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Resource-respectful construction – the case of the Urban Mining and Recycling unit (UMAR)

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Abstract. The growing elimination of resources calls for a paradigm shift from linear material consumption to circular economy - especially in the construction industry. The residential and research unit Urban Mining and Recycling (UMAR) in the modular experimental building NEST of Swiss research institute Empa consequently implements this claim: The design by Werner Sobek with Dirk E. Hebel and Felix Heisel is constructed from separable, ingrade material resources that are completely reusable, recyclable or compostable. The concept of cycles therefore plays a central role: Utilized materials are not consumed and then disposed of; instead, they are borrowed from their technical or biological cycle for a certain period of time and later returned to these material cycles. Considering its many reclaimed material resources, the apartment is a built example of urban mining. Designed for disassembly at the end of its service time, UMAR also represents a material depot for future projects: Instead of connecting elements and components irreversibly through wet connections such as chemical glues, UMAR uses screws, clamps or interlocking systems in order to recover all used substances ingrade and sorted. UMAR is both temporary material depot and material laboratory – while proving the claim that it is possible already today to build within a circular system.

Keywords: urban mining, recycling, design for disassembly, material depot, circular economy, resource-respectful construction

1. Introduction

Globally, the construction industry represents one of the main consumers of resources and energy, as well as one of the main polluters of the environment: buildings account for an estimated 32% of global energy consumption, 25% of CO_2 emissions, 12% of water use, 40% of waste generated, and 40% of material resource use [1, 2]. Providing buildings and infrastructure to an exponentially growing global population with rising expectations and wealth, the global construction market is expected to further increase by 85% (or 8 trillion US Dollars) to 17.5 trillion US Dollars by 2030 [3]. Similarly, resource consumption and wastage within the still predominantly linear construction economy will increase, with potentially catastrophic results for both environment and economy [4, 5, 6]. Since 1970, global extraction of non-renewable resources, particularly industrial and construction minerals, has increased by 376% [7] and is estimated to continue on a similar path: from 84 billion metric tons of raw materials entering the economic system in 2015 to 170-184 billion metric tons in 2050 [4, 8].

The concept of the circular economy (CE) is increasingly gaining attention as a way to overcome the social, economic and environmental problems of this linear economic system. Today's understanding of the CE is informed by several important schools of thought developed within the past 40 years, among others: Walter R. Stahel's *Performance Economy* [9], Werner Sobek's *Triple Zero* guidelines [10], or William McDonough and Michael Braungart's *Cradle to Cradle* approach [11]. The most renown definition of the CE as an economic system has been framed in 2013 (and revised in 2015) by the Ellen MacArthur Foundation: „A circular economy is one that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles [12]".

Despite a body of academic work and political guidelines and directives [13, 14, 15], the implementation of CE principles in the built environment by today remains in its infancy [1]. This paper describes the design and construction of the unit *Urban Mining and Recycling* (UMAR) by Werner Sobek with Dirk E. Hebel and Felix Heisel at the Empa NEST as a case study, which aims to prove the claim that it is possible already today to build according to CE principles.

The article is organised as follows: Section 2 summarises the key aspects of the project background. In section 3, the architectural concept of UMAR is outlined. The CE principles and their implementation are presented in section 4. A discussion on future work is outlined in section 5. Conclusions are provided in Section 6.

2. Background

As a future living and working laboratory, NEST (Next Evolution in Sustainable building Technologies) [16] at the Empa Swiss Federal Laboratories for Materials Science and Technology in Dübendorf, Switzerland consists of a central backbone building with cantilevering platforms to accommodate exchangeable living and office buildings, so-called units. NEST is a modular research and demonstration platform for advanced and innovative building technologies, which allows novel materials, components and innovative systems to be tested, demonstrated and optimised under real-world conditions. The NEST backbone building was completed in 2016.

The UMAR unit (Figures 1 and 2) was installed into the NEST building in 2017 and opened on February 8, 2018 as a two-bedroom living and research module for students of institutes Empa and Eawag. Simultaneously, the unit is open for public tours and events, attracting an average of 1000 visitors per month. In this double role of living lab and showcase, UMAR aims to validate CE principles, while communicating their content, benefits, effects, technical details and aesthetics to clients, industry and stakeholders alike.

Figure 1. UMAR at the Empa NEST (copyright Zooey Braun, Stuttgart)

Figure 2. Interior view of UMAR (copyright Zooey Braun, Stuttgart)

3. Architectural concept

The UMAR unit is located on the second floor of NEST. Situated between two cantilevering concrete slaps (in section) and bordered by the NEST backbone in the northeast (in plan), the unit has a clear orientation towards its southwest façade, facing an open field with Alpine views. To increase the amount of privacy for the students, their two bedrooms were located on the outer extends of the unit, separated by a common area merging kitchen, dining, living and working areas in changing arrangements supported by a turning wall as flexible divider. Towards the backbone and in close proximity to each other and the docking station (connection of water, heat and electricity to the backbone), two bathrooms as well as the technical room were located. The entrance hall near the main door to the backbone doubles as a material library for public functions (Figures 3 and 4).

