility, and finally to the construction site. Often, different companies are involved in these stages, and effective management of all these companies is crucial.

STORAGE

From the time you find an interesting component to the time you can actually use it can be a long time, sometimes several years. During this time you will need a suitable storage facility. While in some cases it's possible to store items in a garage or underground, more often than not you'll need to rent dedicated square metres from a specialised company.

运输

运输零部件的成本是项目预算中的一个重要因素。你需要协调将零部件从矿山转移到存储地点，可能还要转运到维修设施，最终运送到建筑现场。通常，在这些阶段涉及不同的公司，有效管理所有这些公司至关重要。

存储

从你发现一个有趣的组件到实际使用它可能需要很长时间，有时甚至几年。在这段时间里，你将需要一个合适的存储设施。虽然在一些情况下可以将物品存放在车库或地下，但更常见的是你需要从专业公司租专用的位置。

PREPARATION

Reused components often require adjustments, repairs, or refurbishment work before they can be reinstalled. In some cases, testing may also be necessary.

REINSTALLATION

A meticulously documented and well-planned process can ensure a successful reinstallation of the components. Nevertheless, it can be challenging to find companies willing to undertake the installation of reused components. Additionally, these companies may be hesitant to provide warranties for their work, as they typically do with new components.

准备

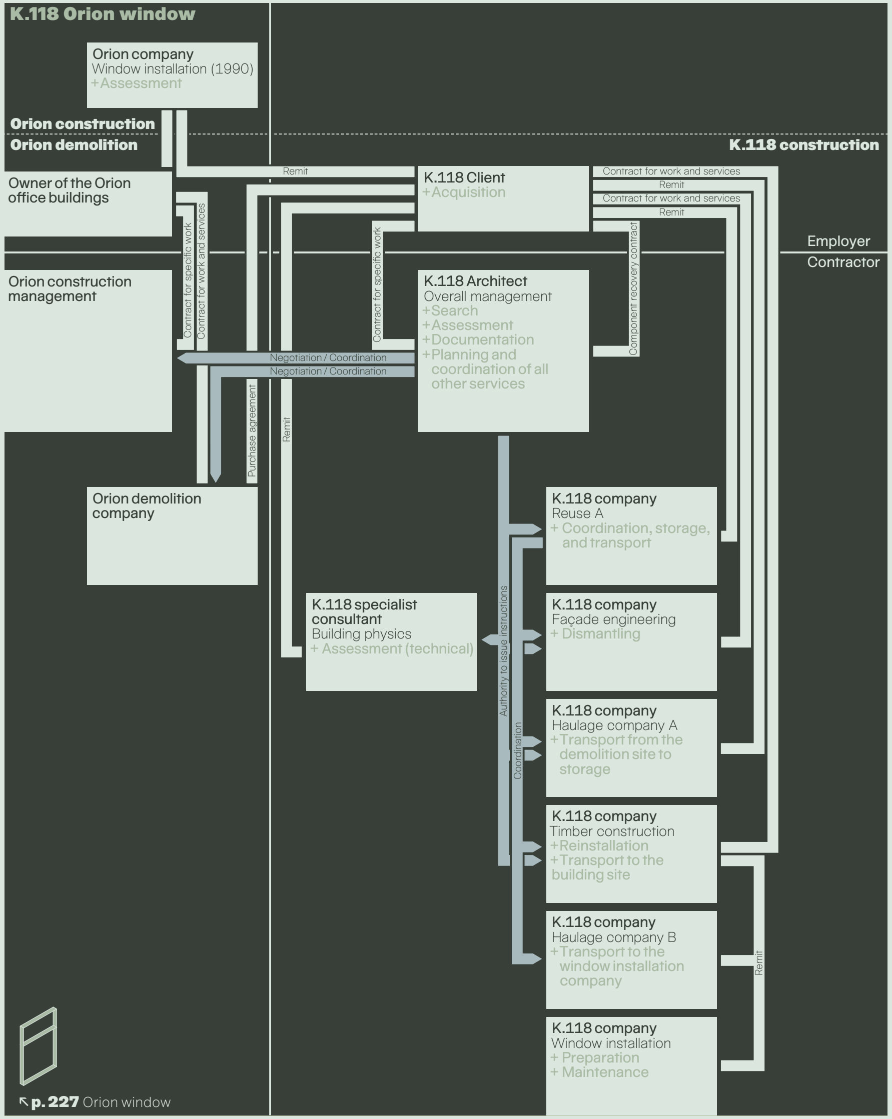
再利用的组件在重新安装之前通常需要调整、修理或翻新工作。在某些情况下，可能还需要进行测试。

