Exploring circular construction

Insights into research-oriented teaching and learning
Panel: 04 RESSOURCES and CIRCULARITY

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The construction sector is one of the most resource- and waste-intensive sectors. Approximately half of all raw material extraction and over 35 % of the total waste generation in the EU is currently due to construction activities[1]. In Germany, an area of around eight hectares or more than ten soccer pitches is mined every day for the extraction of raw materials in open-cast mines. More than 50 % of this raw material is used for the extraction of construction minerals: Sand, gravel, clay or natural stone[2]. Furthermore, the share of greenhouse gas emissions from construction, use, operation as well as maintenance and modernization of residential and non-residential buildings in Germany is around 40 %[3]. This said, there is no doubt that sustainable development – the goal of society as a whole – can only be achieved if the consumption of primary and, above all, finite resources for the construction and operation of buildings is minimized.

In interdisciplinary discourse, efficiency, consistency, and sufficiency have emerged as key strategies for achieving sustainable development[4]. All three strategies have different effects, both in terms of quantity and quality, and in terms of time horizons. Moreover, they are not stand-alone concepts, but complementary strategies, each of which makes a significant contribution to achieving sustainable development. At the same time, approaches cannot always be assigned exclusively to one specific strategy, but may lie at the interface between two strategies[5].

[1] Europäisches Parlament (2024): *Wie will die EU bis 2050 eine Kreislaufwirtschaft erreichen?* Available from: https://www.europarl.europa.eu/pdfs/news/expert/2021/2/story/20210128STO96607/20210128STO96607_de.pdf (all web content accessed 2024 Aug 1).
[2] Umweltbundesamt (2024): *Flächenverbrauch für Rohstoffabbau*. Available from: www.umweltbundesamt.de/daten/flaeche-boden-land-oekosysteme/flaeche/flaechenverbrauch-fuer-rohstoffabbau.
[3] Bundesinstitut für Bau-, Stadt- und Raumforschung (BBSR) (Ed.) (2020): *Umweltfußabdruck von Gebäuden in Deutschland. Kurzstudie zu sektorübergreifenden Wirkungen des Handlungsfelds „Errichtung und Nutzung von Hochbauten" auf Klima und Umwelt*. BBSR-Online-Publikation 17/2020, Bonn, Dezember 2020.
[4] Huber, Joseph (1995): *Nachhaltige Entwicklung durch Suffizienz, Effizienz und Konsistenz*. In: Fritz, Peter; Huber, Joseph und Levi, Hans Wolfgang (Eds.): Nachhaltigkeit in naturwissenschaftlicher und sozialwissenschaftlicher Perspektive. Stuttgart: Wissenschaftliche Verlagsgesellschaft, p. 31–46.
[5] Hegger, Manfred et al. (2013): *Aktivhaus: Das Grundlagenwerk. Vom Passivhaus zum Energieplushaus*. München: Callwey.

While these strategies are controversially discussed relating to construction and operation of buildings, the strategy of keeping building materials and components in circulation and avoiding extraction of raw material as well as disposal seems particularly promising[6]. Circular economy counters the still prevalent linear economy with its idea of producing, using, and disposing. It is a major tackle to sustainability due to avoiding waste and thus limiting the consumption of finite resources – or at best avoiding it altogether[7,8]. The total stock of anthropogenic material in Germany can be estimated at 51.7 billion tons in 2010, of which more than 80 % has increased since 1960[9]. The stock of building materials in all buildings in Germany is currently estimated at 15 billion tons[10]. It is assumed that demolishing an average building with ten residential units produces around 1,500 tons of reusable or recyclable material, including 70 tons of metals and 30 tons of plastics, bitumen, and wood[11]. These figures alone make it utterly clear that our building stock is an immense resource.

Although circular economy is primarily seen as part of the consistency strategy, it should not be overlooked that circularity can only be successfully implemented if we question our current demands on buildings. In this sense, circular economy can also be considered part of the sufficiency strategy. Sufficiency strategies often focus on the individual, relating environmental impact to an individual's lifestyle. But sufficiency can also comprise minimizing the use of untapped resources, if we achieve this by rethinking our building standards, treating existing construction materials as valuable resources, and accepting that form or materiality sometimes follow the availability of resources. Against this backdrop, circular economy is nothing less than a turning point in design, construction, and maintenance of buildings.