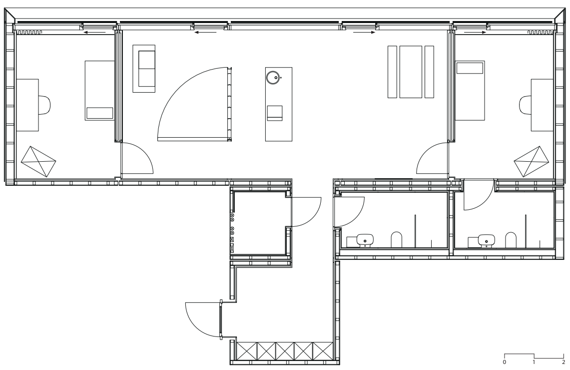

Figure 3. Floor plan of UMAR

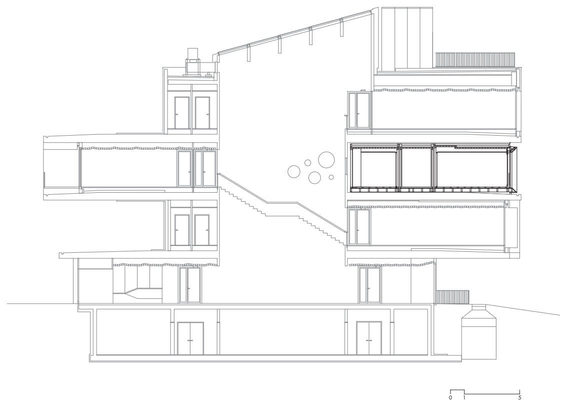

Figure 4. Section of NEST and UMAR

UMAR has been assembled from 7 modules (2x bedrooms, 3x common room, 1x bathrooms and technical room, 1x entrance) that were prefabricated and fully-equipped in the factory and lifted into NEST by two mobile cranes within one day. On site, the modules only had to be connected spatially through fitted boards, and infrastructure-wise through coupling devises such as plugs (electricity) or screw caps (water). The modules are standing on heavy-duty wheels running on rails and can thus be easily moved into place, as well as removed again for disassembly. The floor area of the complete unit is 126m^2, the height between floor and suspended ceiling is 2,50m.

UMAR proposes a solution of very high aesthetic value to both the task of building within the CE, as well as the double function of a living laboratory and exhibition room. The architectural concept aims to provide white-walled (neutral) rooms as most clients might expect in their own homes, while allowing for the visitor to see and experience all materials used in construction (through windows into walls and ceiling, or layered material application). Within this approach, the unit aims to display a wide variety of materials and construction techniques, balancing biological and technical surfaces.

4. Design principles and their application in UMAR

The title of the unit combines two concepts, which in our understanding relate to two complimentary strategies of resource acquisition and utilization: *urban mining and recycling*. While ‘urban mining’ refers to the re-activation of materials accumulated in the urban environment, which were not specifically designed for reuse or recycling (thus mining), ‘recycling’ comprises all those materials that are designed to remain in technical or biological cycles at maximum value and quality. Following the understanding that “cycles have no beginning and no end [17],” materials and components from various sources (and thus at various positions in the cycle) have been used within the UMAR unit – ranging from virgin resources and recycled materials to reused products.

The design and construction of UMAR is based on the following design principles, which will be explained in more detail in sections 4.1.-4.5.:

1. design for disassembly on all scales;
2. separation of biological and technical materials and nutrients;
3. return of nutrients to ingrade and contaminant-free cycles at highest value and quality through reuse, recycling or composting;
4. sufficiency of material input;
5. products as service.

By following these principles, UMAR represents not only the above described material laboratory, but at the same time a material bank for future constructions as materials and components after disassembly remain high quality resources for future use.

4.1. Design for disassembly on all scales
Today, dismantling and subsequent recycling of installed materials in buildings is only in very rare cases an integral part of the planning process. And even where a decommissioning is deliberately planned, a significant resource re-activation all too often fails due to non-recyclable single components or non recycling-compatible connection details. Thus, UMAR applied the principle of design for disassembly on all scales, from the overall connection of prefabricated modules on site all the way to the waterproofing of bathrooms, the re-design of its heating and cooling panels or the development of new mono-material faucets. There is no glue or tape within the whole building (with the exception of one 100% biodegradable product for ingrade timber to timber connections in furniture assembly). All connections are reversible (through screw or interlocking connection), easy to access and documented in preparation of the planned decommissioning of the unit (Figure 5).

