Restructure, repurpose, extend.
Design strategies for future-oriented building and for strengthening the potential of the existing building fabric

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Abstract. Climate neutrality coupled with an overall positive ecological footprint is still a distant dream for new construction. The German building sector is directly and indirectly responsible for about 40% of all German CO₂ emissions and has so far failed its CO₂ reduction goals. For the German building sector, the key to climate neutrality lies not only within new construction but in its existing building fabric. The embodied carbon of new construction needs to be reduced as well as the amount of new construction itself. Hence the reuse of buildings and the extension of their life cycles is a crucial factor in reducing CO₂ emissions and resource consumption. In this paper we present three of our projects (from the office Sauerbruch Hutton), highlighting not only the potentials but also the problems that planners face with existing buildings. Additionally, our project based LCA analysis showcases that retrofitting can have a much smaller CO₂ footprint than a new building.

Keywords: reuse, reinterpret, timber, life cycle assessment, loose fit

1. Introduction
Reusing buildings must become the new normal. Adapted, restructured and/or extended old structures can gain second lives while maintaining close connections to the contemporary urban surroundings.

To achieve the most recent climate action plan goals by 2050, CO₂ emissions must be drastically reduced, especially in the construction sector. Thereby all phases of a building’s life cycle have to be considered. As the environmental impact of construction and demolition has been neglected in the last decades, there is still a high potential to save CO₂ emissions. On average, 25-40% of a building’s CO₂ emissions over a life span of 50 years evolve from new construction processes [1]. This proportion increases up to 100% if the building operation is CO₂ neutral or plus energy. In total, these non-operational CO₂ emissions account for ca. 7% of all CO₂ emissions in Germany, next to ca. 33% of building operations [2]. To reduce the footprint of new construction, the processes from manufacturing, transportation, construction to maintenance and disassembly have to be undertaken using renewable energy and local renewable, reused or recycled materials. Comparing structural systems for example, the use of sustainable local timber can reduce CO₂ emissions by about 40% compared to concrete structures. This can be a big step towards climate neutral construction, but still not sufficient. Reusing buildings and preserving structures, however, has a much higher potential.
The CO₂ life cycle footprint amounts to, on average, 10-25% for retrofits, which is up to ¼ of new construction [1]. Hence, it is imperative to reduce construction as a whole by reusing buildings and enhancing them towards fulfilling current needs. In order to meet current and future spatial demands, we need to use the buildings that are already there. To restructure, reuse and extend the outdated, vacant or insufficient existing building fabric. Only through design and growing experience in dealing with existing buildings can the architectural profession provide arguments for politicians to strengthen the relevant branches of industry and inspire clients as well as other planners to tender and implement a new reuse building culture.

This paper elaborates on three of Sauerbruch Hutton’s reuse projects of buildings from the 70s and 80s in Germany. As design strategies and “lessons learned”, the projects showcase different architectural strategies in rethinking and enhancing the existing while overcoming obstacles in current planning practice. The first project, Munich Re, deals with a building that is perceived as ugly and does not allow for the needed office use. Therefore the design strategy focuses on restructuring the façade and interior of the building through careful extraction and reshaping, giving the building a completely new appearance. The second reuse project, the Telekom Tower in Constance, revolves around the repurposing of office spaces into housing while keeping as much of the existing building as possible. The third project showcases the extension of the Berlin Metropolitan School with a lightweight timber construction. The existing building remains untouched, yet a new aesthetic is created with the rooftop addition. The new structure has an independent appearance from the old while simultaneously enhancing the existing and creating a new aesthetic with new and old. Furthermore, the projects seek to create benefits for the urban surroundings and change the perception of a building not only as an individual object, but as part of the urban tissue and building culture.