From a legal perspective, Europe has committed itself to becoming climate neutral by 2050 with the *European Green Deal* adopted in 2020. In order to take the first steps towards reducing greenhouse gas emissions by up to 55 % by 2030 compared to 1990 levels and achieving climate neutrality, the economy and society need to be reoriented in many areas. One measure to achieve this goal is the 2020 *European Taxonomy Regulation*, which classifies economic activities according to sustainability criteria. Most of the criteria are voluntary, but show the development of legal requirements for sustainable planning and construction in Europe. Not surprisingly, it is not only resource consumption itself that is becoming increasingly important, but also issues such as durability, reparability, upgradeability or reusability of products. For the construction sector, issues of deconstruction and reuse of building materials are also being addressed. The German *Kreislaufwirtschaftsgesetz* (Circular Economy Act) describes the term *circular economy* by contrast as prevention and recycling of waste, while allowing the disposal of non-recyclable waste in a way that is compatible with the common good.

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[6] Hauff, Michael von (2021): *Nachhaltige Entwicklung: Grundlagen und Umsetzung*. Berlin; Boston: De Gruyter.
[7] Hillebrandt, Annette, et al. (2021): *Atlas Recycling: Gebäude als Materialressource*. München: Detail.
[8] Hebel, Dirk E. und Heisel, Felix (2022): *Besser – Weniger – Anders Bauen: Kreislaufgerechtes Bauen und Kreislaufwirtschaft. Grundlagen, Fallbeispiele, Strategien.* Berlin; Boston: Birkhäuser.
[9] Schiller, Georg et al. (2015): *Kartierung des Anthropogenen Lagers in Deutschland zur Optimierung der Sekundär-rohstoffwirtschaft*, Dessau-Roßlau: Umweltbundesamt.
[10] Deilmann, Clemens et al. (2017): *Materialströme im Hochbau: Potenziale für eine Kreislaufwirtschaft*. Bonn: Bundesinstitut für Bau-, Stadt- und Raumforschung im Bundesamt für Bauwesen und Raumordnung.
[11] Müller, Felix et al. (2017): *Urban Mining. Ressourcenschonung im Anthropozän*. Dessau-Roßlau: Umweltbundesamt.

The relevant issue is that in circular economy the use of raw materials is significantly minimized and the use of non-renewable materials is avoided by keeping resources in a loop. The challenge for the construction sector is, and will continue to be, to maintain materials, components, and goods that we currently use in a utilization process. Although in recent years an increasing number of interdisciplinary players have been researching circular construction topics and testing theoretical knowledge in practice, the achievements to date are still in their infancy. In other words, circular construction is still in a pioneering phase, and both theoretical and practical knowledge are not yet widely available.

The School of Architecture at Bremen University of Applied Sciences (SoAB) is currently adapting its curriculum to focus increasingly on sustainable construction. Circular economy is one of the research and teaching areas being developed at the newly established chair of *Sustainable Planning and Building in Urban Context*. To strengthen research-oriented learning and to incorporate prevailing topics into the curriculum, a series of elective modules was initiated.

Research-based teaching and learning is characterized by the fact that learners (co-)design, experience, and reflect on the essential phases of a research project with the aim of generating knowledge that is also of interest to third parties[12]. Intrinsic to the idea of research-orientation is that the acquisition of knowledge through self-activity has a greater learning effect than the transfer of knowledge through teaching methods based on direct instruction or frontal teaching. In comparison to similarly designed project studies, research-based learning is not necessarily about practice-oriented results, but rather about theoretical findings. This said, these modules aim at setting up active learning situations in which students explore authentic problems in multiple contexts and from multiple perspectives, continuously sharing and discussion key findings. From a learning theory perspective, research formats become learning formats, and students move through the essential stages of a research process, developing skills and expanding their knowledge to a great extend independently[13].

The first research-oriented elective module in winter term 2023/24 addressed the topic of circular construction. The aim of the module was to understand what theoretical and practical knowledge is available and how learnings can be applied to future architectural design. It was offered to architecture students from the 5th semester of the Bachelor's and from the Master's programs[14]. Divided into two consecutive work phases, the module comprised a deductive-inductive analysis of principles and tools of circular construction as well as a study of European best practice projects. The first phase lasted five weeks, the second eight. The insights from the first working phase were compiled and shared in form of a reference book. It served as a common body of knowledge for all students and as a basis for the subsequent