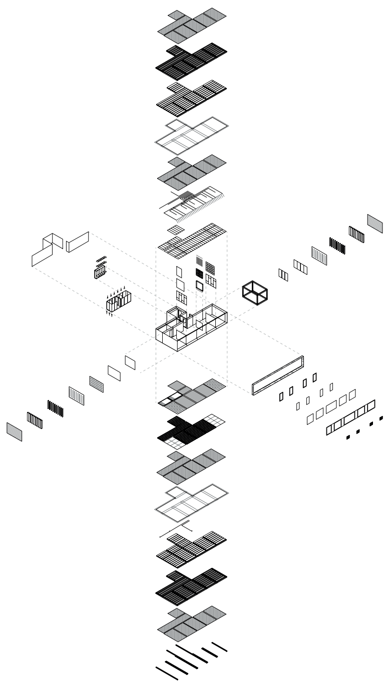

Figure 5. Axonometric representation of UMAR layers, hierarchy and assembly

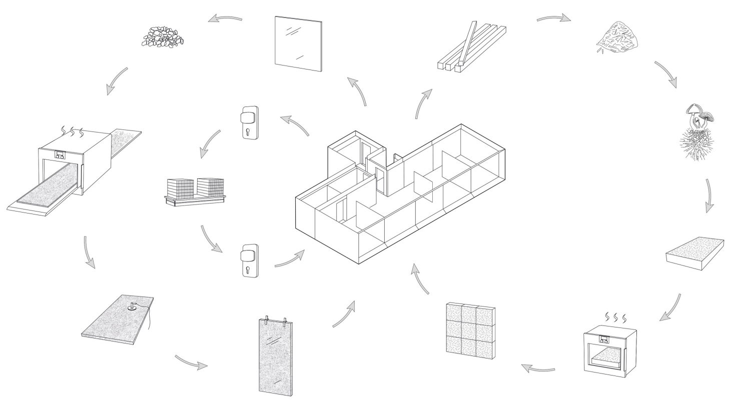

Figure 6. Reuse, recycling and composting within closed biological and technical cycles

4.2. Separation of biological and technical materials and nutrients

We distinguish between the biological metabolism where natural processes of ecosystems utilize nutrients in cycles of abundance, and the technical metabolism where industrial processes maintain and reuse valuable synthetic and mineral nutrients in closed loops. Mixtures of technical and/or biological nutrients that cannot be disassembled at the end of a product's service life can be described as hybrids, and typically end up in landfills or incinerators [11]. In the UMAR unit, no hybrid materials or products were used.

This principle is more difficult to follow than it might seem at first glance. There are a surprising and threatening amount of hybrid materials on the building market today, including some of the most standard products such as typical Oriented Strand Board (OSB), a high percentage of all paints, varnishes and glues, or – as suggested by the name – the majority of all composite materials. In the case of UMAR, a prefabricated modular timber construction typically relying on boards for structural bracing, this principle for example resulted in the introduction of a diagonal cladding from untreated timber slotted into each other through tongue and groove connections to reach the necessary air tightness for physical comfort and fire/smoke protection.

4.3. Reuse, recycling or composting

Within each respective metabolism described earlier, different methods of cycling can be distinguished depending on the size of the respective loop, whereby the smallest loop is the most effective in terms of (grey and added) energy, resource and labour utilization [18]. The technical metabolism differentiates between reuse, repair, remanufacture and recycling, while a cascading use of materials leads to their composting within the biological metabolism [19]. The UMAR unit utilizes three of these methods (reuse, recycling and composting) and Figure 6 illustrates their application through three exemplary materials and products.

Reuse: In 1974, the Generale de Banque contracted the interior design of its Brussels headquarter to renowned designer Jules Wabbes. Aiming to reflect the reliability of the bank, he chose precious high-quality materials such as granite, bronze or brass and pure forms that were meant to last. When BNP Paribas Fortis (as the new owner of the building) received permission to demolish the building in 2016 in favour of a replacement, one of the city's conditions was the development of a sustainability strategy for reuse of all Jules Wabbes' items [20]. As a result, company Rotor Deconstruction took over the inventory, careful dismounting and redistribution of these objects, leading to the installation of Jules Wabbes door handles in the UMAR unit. As loan items, these handles contractually return to Rotor Deconstruction once their service time in the unit ends, ensuring the continuous reuse of the items in yet another building.

Recycling: German company Magna Glaskeramik is producing panels from 100% recycled window and bottle glass. In the process, the company is applying only as much energy and time as needed to sinter single shards of the raw material into homogeneous panels, resulting in aesthetically unique (non-transparent) recycling glass panels with lower embodied energy trough both raw material selection and production process. Next to many other recycled ingrade technical materials such as plastics, metals or minerals, the UMAR unit utilises Magna glass (ice nugget) in the kitchen as table top and in the bathroom as wall cladding material.