2. Life Cycle Analysis
Assessing the environmental impacts of resource flows and material usage – especially with regard to CO₂ emissions - is an important part of a sustainable design process. We assess the environmental performance of our projects using the international normed (DIN EN 15804) EPD data from the German platform Ökobaudat (BMWSB), both retrospectively as well as alongside project development, in order to improve our designs. Our latest LCA results include the production phase (A1-A3), the transport to the construction site (A4, depends on information about regional materials and craft companies), the construction processes (A5), deconstruction (C1), the transport to a disposal site (C2, depends on regional disposal management) and waste management (C3, C4). For waste management we use available product data for C3 and/or C4. If no product data is available, we use general end of life data for construction waste landfill or, in the case of steel products, we apply the end of life data for steel profiles. For the reuse of existing material, the carbon impact for its end of life was not calculated. We verify our results with eLCA, the official tool from the Bundesinstitut für Bau- Stadt- und Raumforschung (BBSR). For a deeper understanding and presentation of environmental impacts, we constantly improve our life cycle analysis. For internal and external discussions, the analysis makes it easier to quantify environmental impacts. With regard to transport, the benefits of using local reusable or renewable materials become more tangible.

3. Restructure - Retrofitting of an Office and Data Centre
3.1. Munich Re
This refurbishment and retrofit of a 1980s office block in Munich in 2014 provided a rare opportunity to thoroughly reuse an existing building. This involved minimising overall energy consumption and improving workplace comfort and environmental quality. The complete renewal of the façade was used to give a previously blank building on the city ring road an elegant and unexpectedly dynamic presence. The old spandrel panels were removed for full-height glazing, and the building’s overall form was modified to conceal the formerly projecting staircases and create a new, dynamic entity.
3.2. Design for reuse

Converting a structure previously designed for a different purpose is challenging. In this case the building was made to host huge computing machines. The deep floor plans allowed for a dark central area with space for the computers, which were incredibly enormous in those days, with daylight office spaces around the perimeter. As the central area was neither naturally ventilated nor lit by daylight, it was decided to take out some ceilings and create a central atrium. This allowed for an office design with standards comparable to those of new build offices.

Although the main structure was retained, the façade was completely replaced. The non-load-bearing concrete balustrades and the lintels above the windows were removed and replaced by large windows with low balustrades. Both measures—the creation of daylight atriums in the middle of the floor plan and expansion of glazed area—resulted in a great improvement in the supply of daylight.

3.3. Lessons learned

When the decision was taken to tear down the slabs in the middle of the floor plan, the consequences on the structure had to be examined. Structures erected in the 1980s, were designed to use as little material as possible. This resulted in a lean structure without any buffer for additional loads. By taking out the middle slab, the static system of the load bearing structure was changed and weakened. Additional reinforcement was therefore required. To leave the remaining concrete slabs intact, a fibre reinforcement was bonded into the soffit.

Following the fire safety regulations, the four upper floors of the main structure were divided into units with a maximum area of 400 m². Direct access to these areas is provided via the main staircases.
and lifts – which were kept in place. Thanks to the atrium, there are no gloomy core areas in the units situated in the middle of the north and south wings. These “conference bridges” create spatial situations that increase the scope for communication between the floors.

It was necessary to remove the ground slab in a limited area to create the pit for a new elevator serving the lower floors. According to the existing ground water survey made at the initial building phase, the building was above the existing water levels. However, when the ground plate was opened, the ground water level showed to be a lot higher than it should have been. This was hard to understand as there had been no heavy rain or flooding that could explain the rise of the ground water level. The water-saturated soil under the ground plate was cooled down and iced, so that the new ground plate could be built. This part was executed in a water resistant quality. Later the engineers found that the reason for the higher water level was a large building that had been erected in the meantime and was causing a pond in the ground water stream.

3.4. Life cycle analysis
Despite necessary structural retrofits, the reuse of the existing building of Munich Re proved to be the most economical solution. Also in terms of ecological sustainability, it was performing better than a new building. Our life cycle analysis showcases that the production of a comparable new structure with 23,000 m³ concrete and 4,700 tons of reinforcement would have consumed ~32,000 MWh because of the high energy input in the concrete and steel production. This can be reduced down to 6,000 MWh by preserving and extending most of the existing building structure. Thereby only 4,250 m³ concrete with 900 tons reinforcement and 26 tons additional steel construction were used. The new roof construction of the additional storey with 1,350 m³ reinforced concrete and the constructive inner walls also in reinforced concrete with 1,250 m³ have the biggest remaining impact on the CO₂ Footprint of the conversion. The saving of 26,000 MWh prevents the emissions of up to 9,600 tons of CO₂. Additionally CO₂ emissions are saved due to the reduced demolition. While the whole demolition of the building produced the waste of 19,500 m³ concrete and 4,000 tons of reinforcement, the conversion caused the waste of 2,800 m³ concrete and 570 tons of reinforcement. So the entire savings are about 10,000 tons CO₂.

