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Environmental assessment of the Urban Mining and Recycling (UMAR) unit by applying the LCA framework

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Abstract. In 2016, Empa inaugurated NEST ("Next Evolution in Sustainable Building Technologies"), a new type of building that expedites the innovation process by providing a platform where new developments in the built environment can be tested, verified and demonstrated under realistic conditions. One of the units within is the "Urban Mining and Recycling" (UMAR) unit by Werner Sobek with Dirk E. Hebel and Felix Heisel – a unit that demonstrates how a responsible approach of dealing with natural resources can go hand in hand with an appealing architectural design. The unit is underpinned by the proposition that all the resources required to construct the building must be fully reusable, recyclable or compostable and are therefore part of a circular economy; propositions that can be tested here in a kind of "real-life" laboratory. Empa's Technology & Society Laboratory (TSL) established – in parallel to the integration of this unit into the NEST building – an ecological evaluation of this unit, using the tool of "life cycle assessment" (LCA). Compared to a hypothetical reference unit in same size and standard constructed out of common building materials such as concrete, the UMAR unit shows over its entire life cycle a reduction of the environmental impacts of 18% (for grey energy) to more than 40% (global warming potential).

Keywords: urban mining, life cycle assessment, circular economy, sustainability, sustainable construction, residential building sector

1. Introduction

The construction and operation of buildings in the EU accounts for 42% of the total energy consumption (power and heating), about 35% of greenhouse gas emissions, up to 30% of water consumption and more than 50% of all extracted (mined) materials [1]. Furthermore, about one third of all waste being generated within the EU can be attributed to the building industry, such as construction, operation, renovation, and deconstruction or disposal [1]. In view of the current ecological challenges, the construction industry must adapt and show larger commitment and responsibility than ever before. It is for example urgently necessary to put into practice new concepts of a circular building system. Such buildings can be conceived as a temporary material bank, not being seen as waste but constituting new resources for a next generation of buildings.

One basis for such an alternative view of the construction industry is the concept of urban mining - a concept that identifies the existing built environment as a supply system, and waste (whether from the dismantling of houses or from other sources) merely as a transitional state from which something new can emerge [2]. According to Cossu and Williams [3], urban mining represents all the activities and processes of recovering materials and elements from used buildings, infrastructure or waste. Key idea behind the concept is that the necessary materials are no longer obtained from primary resources and disposed after use, but borrowed from an endless operational cycle (being biological or technical) for a specific amount of time and then returned to it. Urban mining is in line with the principles and definitions of the circular economy [4], calling for a paradigm shift in our current mode of action that is mainly based on the linear model of "take make throw", ignoring the already existing waste as a potential resource [2]. A variety of such materials, such as copper, are seen to have accumulated over the past centuries in great amounts within the global building-stock. In fact, those urban mines are seen to be a bigger and more important source than the mines still excavating the earth's crust [3]. Recovery and reuse of urban resources in this way provide a secondary material stream that can substitute primary resources [5]. Furthermore, circular material flows help to reduce emissions e.g. greenhouse gas (GHG) through reduced energy input and avoided waste treatment processes [6]. In that sense, urban mining places life cycle thinking at the forefront of design, contributes to the protection of natural resources and opens up a new way of putting the use of materials over its consumption and destruction.

In 2018, the "Urban Mining and Recycling" (UMAR) unit by Werner Sobek with Dirk E. Hebel and Felix Heisel has been installed into the NEST building in Dübendorf, Switzerland. NEST stands for "Next Evolution in Sustainable Building Technologies" and represents a modular research and innovation building of Empa (Swiss Federal Laboratories for Material Science and Technologies) and Eawag (Swiss Federal Institute of Aquatic Science and Technology). Here, in the form of various added thematic living and working units, new technologies, materials, operation systems and user behaviours can be tested, researched and validated under realistic conditions, fostering an acceleration of innovation processes in the building sector. The specific aim of the UMAR project is to develop a prototypical living unit (its floor plan is shown in Figure 1 below), which shows the potential for closed material cycles in construction. As the UMAR unit serves as a temporary material bank, a comprehensive design-for-disassembly concept has been conceived already at the beginning of the design and planning stage in order to allow easy access, separation and in-grade sorting of all individual materials at the end of their life time.