[12] Huber, Ludwig (2009): *Warum Forschendes Lernen nötig und möglich ist*. In: Huber, Ludwig; Hellmer, Julia und Schneider, Friederike (Eds.), Forschendes Lernen im Studium. Aktuelle Konzepte und Erfahrungen, Bielefeld: Universitätsverlag Webler, p. 9–36.
[13] Schneider, Ralf und Wildt, Johannes (2009): *Forschendes Lernen und Kompetenzentwicklung*. In: ibid.
[14] In accordance with the accreditation of the architecture degree programs at Hochschule Bremen, all elective modules comprise 6 ECTS and are open to students from the 4th semester of the Bachelor's program as well as to all students of the Master's program, with a total of 20 to 25 participants.

study of the reference projects. The syllabus was designed to alternate individual consultations with presentations of research results. This structure proved to be appropriate, as students in the Bachelor's program in particular, but also students in the Master's program, have not yet had extensive experience with research-oriented learning. The alternating curriculum made it possible to support individual students with more opportunities for consultation, while at the same time all students benefited from regular presentations of findings.

For the literature review, topics and guidelines for the systematization of the results were defined. The categories of material life cycle, component life cycle, and building life cycle have been specified for the principles of circular construction. The tools were categorized as legal, organizational, and structural. These taxonomies were brought up for discussion in class but not modified during the module. As the chair's initial research revealed an inconsistent, if not confusing, use of terms to describe different methods of circular construction, it seemed inevitable to first analyze and describe essential terms with the help of relevant literature. Students were provided with a bibliography of key literature on the topic, as well as applicable legal texts and standards, but were also encouraged to continue researching on their own. They worked in teams of two to explore suggested principles: recycling, upcycling and downcycling, renewable materials, cradle-to-cradle, urban mining, adaptability, durability, as well as reusability of entire buildings. In parallel, other groups of students did research on the tools of circular construction. On a legal level, students elaborated on German laws, policies , and regulations, such as the *Resourceneffizienzprogramm* (Resource Efficiency Program), *Kreislaufwirtschaftsgesetz* (German Circular Economy Act), and *Abfallrichtlinie* (Waste Policy). On an organizational level, students studied online databases and material passports, such as *Madaster*, *Concular*, and the *DGNB Gebäuderessourcenpass* (DGNB Building Resource Passport). Regarding construction methods and materials, students examined single-material and unmixed construction methods as well as dry-built and demountable constructions.

The results were then used for the analysis of the planning and construction process of a series of best practice projects in Germany and neighboring countries such as Switzerland, the Netherlands and Denmark. In terms of content, it was specified that the reference project analysis should consider four aspects: The respective positions on circular construction including the principles applied, the actors involved in the project, the planning and construction process, as well as the description of the building itself including construction details. The reference buildings were suggested by the chair according to the results of the preparatory research. Unlike the literature review, all sources needed for the desk research had to be identified and collected by the students. Requirement was to gather primary and secondary literature, including expert and media reports, as well as photographs and planning documents from the urban planning scale to the construction details. Since not all of the reference projects had extensive documentation publicly available, various project participants were contacted, with some providing expedient information to the students. On-site visits, as well as interviews or surveys of stakeholders did not take place. Again, teams of two students researched one reference project. During this phase, the students presented their interim results to the entire group every two weeks: first a stakeholder analysis, then insights into the building, followed by information about materials and details, and finally insights into the principles and tools of circular construction applied.

Concise vignettes on three best-practice-projects exemplify some of the findings and lessons learned:

(1) The *recycling house* in Hannover, Germany, was initiated as an experimental pilot project for circular construction. Initiator and client was a building and housing company[15]. The aim was to primarily use dismantled building materials and components from the client's own building stock. If own building materials were not available, used materials from regional sources such as the local *Bauteilbörse* (building component exchange) were to be used to minimize transportation costs[16]. Aluminum windows, for example, were part of the owners' inventory. The students' research revealed that these were only 10 years old at the time of removal and still fully intact. Although local building regulations did not allow the use of aluminum as a facade material, an exemption permit was obtained in consultation with the building department. Furthermore, the double-glazed windows had a relatively good energy standard, but could not meet the requirements of a *KFW 55* energy standard. However, this was mandatory in the new development area. After consultation with the manufacturer, the frames were upgraded by installing insulators and new triple glazing to achieve the required insulation value. In keeping with the spirit of the project, the remaining double glazing was used in a temporary event pavilion for a cultural project. Regarding the supporting structure, the original intention was to use a steel frame construction made from recycled steel profiles. The lack of CE certificates for these profiles was to be compensated by examinations of a materials testing institute. However, these considerations were discarded during the planning phase due to considerable cost and time involved. In addition, necessary static calculations would have been too time consuming. Instead, in keeping with the principles of circular construction, it was decided to use glue-free timber – a renewable material – for the load-bearing structure and a facade insulation made from recycled cocoa bean jute sacks. Since the windows were a fixed size, the timber structure was designed around them.