The operational energy demand was optimized by the new outer skin providing thermal insulation and solar protection, as well as natural lighting and ventilation in the offices. With these measures and the connection to the district heating of the Stadtwerke München, the CO₂ emissions for heating are reduced down to 36% compared to a conventional gas-heating. Because the Stadtwerke München produces a lot of energy with renewable sources such as geothermal, wind, sun or water, the CO₂ missions for power, especially for cooling the building, could potentially be lowered by ca. 95%.

![Energy Balance](image1)

![Accumulated Heating Energy Annually](image2)

Figure 5. © Sauerbruch Hutton
4. **Reuse - Changing an Office Tower into Housing**

4.1. **Telekom Tower Constance**
Constance is characterised by recreational spaces and historical buildings partially dating back to the middle ages. Appearing like a “Fremdkörper” in the historical cityscape is a 16-storey high rise approximately 60 m high from 1971 with a 36 m Antenna on top. Built for the German post office, the planning rights were abolished as a state owned enterprise. Later Telekom owned the building until it was sold due to long-term vacancies. Besides functioning as an office building, it provided the telecommunication for the area and will continue to do so. Instead of demolition, the new owner decided to convert it into a residential building. The conversions mission was to better integrate the building into the cityscape while minimizing demolition and creating adequate living spaces.

The new elements are balconies on the facades towards the east and west. The thereby extended floorplans provide 98 apartments varying from 1-5 rooms with a total of 30 – 170 m². The balconies break the anonymity of the rigid existing façade. The colour of ceramic balcony tiles integrate the building into the city by reflecting the surrounding green areas. The ground floor and two pavilions accommodate retail spaces and a restaurant. The plinth additions make the site more accessible for the community with the possibility of social interaction and networking within the quarter.

![Figure 6. before and after conversion © Sauerbruch Hutton](image)

4.2. **Design for reuse**
The project’s focal point was the maximum preservation of the existing structure. This entails a strong dependency on the existing and was the fundamental factor of the design process. Thus the apartment organization and interior fittings had to be optimized according to step by step investigations of the existing structure. The resulting shaft planning was bundled to minimize changes on the existing floor slabs. In the end, 93% of the structure is preserved. With the additions, 77% of the future housing tower’s area was already in use for the last 50 years and 23% were added during the conversion.
Reuse of materials was implemented where feasible. An example for a successful material reuse were natural stone tiles of the existing entrance area. The client contacted a local floor tiler, who evaluated the plates. He estimated an easy disassembly and reuse, because of an adequate tile size and thickness as well as a loose laying. The plates were selectively dismantled by the tilers and stored at their workshop until they were used again in the entrance hall. Other element reuse was also successful for the communal roof top terrace, for example with the flooring material.

4.3. Lessons learned
The existing reinforced concrete structure consists of very slim components with moderate reinforcement. The overall load bearing capacity is low, but sufficient for housing. Earthquake loads, however, demanded a structural retrofit. Constance is classified to be in Earthquake Zone 2, placing it in an endangered area. Due to the lack of previous standards, the earthquake loads were never calculated during the original construction and the current earthquake norm EC8 in the state of Baden Württemberg was not implemented. In order to calculate the loads, the project’s soil surveyor recommended an elastic response spectrum, which was specific to the zone and soil quality of the site. The calculation concluded a necessary strengthening of the bracing to absorb the loads and resulted in the removal and frictional connection of the expansion joints in the 1st-6th floor slabs. The structural calculation was accepted according to current norms, but the integration of an elevator matching today’s fire regulations in the existing shafts was only possible because of a special consent by the fire department. On the other hand, a functioning staircase to the roof terrace on the 16th floor had to be demolished and renewed to match today’s standards.

The added balconies have their own, mostly independent system with a separate pile foundation as to not overstrain the existing load bearing structure. Nonetheless, some loads still have to be transmitted into the existing outer beams and columns. This interference led to a necessary strengthening of the construction. However, the structural execution posed to be a challenge and the balcony structure had to be redesigned accordingly and in cooperation with the executing building company.