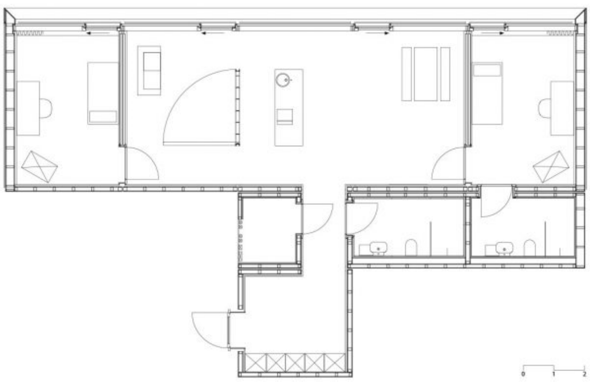

Figure 1. Floor plan of the UMAR unit (Werner Sobek with Dirk E. Hebel and Felix Heisel).

Consequently, UMAR consists of a primary, modular de-constructible frame structure with replaceable wall, floor and roof elements, which are obtained only from reused, recyclable and/or recycled, or compostable materials. Furthermore, no glues, paints, foams or other wet sealants have been used in order to achieve a fully de-constructible building system. The introduction of new business models such as renting of building elements or replacement of materials through digital alternatives are further research objectives of the UMAR unit and its application to a circular construction industry.

The present study aims to evaluate the environmental impacts as well as the potential benefits of the application of the urban mining concept on a building element and building level (using for the latter the UMAR unit in the NEST building as a case study), through the use of the life cycle assessment (LCA) methodology. The structure of this manuscript is the following: Section 2 describes briefly the general, stepwise approach applied here for the assessment of the sustainability potential at the building element and the building level, section 3 reports the key elements for the application of the LCA methodology, section 4 shows the results of all these LCA calculations, and section 5 summarizes the conclusions for this case study and gives a short outlook into further steps.

2. General approach

The analysis of the UMAR unit was done in a two-step procedure, with each single step representing a different level of analysis and therefore requiring an individual and independent LCA calculation. In the first step, a comparison on the level of single building elements (such as the inside wall) between the conventional means of construction and the respective UMAR elements has been established. In the second step, the entire UMAR unit is compared to a hypothetical unit in same size and standard, constructed with conventional (typical) Swiss building elements, in order to evaluate which of the two means of construction shows the lower environmental impacts. This stepwise approach allows to showcase step by step the sustainability potential that arise from a switch in the construction towards the principles that are behind the concept of Urban Mining at different levels of application. Due to unsolved methodological challenges, as starting point natural resources rather than recyclable or remanufactured materials have been considered here for both LCA evaluations, meaning that the analysis in the hands-on manuscript represents somehow the "very first" life cycle of buildings and building elements according to the urban mining concept.

2.1. Building element level

The conventional elements that have been compared with the respective UMAR elements were chosen from the freely accessible online-version of the "Bauteilkatalog" [7], representing the most commonly used construction elements and construction methods/materials in Switzerland (see Table 1). In the case of the conventional dry wall construction from gypsum boards (i.e. the inside wall), no code is available in the database; hence, this element was established here based on further information of conventional practice in the Swiss construction sector. No comparison of roof elements has been made because the UMAR unit has no actual roof, but is covered by the concrete slab of the NEST building.

Table 1. Conventional elements applied in this study from "Bauteilkatalog".

Element	Conventional material	Code
Outside wall	Sand lime Brick wall	W03
	Concrete wall	W08
Inside wall	Gypsum dry wall	-
Floor	Concrete floor	B01

2.2. Building level

Goal of the building level analysis is a first comparison of a unit based on the UMAR concept with a hypothetical unit in same size and standard, constructed with conventional (typical) Swiss building elements, and to identify the potential savings from such a change in the construction techniques and materials. Covering the entire life cycle (here from the resource extraction up to the final disposal and/or respective recycling activities), this analysis here shows also the difference (in terms of environmental impacts and benefits) between a traditional way of demolition (as applied to the conventional building) and a planned and monitored de-construction being possible in case of the UMAR unit.