重新安装

一份详细记录和精心规划的流程可以确保零部件的成功安装。然而，找到愿意承担再利用零部件安装的公司可能会具有挑战性。此外，这些公司可能不愿提供再安装的部件保修，因为他们通常在新零部件上提供保修。

MAINTENANCE

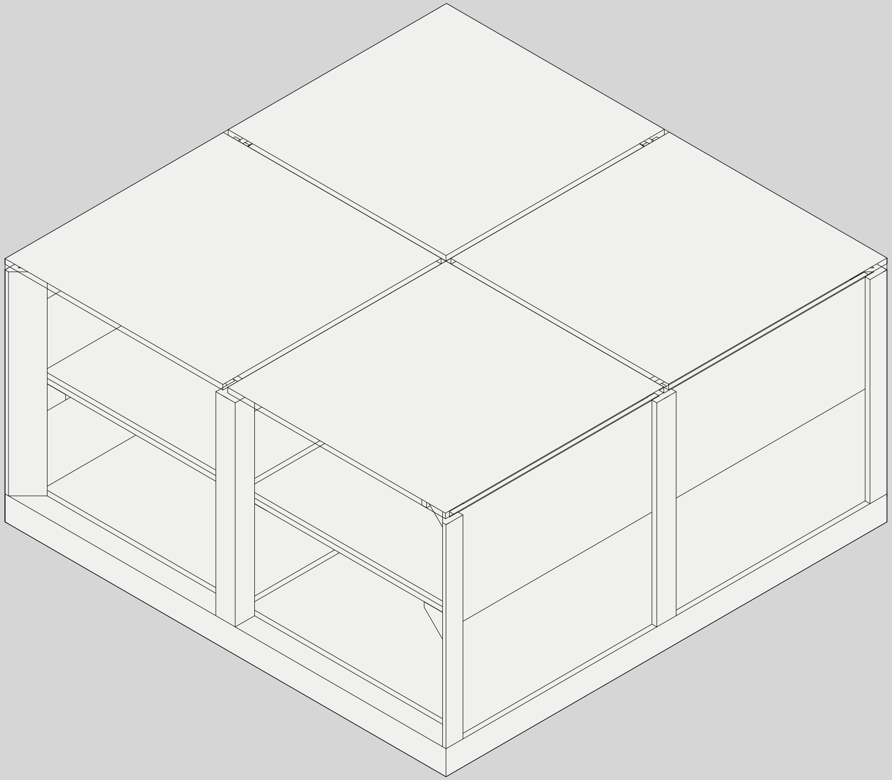
Similar to new components, regular maintenance of your installed reused components can significantly extend their lifespan. Maintenance is often carried out by the manufacturer, but more frequently, it's entrusted to other companies who are compensated for their services. In some cases, the owner or user may also take on the responsibility for maintenance.



维护

与新组件类似，定期对已安装的再利用组件进行维护可以显著延长它们的寿命。维护通常由制造商进行，但更频繁地，它被委托给其他公司，这些公司会得到服务费用的补偿。在某些情况下，业主或用户也可能承担维护的责任。

3: DESIGN
设计



MATERIAL:

The money left over

All the reused materials bought

The Bank of new materials

1 Building structure per team

材料：

剩余的资金

所有购买的再利用材料

新材料银行

每队1个建筑结构

1. Each team has to build its extension using:
12 facade elements
12 wall structure elements
8 slab elements
8 flooring elements
4 roof elements

2. All the materials you collect can be used for this. Missing materials can be purchased from the Bank of new components. No reused materials can be bought anymore, exchanges are permitted between the teams.