Unfortunately, after the dismantling of the interior fittings, the 10 cm thick ceilings lacked sufficient covering of the steel reinforcement and needed to be retrofitted to meet the F90 fire standards with a layer of gypsum plaster on the downside and a thin layer of screed on the top (2cm necessary for fire protection, but only 3cm possible to build). Additionally a survey of the floor slabs revealed a varying
height difference in each floor from 2-8 cm because of the buildings settlement on one side, as well as an extensive unevenness of the surfaces. Thus the floor layering depended on five main factors: 1. fire protection of the existing structure, 2. meeting the necessary acoustics for a residential building, 3. levelling out the uneven floor slabs, 4. fitting pipes and 5. not exceeding the weight limit for the bearable loads.

![Figure 8. reinforcement steel with minimal concrete cover © Sauerbruch Hutton](image)

![Figure 9. aluminium façade © Sauerbruch Hutton](image)

Regarding the reuse of materials, not all efforts were fruitful and many materials proved to be more difficult to reuse. The bad quality in the existing interior fittings and exterior elements made a reuse challenging, as well as contaminations like asbestos in some interior elements. The investigation of the façade panels showcase the difficulty of reusing composite material and necessary time management. The façade panels were extruded around a polyurethane foam layer, which had already started to deteriorate. The necessary processing of the materials for reuse and the upcoming costs had to be defined with the help of a reuse material agency. The separation of the foam from the metal proved to be difficult and a reuse without separation turned out to be more cost efficient. Detailed and advanced examinations were organized to learn about the durability of the metal as well as the quality and thermal values of the foam for interested buyers, who wanted to reuse the elements as roof covering. The logistics and estimated costs of a selective disassembly and transport were determined for the client and revealed a financial profit. However, the search for a buyer was unsuccessful because of the lack of time and a limited usability due to the old mounting system. As the process of reuse and reselling of building material was unfamiliar, the decision for its investigation with the reuse agency was unfortunately made too late. Due to a missing logistical infrastructure, the storage of the materials for a sale at a later time was also not yet possible.

Another investigation involved the recycling of concrete from the demolition of a bunker on the site: to reuse the rubble as an unsealed exterior pavement. Due to the difficulty in storing the material and the noise pollution for the neighbouring school, the idea was abandoned by the client. An alternate reuse of the concrete fragments as fillings for the excavation pit or the landscaping was declined because of possible soil contamination. Thus no recycling could be achieved; solutions for this problems still need to be found.
4.4. Life cycle analysis

From the beginning of the planning, in addition to the economic perspective, there was a strong focus on keeping as much of the existing building as possible. The main new components are the concrete slab for the balconies with 570 m³ reinforced concrete completed by slab additions of 400 m³ and 180 m³ precast concrete balustrades. The emissions for the new elements are estimated at around 800 tons of CO₂ in total. In addition there are ca. 10 tons of CO₂ for demolition caused by 290 m³ reinforced concrete in a few deconstructed slabs with columns, beams and some walls especially in the lower floors with 130 m³ reinforced concrete.

The saving of the conversion compared to a new residential building is estimated with at least 2,200 tons of CO₂. So the preservation of the existing building causes only 25% of the CO₂ emissions that a comparable new building construction would have emitted. The masses of a new building with the same dimension and standard are estimated at 6,250 m³ concrete and 1,160 tons of reinforcement.

In addition to a high standard of living, the newly created apartments also meet modern energy standards. With approx. 80–85 kWh per m², the building is comparable to a new building. The emissions saved by keeping the existing building are comparable to 15 years of heating for all apartments in the tower.

5. Extend – Adding a new structure to an existing school building

5.1. Berlin Metropolitan School

Berlin Metropolitan School was founded in 2004 and is the oldest international school in Berlin Mitte. In order to implement their advanced educational concept and accommodate their recently established senior classes, the school required additional floor space. The school is housed in an existing prefabricated building from the GDR era that was erected in 1987, with building types of ‘Schulbaureihe 80’. [3] Four building sections cluster around a generous schoolyard inside the block. The scheme consists of rooftop extensions to three of the existing buildings, as well as a lateral annex that continues all the way down to ground level. The new spaces provide additional classrooms, music rooms, a library with access to a roof garden, administration offices as well as a large auditorium where the main events of the school year are hosted.