Composting: Mycelium is the root network of mushrooms, a fast growing matrix that can act as naturally growing and biological glue. Digesting plant-based waste products, such as sawdust or straw, mycelium's dense network binds the substrate into a material composite [21]. In the UMAR unit, mycelium-based products grown by US company Ecovative were installed as insulation boards. Attached reversibly to the wall's substructure, these panels can be completely composted at the end of the service life, providing nutrients yet again for the growth of biological organisms and potential building materials. To guarantee contaminant-free composting, all biological materials in the UMAR unit are untreated (with the exception of a carefully selected biological oil for the protection of the unit's floor).

4.4. Sufficiency of material input
Every amount of material saved in the design of buildings consequently does not need to be reintroduced into its biological or technical metabolism. Although mostly known from the urban planning debate on decreasing square meter per person usage, the question of sufficiency, or how much material input is sufficient to fulfil a specific and desired function is an important CE design principle on all scales. Successful examples are a 70% reduction of concrete usage in ceiling slabs through the combination of 3D printing technologies and informed structural engineering in the NEST HiLo unit [22] or the activation of the buildings thermal mass of 5-story office building 2226 to dispense with technical heating and cooling infrastructure solutions [23]. The UMAR unit applied the concept, next to other areas, to the internal cabling by using wireless solutions where possible. As part of a wireless building automation, for example, the unit's light switches generate the necessary energy for signal transmission kinetically by their users, and thus need no cable or battery in the unit's walls.

4.5. Product as service
Within the CE, business model concepts such a *product as service* or the *performance economy* [24, 9] promise high ecologic and social benefits through economic incentives. Essentially, users pay only for the service they hope to receive from a product, without having to own the hardware that allows or performs the requested function. From the perspective of the manufacturer, product as service is profitable because (once a circular product has been developed and produced) ownership of knowledge, labour, energy and raw material remain within the company, securing planning dependability and independence from a volatile resource market. Consequently, return concepts, design for disassembly, reuse and recycling become integral elements of long-term business plans, increasing awareness for product liability, durability, material selection and costs of disposal with the manufacturer and designer. In product design and mobility, such business models have already permanently changed the economy with prominent sharing services for music, films, cars, bicycles or fashion. In construction, product as service concepts are rapidly gaining interest, however not many such building elements have reached the market yet. As one example, carpets by Dutch company Desso / Tarkett are installed as a service in the UMAR unit, and will return to their factory in order to be recycled into new carpets at the end of the unit's service time.

5. Future Work
The UMAR unit was designed and built as a prototype, showcase and demonstrator for a paradigm shift towards a circular building industry. As such, the documentation of the materials, design, details and construction process are a crucial aspect of the process. Several elements of this documentation have been implemented already: A material library within the unit offers samples of all materials used in construction. These samples are additionally linked to a digital material library with further information, data sheets and contact details on the project's website [25]. Future work now involves the on-going monitoring and analysis of the unit's performance as a lived-in laboratory as well as the durability and handling of materials in use. Certainly the biggest task will be the upcoming disassembly of the unit and subsequent reintroduction of materials and products into their respective material cycles.

Understanding UMAR as one case study for an anthropocene material bank, which will provide building elements for (all) future constructions, an in-depth understanding of material stocks and flows in the circular building industry is essential. As such, knowledge of materials and their properties within the unit is only a first step towards the creation of an informed urban stock management. Applied to an urban scale, a system needs to be developed to document and communicate (at the right moment) which materials in what quantities and qualities become available for reuse or recycling at what time in the future. Question about big-data management, data security, file formats, jurisdiction and many more aspects of such an undertaking immediately come to mind when upscaling the process of a single building to the city, country or world level. Researchers around the world are working on addressing various elements of this paradigm shift [26, 27, 28], and we hope to contribute a significant and unique data set to this endeavour to develop and verify such approaches.

6. Conclusion

The growing elimination of resources and the connected environmental, social and economic losses call for a paradigm shift in the construction industry from a linear system of take, make, throw towards a circular building industry. The UMAR unit as a demonstrator and living lab proves that it is possible already today to build according to CE principles. It showed the importance of interdisciplinary teamwork in design and construction throughout all involved professions, from the very beginning of the process until the very end. The unit acts as an important case study in communicating these principles and their benefits to the involved actors. It also revealed the many obstacles on political and administrative levels that still need to be overcome towards a circular building industry; and it provides a unique set of materials, details and data in the continuing research on upscaling single circular prototypes and approaches towards a circular city or a circular industry.

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