3. The best project will be the one with the less CO_2, but also the best disassembly score. Esthetic and structure are also very important!

1、每个队必须使用以下材料建造自己的扩建部分：
12个立面元素，
12个墙体结构元素，
8个板块元素，
8个地板元素，
4个屋顶元素。

2、你收集到的所有材料都可以用于此目的。缺少的材料可以从新组件银行购买。不能再购买再利用的材料，可以在队伍之间进行交换。

3、最佳项目将是二氧化碳排放最少的项目，同时拆解得分最高。美学和结构也非常重要！

4: EVALUATION
评估

Material 交易		Per component 交易						Total 交易				
		Reused 交易	New 交易	Price 交易	CO2 交易	Disassembly 交易	Risk 交易	Quantity 交易	Price 交易	CO2 交易	Disassembly 交易	Risk 交易
Slab 交易	Concrete 交易											
	Steel 交易											
	Wood 交易											
	Concrete 交易											
	Steel 交易											
	Wood 交易											
Wall 交易	Concrete 交易											
	Steel 交易											
	Wood 交易											
	Concrete 交易											
	Steel 交易											
	Wood 交易											
Flooring 交易	Parquet 交易											
	Tiles 交易											
	Parquet 交易											
	Tiles 交易											
	Linoleum 交易											
Facade 交易	Wood 交易											
	Metal 交易											
	Wood 交易											
	Metal 交易											
	Plaster 交易											
Roof 交易	Flat 交易											
	Flat 交易											
								Total 交易				

1. Each team must count its number of components by folding up the attached table.

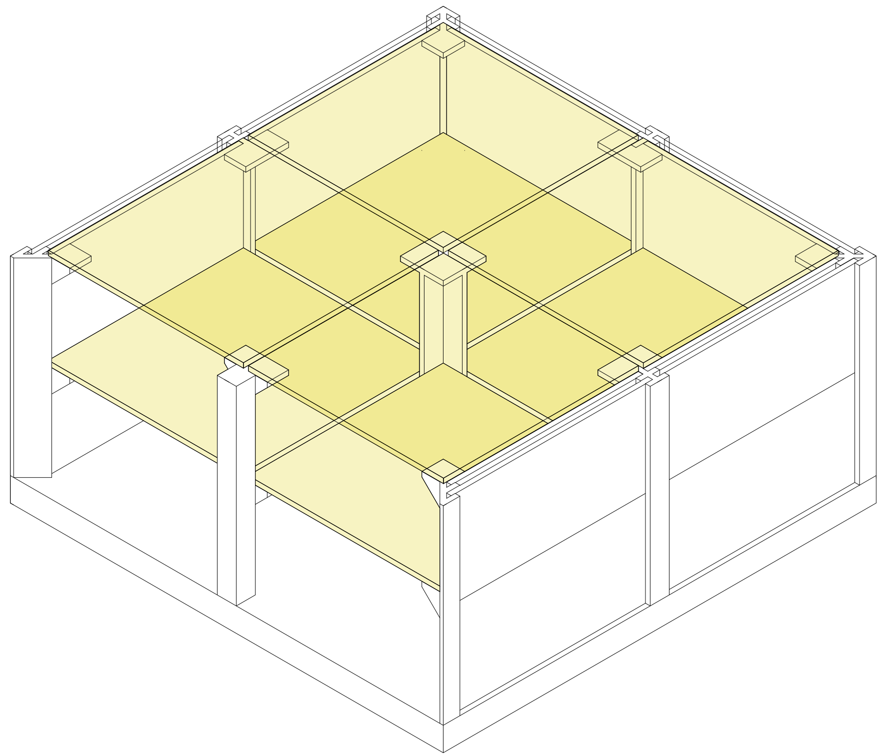
2. The final evaluation is given by the game master.