The UMAR unit within the NEST building represents an experimental setting with a duration of ‘only’ 5 years. However, in order to be able to compare the UMAR unit with the hypothetical reference unit, the typical lifetime for Swiss buildings of approximatelys 60 years has been applied to both units. During the applied life span, an average Swiss heating mix has been assumed. The authors assume furthermore that the heating and the electricity requirements in the applied life span of both units are similar; i.e. the study is focussing on differences due to the construction technique.

3. Life Cycle Assessment

Life Cycle Assessment (LCA) is the most established and a well-developed comprehensive framework that quantifies ecological and human health impacts of a product or system over its complete life cycle; hence allows a comprehensive environmental sustainability assessment [8]. According to [9] the roots of this framework can be found in the energy related research in the 1960s and the pollution prevention, initiated formally in the 1970s. LCA can actually be applied to any kind of product and to any decision where the environmental impacts are of interest. Nowadays, this framework is applied by a broad variety of actors – from governmental organisations to any kind of industry, with or without the support from specialized research and/or consulting organisations. Reasons for this wide application could be found e.g. in the clear guidance for the application in form of the ISO 14’040 standard [10], as well as the broad data base available today (see [9] for an overview) – allowing a much faster calculation of first (rough) results. The LCA framework applied in this study here follows the specific guidelines for the construction sector, defined in the European Standard EN 15'804 [11]. The software tool used for the calculation of the LCA studies here is SimaPro (in its Version 8.5.2) and as database for background processes the database ecoinvent Version 3.3 has been used.

3.1. Goal and Scope

At building element level, the goal is to assess the environmental impacts of the three most important elements of the UMAR unit and compare them with those of the respective conventional elements used in today’s construction practice in Switzerland. In total, four different LCAs are conducted within this step, one for each individual building element. The functional unit is $1m^2$ (inside area) for each of the four building elements under examination. Since the main objective of this first step is to get a first understanding of the potential that arises by using circular materials, the system boundaries are limited to the production stage of the individual element and their respective materials (i.e. the stages A1-A3, according to the terminology of EN 15'804, as shown in Figure 2).

At building level, the goal is to assess the average annual environmental impacts of the entire life cycle (i.e. construction, use and end-of-life stage) of the UMAR unit and to compare those impacts with the respective impacts of a hypothetical unit in same size and standard, constructed with conventional (typical) Swiss building elements, such as concrete. The functional unit for this second part is $1m^2$ of gross floor area per one-year lifetime of the building under study. The system boundaries are extended and the use phase of the building (taking into account the topics "replacement" (i.e. B4) and "operational energy use" (B6) only) as well as the end of life stage are considered. All here included life cycle stages according to the terminology of EN 15'804 are highlighted in grey in Figure 2.