The construction work needed to be executed during school hours and was realized in stages, according to the gradually increasing demand for additional area. Therefore, the extension was designed as a prefabricated timber system that ensured speedy erection with minimal disturbance. On account of its low self weight, the timber construction required neither additional foundations nor alterations to the supporting structure of the existing fabric.

Variation in room size and quality results in spaces that are fit for community as well as for retreat, for individual learning and team-based work. The light and sustainable building material timber is clad, but left visible on the inside, creating healthy, pleasant workplaces for students and teachers alike. Seen from the outside, the copper cladding matches the warm tone of the brick slips of the existing prefabricated modules, and at the same time distinguishes the new intervention from the existing building. Applied as a circular construction, the copper façade is both durable and reusable, not loosing its value over time.

5.2. Design for extension

The initial focus was on the existing structure and how to deal with it regarding extra loads and aesthetics. The as-built and detailed structure plans were studied to avoid additional foundation costs. The load-bearing structure of the extension was adapted in small parts to the existing structure in order
to be as economical as possible. It was also clear that the extension had to be built from a material that was as light as possible. Wood was the most suitable material.

Figure 10. Berlin Metropolitan School © Jan Bitter/ Figure 11. Berlin Metropolitan School © Jan Bitter

In terms of design, it was important to break up the extreme grid of the façade, which was somewhat monotonous as a result, without negating the load-bearing grid of the existing building. The impression of the existing building was also to be preserved as far as possible, and the aim was for it to retain its independence and be enhanced by the extension. In contrast to the existing building, three different window formats were used for the extension, which are irregularly interspersed in a copper façade. The outer wall of the extended areas slopes outwards on the courtyard side, closing off the existing building. On the street side, the roofs slope inwards, reinterpreting the existing roof.

The centre piece of the extension is an urgently needed meeting place that could not be realized in the existing building due to its narrow structural grid. It is housed in a large roof that hardly reveals its size from the outside due to its various angles. School spaces are usually only used during the day, and public schools in particular tend to close themselves off from the public. Sustainable design however is also when buildings can be used as much as possible for different purposes. If designed for multifunctional use and access, spaces that are vacant for some days or hours in a week have a great potential to satisfy spatial needs in dense cities and avoid new construction. The school’s auditorium was approved as a meeting place for 1,150 people after school hours. It can thus be handed over to external parties and used for very different events, accessed through the one staircase with an elevator that can be used independently after school hours.

If one thinks about where and how learning takes place today, it is easy to see that it can take place anywhere thanks to digitalization. At the same time, the existing building has very wide corridors that have always been used for teaching purposes. In the extension, the corridors are to be actively used and supplemented with solid oak furniture. They are to be used for learning or just for meeting to exchange the latest news. It is important to mention that for this reason all corridors have the same acoustic ceilings as the classrooms.

The new staircase in the annex to Linienstrasse also addresses the approach of multiple use. There are windows where you can sit in pairs and have a good view of the schoolyard, and although this staircase is a circulation area, this window has created a lounge area and a place to take a break. A café is to be built on the ground floor of the extension on Linienstrasse. Linienstrasse has very few public uses in this section, as the ground floor of many buildings are elevated. It was important to bring the school together with the public life of the city and to open it up instead of closing it off.

5.3. Lessons learned
One goal was to use as little new material as possible. This had to be agreed in advance with the approving authorities, as flammable surfaces cannot be approved in building class 5. The first step was therefore to avoid using cladding, such as plasterboard, and to determine the combustibility of the
surfaces with the authorities. In total, this resulted in 33 applications for deviation in the fire protection concept with regard to timber visibility.

The timber shell should remain visible as far as possible. In order to meet the requirements for sound insulation and building services installations, two walls in each classroom had to be covered with additional cladding. The other walls remained in the shell. In order to protect the raw wood surfaces from damage, only a pigmented wax was applied here. This can be partially repaired should damage occur. The new ceiling system consists of hollow box ceilings with split fill and spans of 10.80m. This is the distance from bracing wall to bracing wall in the existing building. This ceiling system has a high proportion of wood, unlike HBV ceilings, and can be reused as there are very long elements. The façade material is a standard copper sheet that is available on the market in rolls. The width of 35 cm results in a façade grid of 30 cm. The copper sheet is back-ventilated and can be easily recycled.