1、每个队必须通过展开附表来统计其零部件的数量。

2、最终评估由游戏主持人进行。

CATALOG
目录

SLAB ELEMENTS
板块元素



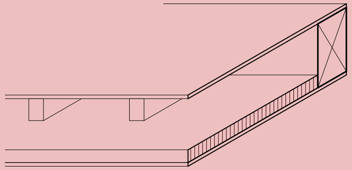
WOOD SLAB
木质板材

CO2 二氧化碳 1'500

RISK 风险 2

DISASSEMBLY 拆解 4

50 Ƶ



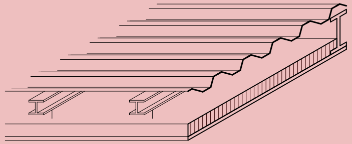
METAL SLAB
钢铁板材

CO2 二氧化碳 4'000

RISK 风险 2

DISASSEMBLY 拆解 6

30 Ƶ



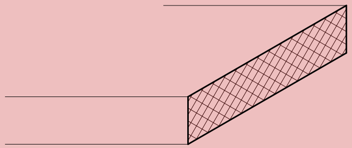
CONCRETE SLAB
混凝土板材

CO2 二氧化碳 5'000

RISK 风险 1

DISASSEMBLY 拆解 2

10 Ƶ



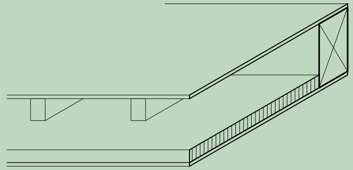
WOOD SLAB
木质板材

CO2 二氧化碳 150

RISK 风险 4

DISASSEMBLY 拆解 4

60 Ƶ



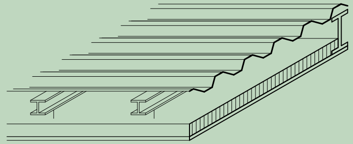
METAL SLAB
钢铁板材

CO2 二氧化碳 400

RISK 风险 3

DISASSEMBLY 拆解 6