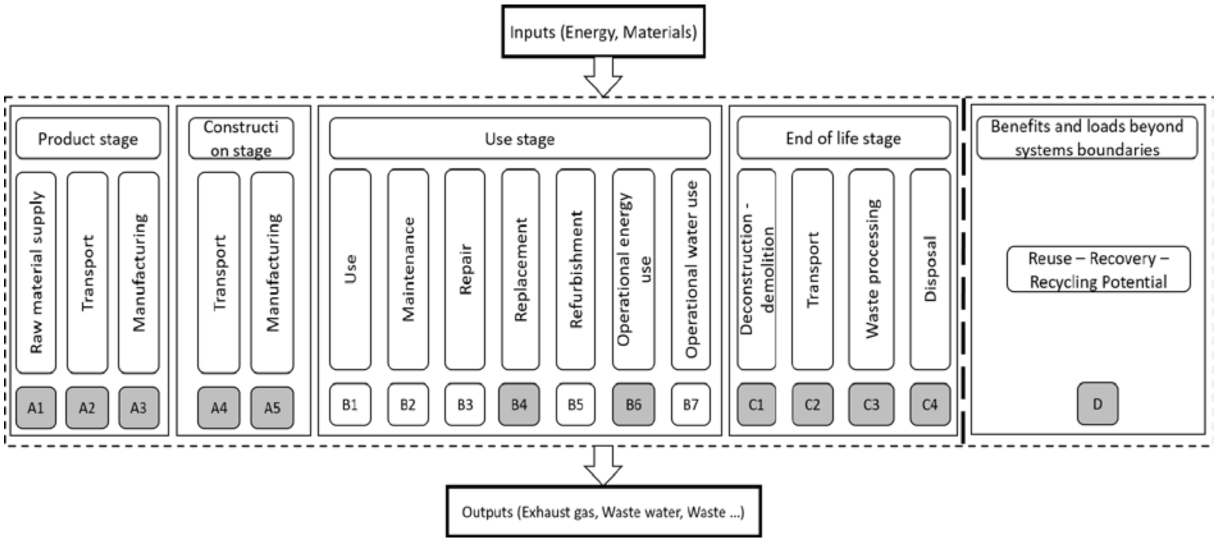

Figure 2. LCA stages according to EN 15'804.

3.2. Inventory Analysis

The so-called Life Cycle Inventory (LCI) data comprises all input and output flows of the system under examination; i.e. material input (including replacing materials in the use phase), energy consumption, construction and deconstruction processes, treatment of generated construction and demolition waste (CDW), as well as all the transport efforts to (and from) the building site. On the building level, in addition also the so-called "stage D" from EN 15'804 is taken into account as well, representing the avoided environmental burdens due to (direct or indirect) reuse of building elements in a different project (building) or due to the recycling potential of the materials out of the demolished building. This stage actually shows how far a building is in accordance with the concept of Urban Mining.

3.3. Impact Assessment

In accordance with the Swiss construction industry, the following impact categories were considered in this study: Global warming potential (GWP) expressed in kg CO_2-equivalents (CO_2-Eq) [12], the total consumption of fossil energy carriers in the form of the (non-renewable) cumulative energy demand expressed in MJ-Eq, and the overall environmental impact of the examined system expressed in Swiss Eco-points (the «Umweltbelastungspunkte» in German) according to the Swiss method of the ecological scarcity [13]. In Switzerland, these three impact categories are also often used as overall indicators of potential impacts in simplified LCA studies (see e.g. [14]). They represent many of the most relevant environmental issues in society today (GWP, CED), and, through the third factor in particular, a "true and fair view" of the overall potential environmental impacts (at least from the view of the Swiss Government, who commissioned the method of ecological scarcity).

4. Results

4.1. Building element level

The results in Figure 3 on the next page show that the various elements of the UMAR unit perform – even in their "initial" life cycle (i.e. being constructed with raw materials extracted from nature) – better than the here chosen conventional building elements. The impact reduction depends on the building element as well as the indicator under examination. More specifically, the (non-renewable) cumulative energy demand can be reduced by 6% (inside wall) up to 45% (floor), while on the level of Global Warming a reduction going from 45% (inside wall) to 66% (floor) could be observed. Last but not least, the reduction in terms of Swiss Ecopoints (UBP) lays between 31% (for brick wall) and 68% (floor).

All these results are somehow in accordance with the expectations, based on the fact that wood is used as the primary structural material for the various elements of the UMAR unit and concrete as the primary construction material of the conventional elements.