5.4. Life cycle analysis

Urban densification with rooftop extensions avoids the sealing off of new ground and saves infrastructure. As existing structures can often only handle light weight additions, timber structures are more suitable than heavy massive construction. In this project almost 1.000 m³ of wood, primarily pine, was used for the new structure. The wood used for the roof extension stores in total around 720 tons of CO₂. Timber comes with the benefit of renewable, CO₂ binding growth and a considerably less energy-intensive production than other conventional materials such as concrete or steel. Timber constructions can have an up to 40% lower CO₂ footprint over the life cycle than conventional construction types. However, larger spans and lower floor slabs can currently only be achieved with hybrid structures (e.g. with concrete). As a result, hybrid systems are currently developing rapidly and new CO₂ reduction potentials are being tapped compared to conventional construction types. The recycling of wood concrete composites however is difficult, if the concrete is cast onto the wood and on site. Prefabrication with a separate cast could be a solution. Also for timber construction with glued components (e.g. CLT) solutions have yet to be found for recycling in order to not downcycle or burn the wood.

6. Conclusion

In the three projects presented, Sauerbruch Hutton dealt with the question of how old buildings can serve a new purpose. Germany’s existing building fabric reflects the past building culture. Today’s challenge is not to build new, but to find a building culture and thus architectural language in continuing building with the old. The existing matter is appreciated but needs change or enhancement in order to be preserved for the next generation. In collaboration with consultants the architects try to complement the existing structure with the new, both minimal and more drastic changes.

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1 The tree draws carbon dioxide (CO₂) from the atmosphere. Due to reduction carbon dioxide molecules were splited in carbon and oxygen. While the tree releases oxygen the carbon is stored in the biomass. The calculation factor from carbon dioxide to carbon is 3.67. Around 50% biomass of timber is carbon.
Figure 12. comparison of the three project’s main design strategies © Sauerbruch Hutton

For the Munich Re it was soon realised that the deep floor plan was difficult to use in a contemporary office layout. Therefore some floor plates were removed to create a large atrium. Sometimes realizing what cannot be done with the existing structure and create a small but brave innovation can change the building completely. When building with existing structures, it is also crucial to know old plans and how they have been implemented, how the building has aged and how the surrounding circumstances have changed (e.g. ground water level, subsidence of parts of the building). Planning risks often arise from not knowing the exact built circumstances due to a lack of documentation and investigation. In the Telekom tower high-rise on the other hand, a great effort was made to keep as much of the structure as possible and the division of the offices became the guide to the apartment layouts. Using these two first projects as well as other experiences within our office, one can understand patterns in the historic structures and already anticipate similar issues in other projects. Buildings from the 70s and 80s have often been built with less material use for minimal loads. They often need new fire protection and structural retrofit due to a poor quality of building elements (e.g. little concrete covering of reinforcement) or changing of loads during the retrofit. The Berlin School example, on the other hand, showed an over dimensioned structure, in this case due to its standardized prefabrication, and thus has great potential for structural adaptations and light weight extension.

When facing the challenge of an unknown building and the less common reuse of materials, all project actors have to work together with a common understanding and goal. The decision to reuse a building or individual materials needs to be undertaken as soon as possible in order to have enough time to investigate diverse reuse possibilities with the client and executing firms - or other potential buyers in the case of building elements. Likewise, there also needs to be a common understanding of the limits of the existing building. Together the planning team needs to detect weak links and how to make them stronger and the authorities need to trust and support this work. The standards of today’s norms can pose an unnecessary challenge for the reuse when we need to encourage it. Regulations must ensure safety, but not worsen planning risks. They should reassure that it is more reliable, faster and less expensive to reuse buildings compared to new constructions.

The processes of building with the existing are challenging and not (yet) conventional, but solutions can be found and benefits created not only by saving resources and CO₂, but by enabling an appreciation of our past building culture and finding a new architectural language that enhances the old with the new.

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