40 Ƶ



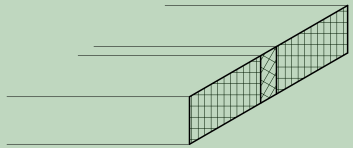
CONCRETE SLAB
混凝土板材

CO2 二氧化碳 500

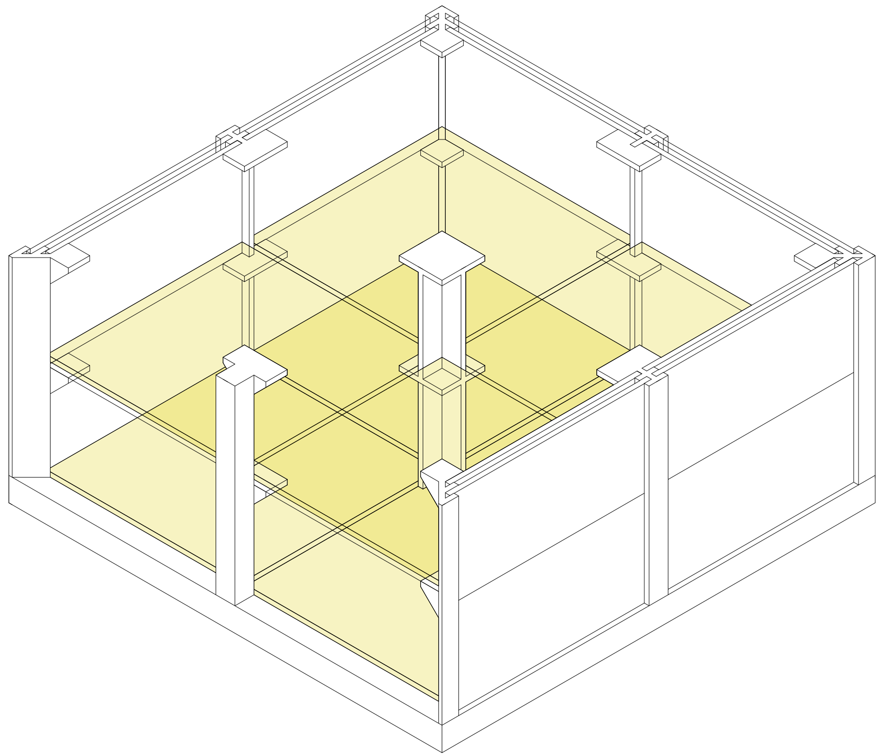
RISK 风险 5

DISASSEMBLY 拆解 2

20 Ƶ



FLOORING ELEMENTS
地板元素



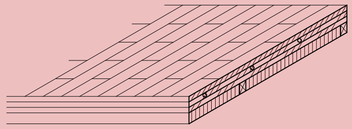
PARQUET FLOOR
镶嵌地板

CO2 二氧化碳 1'000

RISK 风险 1

DISASSEMBLY 拆解 5

20 Ƶ



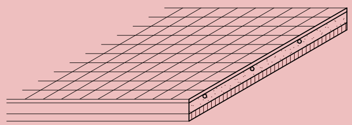
TILE FLOOR
瓷砖地板

CO2 二氧化碳 2'000

RISK 风险 2

DISASSEMBLY 拆解 3

10 Ƶ



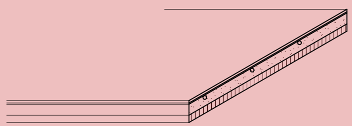
LINOLEUM FLOOR
油毡地板

CO2 二氧化碳 1'500

RISK 风险 2

DISASSEMBLY 拆解 2

5 Ƶ



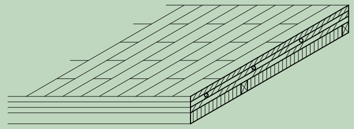
PARQUET FLOOR
镶嵌地板

CO2 二氧化碳 100

RISK 风险 3