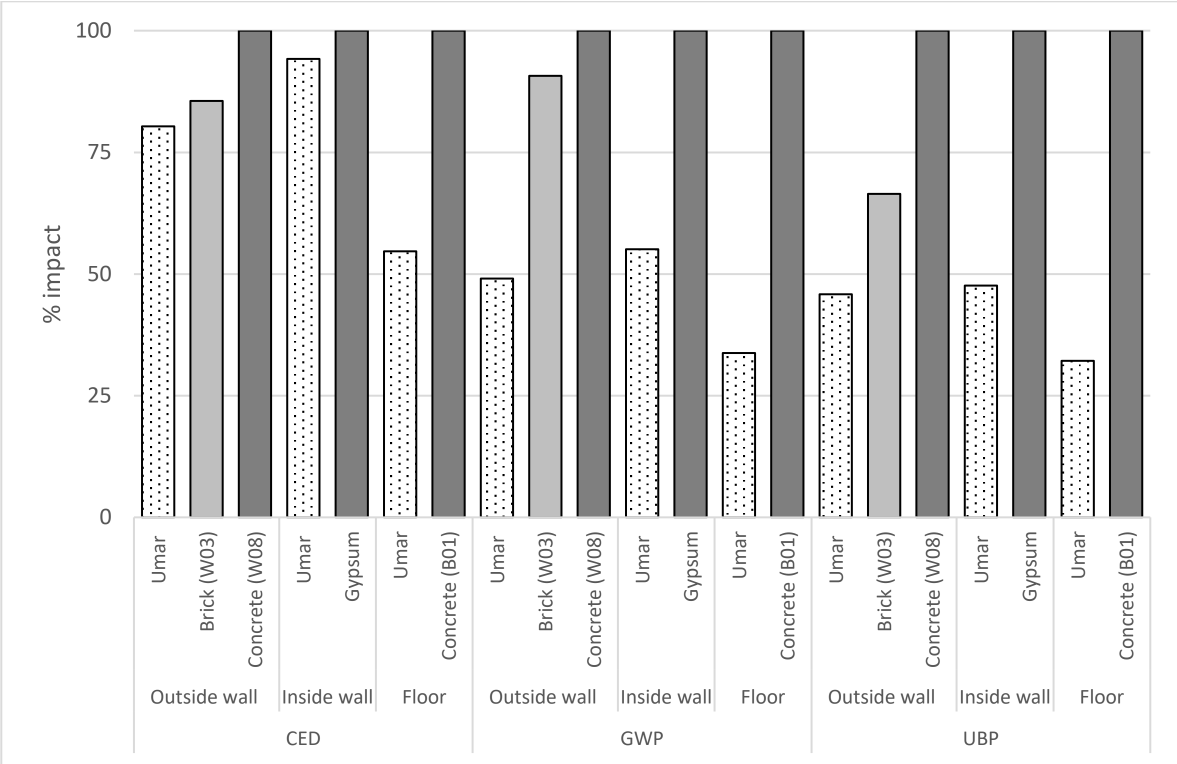

Figure 3. Relative impact of each UMAR element (scattered bars) per indicator in relation to the highest impact contributor of the respective element (dark grey bars).

4.2. Building level

In Figure 4 on the next page, the impacts from the comparison between UMAR and the reference unit are illustrated. The UMAR unit performs better than its hypothetical traditional built countepart and the impact reduction again hinges on the indicator under examination (18%, 39% and 31% for CED, GWP and UBP respectively). The main difference in contrast to the building element level analysis above is the fact that the operation phase dominates all three indicators with its impacts ranging from 46% (GWP) to almost 70% (CED) for the concerete unit, and from 44% (GWP) to nearly 70% (CED) for the UMAR unit. Here, the life-time of the building of 60 years gets clearly visible – then while the material input (except for the replacement of some parts) takes place one times, the energy consumption takes places every year over the entire time period of 60 years.

The potential credits from recovery and reuse of the materials (i.e. stage "D" according to EN 15'804) show a higher value for the UMAR unit than the concrete one. Main contributor are the (assumed) direct use of all the UMAR materials (in accordance with the urban mining principle), opposite to the concrete unit where only one part can actually be reused. Be cautious that the model for this stage "D" here is simplified, as no further treatment activities for the reuse of the various UMAR materials have been included due to a lack of respective data. However, the fact that the material quantities for direct reuse after the inclusion of such treatment activities would be smaller than here most probably offsets the fact that the resulting potential would simultaneously decrease, thus keeping the impact of the UMAR unit at approximately the same level. As stipulated above, the here shown data is not taking into account neither that such a UMAR unit is built out of waste materials as input (which in the end would further reduce the impact of the unit), instead natural resources have been used as starting point – resulting in a somehow conservative value for the production stages A1-A3 (i.e. a higher impact for the production than when using recyclable materials from a former building).