Ultimately, the research results show that recycling is neither the only nor the primary circular construction principle applied. Besides recycling, the principles of reusing materials and components, upcycling, as well as the use of renewable resources were applied. The term *recycling house* therefore seems misleading and is more likely to be understood as an attention grabber. The students' main insight, however, was that in addition to the availability of used building materials, a significant issue in circular construction is obtaining approval under building regulations. Since either the current standards are not met or the components removed no longer have a verifiable permit, approvals usually have to be obtained on a case-by-case basis. This is time consuming and expensive. The students recognized that a simpler and, above all, standardized certification procedure for building materials and components used would make it possible to significantly shorten the planning phases in the future. It would also be a solution to the problem of the availability of used materials and thus increase the overall attractiveness of circular construction.

[15] Recyclinghaus Hannover, Germany, 2019, new residential building, approx. 280 m^2 GFA. Architects: Cityförster; specialist planners and consultants: Drewes + Speth, H2A von Heeren Habibi, Institut für Bauforschung, Hannover, etc.; client: Gundlach Bau & Immobilien. Project analysis by Lorenz Haart und Alireza Habibikhadem, B.A. degree program at HSB School of Architecture.
[16] Maier-Solgk, Frank (2020): *Recyclinghaus in Hannover von Cityförster*. In: Deutsches Architektenblatt. Available from: www.dabonline.de/2020/08/28/recyclinghaus-in-hannover-von-cityfoerster-baustoffe-baumaterialien.

(2) An existing warehouse in Winterthur, Switzerland, was extended with the aim of using solely existing components from dismantled buildings[17]. The structure of the new *Kopfbau Halle 118* is formed by steel girders that previously supported a distribution center in Basel. This reused structure was reassembled using screws and plugs and is independent of the façade grid in order to follow the principles of adaptability and deconstructability. The new stories are accessed via an external steel staircase from a former office building in Zurich. Due to the given floor heights of the existing staircase, the steel structure had to be raised to match the height of the building. Insulated aluminum windows and a metal façade sheet from Winterthur and Zurich are used as cladding. In addition, renewable building materials such as wood, straw, and clay were used. An energy expert from the Zurich University of Applied Sciences (ZHAW) accompanied the planning and construction process as an external expert and examined the energy consumption and greenhouse gas emissions of the project. Greenhouse gas emissions for dismantling, transportation, processing, and reinstallation were considered individually for all building components individually.

The students were surprised to find that the transportation of used building materials has the greatest impact, despite the small radius of origin of the components, a maximum of 100 km. Disassembly and reassembly also had a large impact because of the heavy equipment required for steel construction. The refurbishment of existing building components proved to be negligible. The overall balance indicates that compared to a hypothetical construction with new components, a total of 59 % CO2 equivalents can be saved if circular construction is consistently implemented[18]. In their further research, the students focused on the transport routes and storage of the dismantled components. It turned out that out of a total of fifteen components, only four had the presumed short transport route. Seven components have unexpectedly long transport routes, which can only be explained by the location of the chosen storage space. It therefore became clear that the storage of used building components is a critical parameter and can significantly worsen the carbon footprint of circular construction.

(3) In Korbach, Germany, the 1970s extension to the historic town hall, which was slated for demolition, served as an urban mine for the new addition[19]. This new extension was designed using circular construction principles so that it could also serve as a material storage facility in the future. An Urban Mining Index[20] was used to quantitatively assess the circular potential of building structures. For this purpose, all materials used throughout the entire life cycle as well as all recyclable materials and waste generated were calculated and evaluated according to the quality levels of their subsequent use. Theoretically, a circularity rate of 100 % is possible

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[17] Kopfbau Halle 118, Winterthur, Switzerland, 2021, addition of three stories to an existing industrial hall, studios and workshop, approx. 1,100 m^2 GFA. Architects: baubüro in situ; specialist planners and consultants: Oberli Ingenieurbau AG, Institut für Konstruktives Entwerfen Zürich (ZHAW), etc.; client: Stiftung Abendrot. Project analysis by Jan Evers und Mathis Langejürgen, B.A. degree program at HSB School of Architecture.

[18] Stricker, Eva et al. (Eds.) (2021): *Bauteile wiederverwenden: ein Kompendium zum zirkulären Bauen*. Zürich: Park Books.