DISASSEMBLY 拆解 5

30 Ƶ



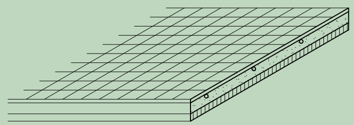
TILE FLOOR
瓷砖地板

CO2 二氧化碳 200

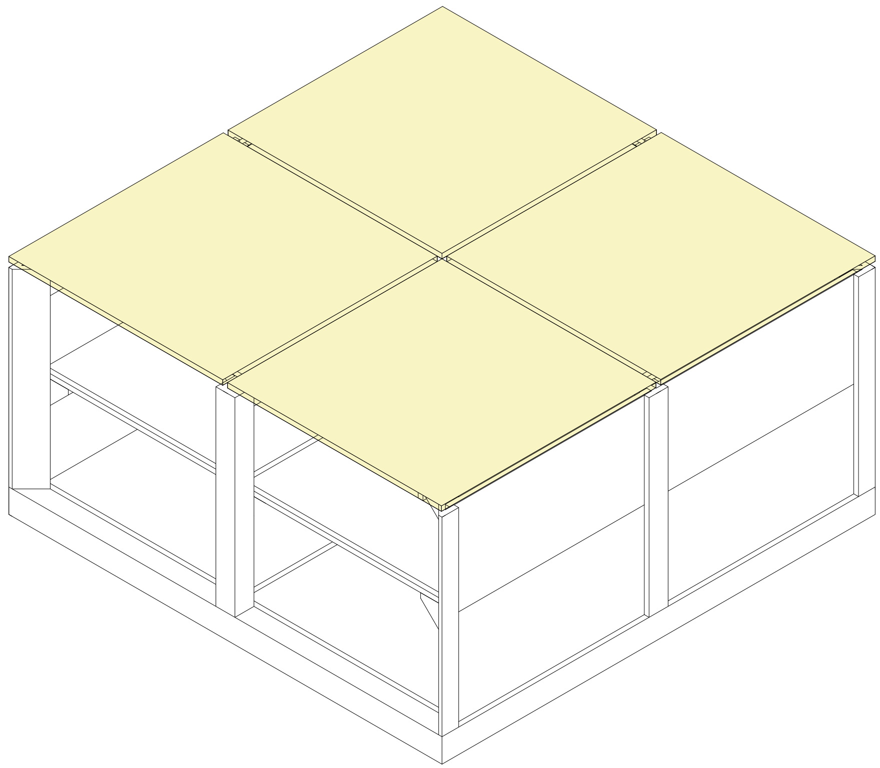
RISK 风险 3

DISASSEMBLY 拆解 3

20 Ƶ

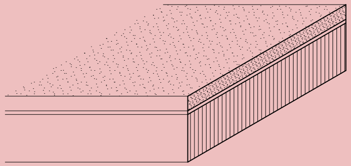


ROOF ELEMENTS
屋顶元素



ROOF
屋顶

30 Ƶ



CO2 二氧化碳

5'000

RISK 风险

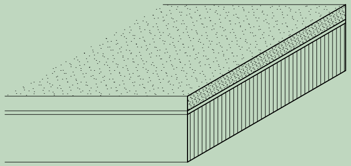
2

DISASSEMBLY 拆解

4

ROOF
屋顶

40 Ƶ



CO2 二氧化碳

500

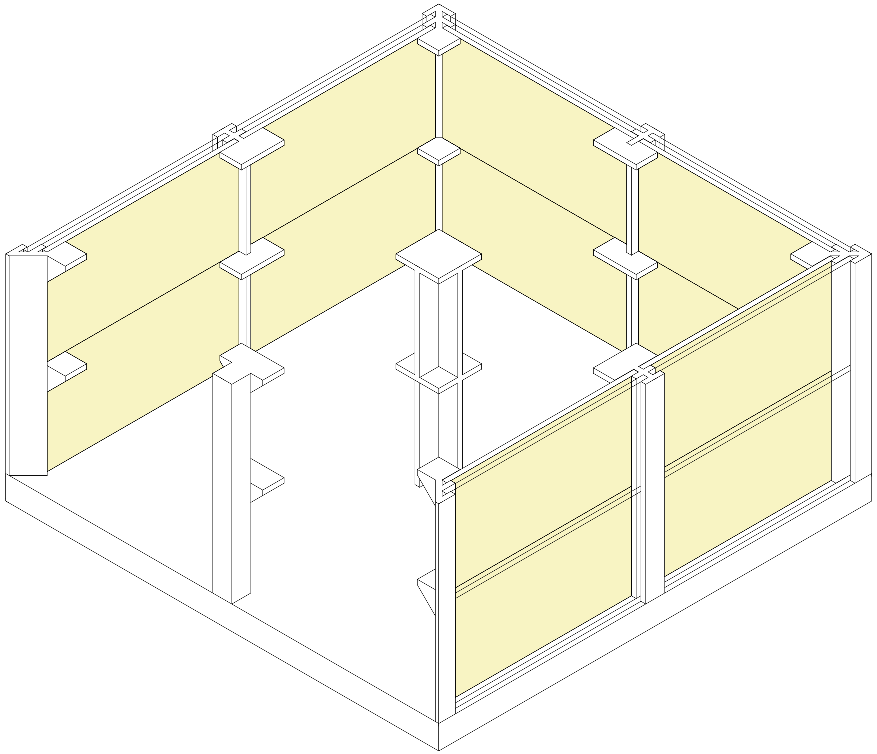
RISK 风险

6

DISASSEMBLY 拆解

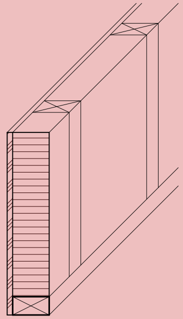
4

WALL STRUCTURE
墙面结构



WOOD STRUCTURE
木结构

50 Ƶ



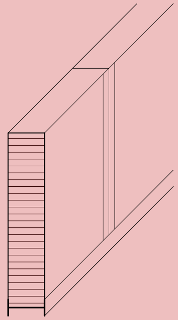
CO2 二氧化碳 2'000

RISK 风险 2

DISASSEMBLY 拆解 4