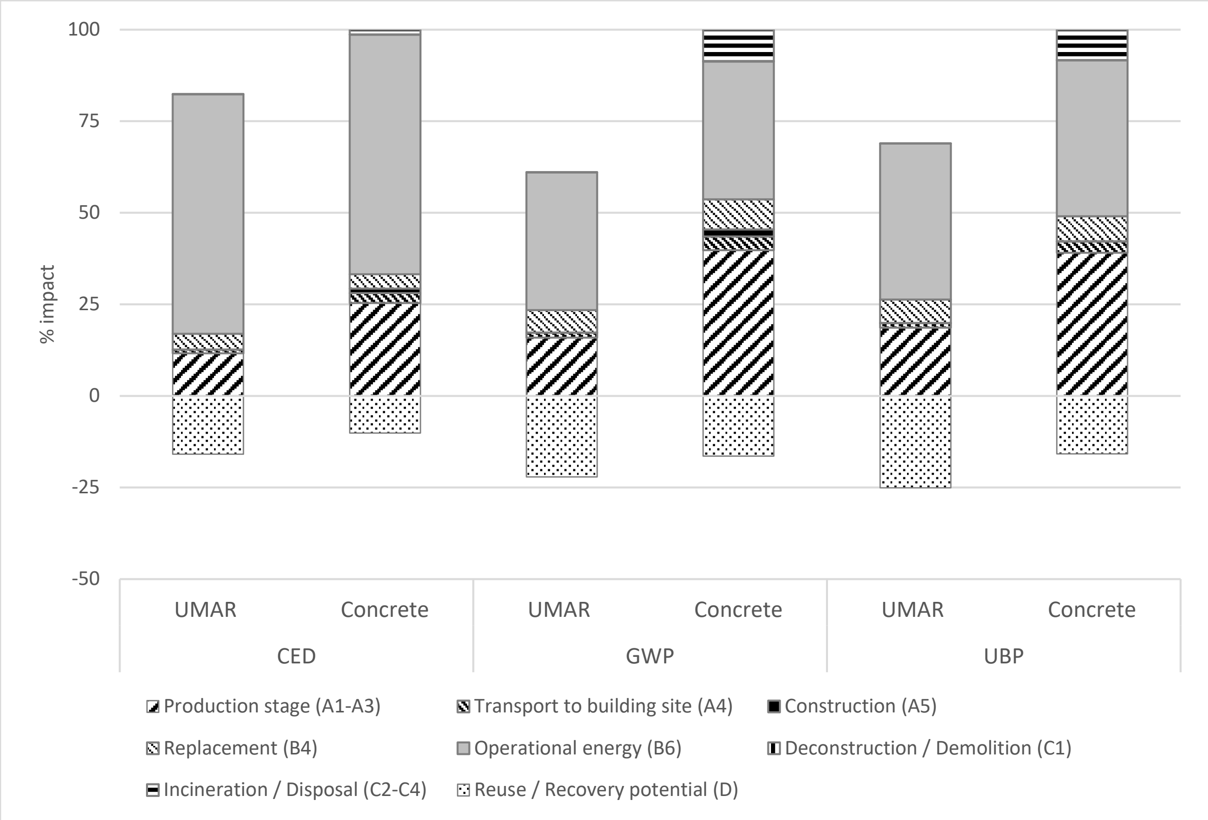

Figure 4. Impacts of the UMAR unit (split into various life cycle stages) in comparison with the here modelled, hypothetical concrete unit.

5. Conclusion

An application of the urban mining concept (such as realized in the UMAR unit) can lead to a reduction of the used primary energy, the global warming potential as well as the overall environmental impact of buildings, both at the construction element and the entire building level. Considering that within the Swiss Energy Strategy 2050, the energy requirements in the building sector have to be reduced by a total of 40% by 2035 and the amount of fossil energy even to one third of its current amount, a fundamental transformation of Switzerland's building stock is imperative. Therefore, these results described here will allow us in a next step to extrapolate the sustainability potential that lays in such an alternative construction concept towards a specific area or region – such as a city or even an entire country. Respective studies for the case of Switzerland, using the 2012 to 2016 net changes in the built environment for residential buildings (single and multi-family houses) as the area of investigations, are currently on-going in order to reach a better understanding of the implications and the potential of a shift from a linear building industry towards a circular economy [15].

6. References

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