[19] Rathaus Korbach, Germany, 2022, administration and office building, approx. 7,000 m^2 GFA. Architect: ARGE agn – heimspiel architekten; specialist planners and consultants: Anja Rosen, EFG Beratende Ingenieure, Hering Bau, etc.; client: City of Korbach. Project analysis by Julia Redmann, Derya Kuziak, B.A. degree program at HSB School of Architecture.

[20] Rosen, Anja (2021): *Urban Mining Index: Entwicklung einer Systematik zur quantitativen Bewertung der Kreislaufkonsistenz von Baukonstruktionen in der Neubauplanung*. Stuttgart: Fraunhofer IRB Verlag.

by achieving 50 % in the pre-use phase and 50 % in the post-use phase. For Korbach Town Hall, the final circularity rate is 41 %. This is mainly due to the fact that the production of recycled concrete was only half of what was planned[21]. A total of 8,100 tons of demolition material was expected. 7,400 tons of concrete, of which 5,000 tons were to be deposited and approx. 3,000 tons recycled. In reality, 9,848 tons of demolition material were recovered, of which 6,871 tons were concrete. However, the heavy soiling of composite structures, such as the ribbed ceiling in the Council Chamber, resulted in the disposal of concrete and other construction materials. In addition, the company selected to recycle the mineral demolition material could only perform dry processing. Wet processing could have separated the demolished concrete more effectively, thus increasing the amount of recycled concrete.

The students therefore wondered whether it would have made more sense to accept longer transport routes to a better-equipped processing plant, as well as the associated higher costs and CO2 emissions, in order to avoid the environmental impact of the newly produced concrete. However, discussions with the group and comparisons with other reference projects made it clear that there are still many conflicting goals, not only in transportation. On the one hand, resources saved should not be dissipated for transportation; on the other hand, the barriers to circular economy that currently exist, for example, in the processing of demolition material must be identified and removed by establishing the necessary services. Furthermore, the students noted that the declaration adopted by the *Bundeskammerversammlung* (Federal Chamber Assembly) in 2022 for more leeway and innovation in the construction industry could mean a significant step forward for circular construction in Germany. *Building type E* – as it is currently called – is intended to allow competent builders to deviate from mandatory legal requirements in order to build in a simpler, more experimental and innovative way.

In summary, the module has been like an immersion into a new world. Participating students not only gained in-depth knowledge of the theoretical positions, opportunities and barriers of designing and constructing buildings according to circular economy principles. They also realized that many aspects that they had not previously been exposed to during their higher education or had little interest in, such as the origin of materials, the approval of building products, and demountable construction methods, are crucial to architectural design in a circular economy. It was eye-opening that the principles of circular construction – particularly urban mining – almost reverse the architectural design process of the linear economy: If we want to incorporate what is there, we need to know it. A site visit is not enough; comprehensive on-site research is required. Architectural design and the search for building components are thus inextricably linked. At the same time, several reference projects illustrate that architectural design based on the principles of circular construction occasionally leads to a new collage-like aesthetic. What is built is what is available – and to some extent a product of coincidence. However, the module also demonstrated that not only a great deal of specialist knowledge is required, but also a high degree of creativity. Or, to take up the central theme of the conference: Less ideology and less reliance on long-established guiding principles in

[21] Rosen, Anja (2022): *Gutachten „Ressourcenschonendes Bauen“ am Beispiel Rathaus Korbach*. Available from: https://landwirtschaft.hessen.de//sites/umwelt.hessen.de/files/2022-08/rhk_gutachten_ressourcenschonendes_bauen.pdf.

architectural design and education are a must in order to integrate circular construction into the training of architects.

To conclude, four key findings will guide future research-oriented modules on circularity at SoAB: First, since a major drawback of our research was that there were few primary sources or detailed technical information on circular construction for some reference, research methods such as on-site analyses and stakeholder interviews need to be integrated. Interviewees should include a wide range of stakeholders, as clients as well as owners of demolition properties and material storages. Second, a stronger research focus is to be put on the origin, transportation, and storage of building materials and components. As research findings show, these issues play a critical role in how materials, components, and goods can be sustainably maintained in the utilization process. Third, the degree of circularity needs to be quantified in order to better compare knowledge gained in theory and practice. The Urban Mining Index is a promising tool for this purpose. Fourth, follow-up modules on the application of theoretical knowledge with emphasis on the design of single material and demountable construction details are essential. Thus, this elective module, which was itself an experiment, can be considered a successful test run for research-oriented teaching on the subject of circular construction.