METAL STRUCTURE
金属结构

30 Ƶ



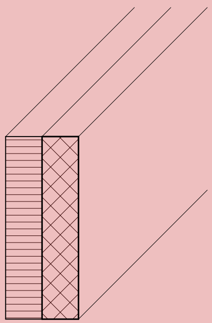
CO2 二氧化碳 2'500

RISK 风险 2

DISASSEMBLY 拆解 6

CONCRETE STRUCTURE
混凝土结构

10 Ƶ



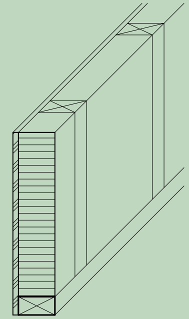
CO2 二氧化碳 3'500

RISK 风险 1

DISASSEMBLY 拆解 2

WOOD STRUCTURE
木结构

60 Ƶ



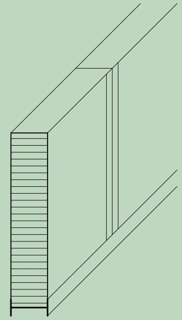
CO2 二氧化碳 200

RISK 风险 4

DISASSEMBLY 拆解 4

METAL STRUCTURE
金属结构

40 Ƶ



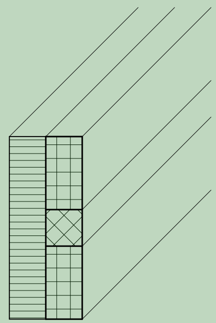
CO2 二氧化碳 250

RISK 风险 3

DISASSEMBLY 拆解 6

CONCRETE STRUCTURE
混凝土结构

20 Ƶ

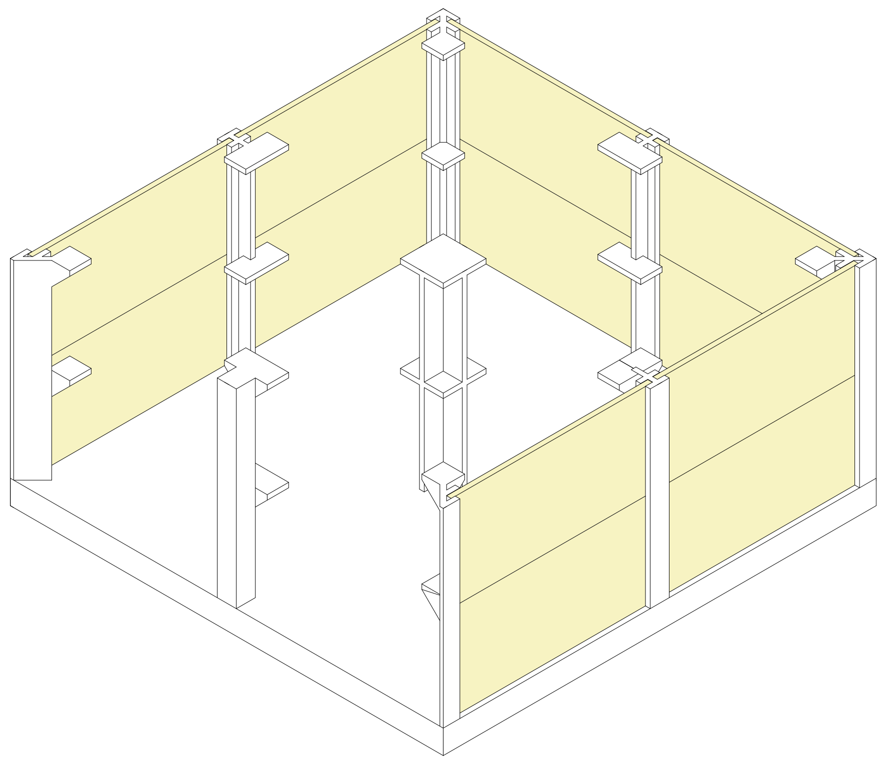


CO2 二氧化碳 350

RISK 风险 5

DISASSEMBLY 拆解 2

FACADE ELEMENTS
立面元素

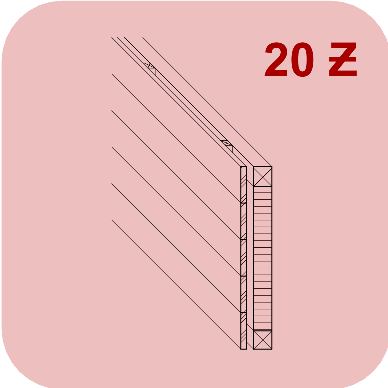


WOOD FACADE
木质立面

CO2 二氧化碳 500

RISK 风险 1

DISASSEMBLY 拆解 4

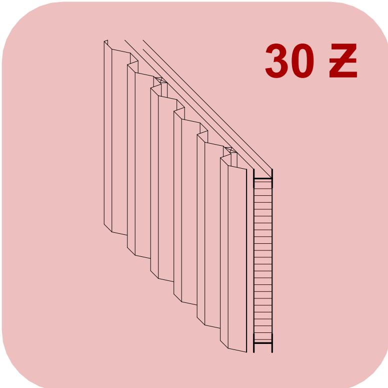


METAL FACADE
金属立面

CO2 二氧化碳 1'500

RISK 风险 1

DISASSEMBLY 拆解 6

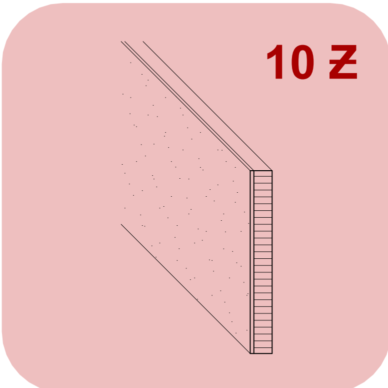


PLASTER FACADE
石膏立面

CO2 二氧化碳 1'000

RISK 风险 2

DISASSEMBLY 拆解 2

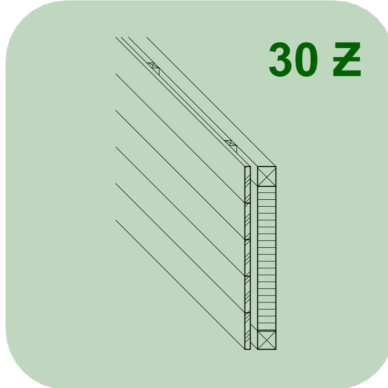


WOOD FACADE
木质立面

CO2 二氧化碳 50

RISK 风险 4

DISASSEMBLY 拆解 4

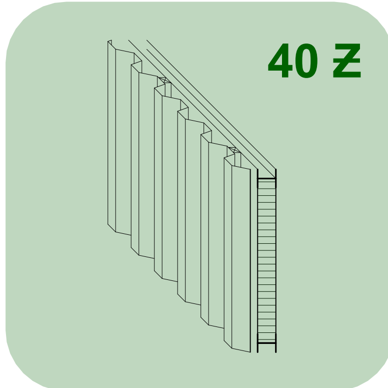


METAL FACADE
金属立面

CO2 二氧化碳 150

RISK 风险 3

DISASSEMBLY 拆解 6



让我们共同打造气候中和的未来
Building a climate-neutral future together

BUILDING A CLIMATE – NEUTRAL FUTURE TOGETHER