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## Circular design: reused materials and the future reuse of building elements in architecture. Process, challenges and case studies

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# Circular design: reused materials and the future reuse of building elements in architecture. Process, challenges and case studies

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**Abstract.** The design process in which existing materials are reused or which aims to enable future reuse of building elements differs significantly from a standard design trajectory. Working with construction waste requires material tests, assessments, and consultations as well as defining available waste sources. Designing for future reuse demands extended research on the layers of buildings, properties of materials, dismountable joints, maintenance techniques, and reuse scenarios. This results in a longer introductory phase and often in a higher cost of the project. Circular design also faces other challenges, which concern environmental (e.g., recycling potential), social (e.g., social perception of reused materials), infrastructural (e.g., lack of processing plants) and legal issues (e.g., non-flexible construction law). These aspects often influence already technically complicated design process. However, there are projects in which reused materials were successfully implemented. Buildings designed for future reuse of their elements are also being built. In this paper selected case studies from Germany, the Netherlands, Poland and Denmark present how different types of construction waste (incl. waste from concrete, brick, wooden, metal, plastic and glass elements) can be reused in architecture. Moreover, this article analyses the circular design process, related challenges and investigates the emerging role of the architect.

**Keywords:** reused materials, design for reuse, reuse, construction waste, design process

## 1. Introduction

A circular economy is a new, regenerative economic model which synthesizes such concepts as functional economy [1], design philosophy Cradle-to-cradle [2], biomimicry [3], industrial ecology [4], natural capitalism [5] and blue economy [6]. Circular economy transforms products and services to eliminate the problem of waste and its negative environmental impacts. It uses renewable resources and closed material loops as well as it derives from social and environmental capital [7]. It depends on systemic innovation and non-standard management systems, and it aims to decouple socio-economic growth and the consumption of non-renewable resources.



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The principles of a circular economy have been introduced to the construction sector in the projects which reuse construction waste or enable the future reuse of building elements. Such circular solutions gain in popularity, but the reuse of building materials remains a niche practice in architecture [8]. This is because the design process in which existing materials are reused or which aims to enable future reuse of building elements differs significantly from a standard design trajectory. Circular design also faces other challenges, which concern environmental, social, economic, infrastructural and legal issues. This paper investigates the differences in the design process, related challenges and successful case studies to create an understanding of adequate conditions to implement circular solutions in the built environment. Moreover, conducted analysis discusses a changing role of the architect and the emerging aspects of the current practice.

## 2. Design process

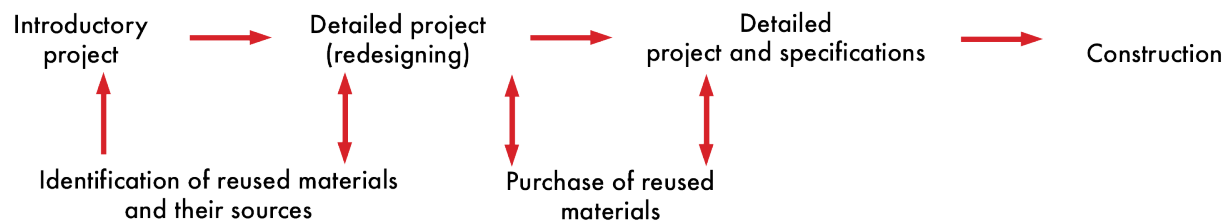
The interdisciplinary and flexible design process which reuses construction waste and enables the future reuse of building materials facilitates the collaboration of experts from diverse disciplines. The adequately elongated introductory phase includes research activities, specialist consultations, material tests, and experiments. It integrates the work of the design team, construction engineers, installation engineers, and future contractors. To define the optimal way of reusing construction waste it is necessary to conduct the detailed, often specialist assessment of its technical properties, current state, previous modes of use, durability, chemical composition, environmental impact, toxicity, contamination, and other defects. Participation of experts and contractors in the conceptual phase of the design process facilitates the assessment of construction waste – it provides information concerning the optimal ways of materials' sourcing, processing, assembly, disassembly and finishing as well as it enables realistic cost calculations of those processes [9]. The choice of reused materials needs to include the analysis of multiple technical, aesthetic, economic and social aspects which often results in a longer and more expensive design and construction process. A similar effect is a consequence of the necessity to conduct material tests and expertise necessary to meet obligatory standards or to obtain certifications and permits. Unlike the standard process, in which those obligations belong to the producers of building materials, the reuse of materials often requires that adequate permits are procured by the designers [9]. Moreover, the flexible cost plan and the project schedule should take account of the unpredictability of the reused materials' market, their limited availability, problems with sourcing and the absence of regulated procedures and work methods. The main environmental goals (e.g., in the form of the amount of reused materials implemented) need to be defined at the beginning of the project and to be included in the brief and specification. The implementation of environmental priorities should be monitored on every stage of the design and construction process by the skilled design team. The knowledge and skills of the designers should be developed through professional education training or workshops which integrate the designers, specialists, contractors, and investors. It is necessary that the collaboration of mentioned stakeholders start early in a conceptual phase of the design process to enable a better understanding of design priorities and decisions.

The main difference (Table 1) between the standard design and construction process (Figure 1) and the one in which reused materials are used (Figure 2) can be observed in data collection. The use of popular and commonly accessible building materials requires adequate knowledge which is developed by designers during their education and practice. Indispensable information is found in catalogues, leaflets, websites or it is acquired from qualified experts. Designing and constructing with reused materials is more complicated – students and practitioners are not educated in the reuse of materials. They do not have adequate experience. Research activities necessary to facilitate the process of reusing are often only conducted when it is required by the historic preservation officers. Moreover, the information concerning the availability, the location and the properties of reused materials is often limited. Another challenge is to define the optimal ways of sourcing, processing and adapting construction waste for a new use. Thus, the design and construction process should account the time necessary to identify sources of reused materials, to ensure their availability, to consult their way of reusing as well as to enable iterative modifications of the project and specifications. This results in a

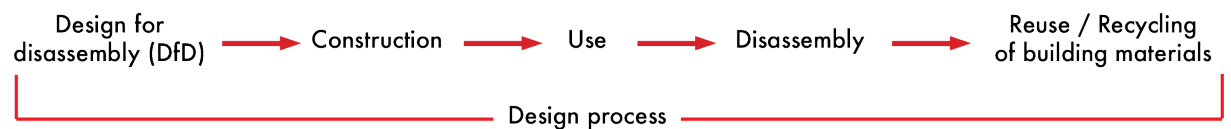
non-linear design process. In the introductory conceptual phase, reused materials are chosen, and their sources are defined. The process of materials' sourcing often is facilitated by the employment of qualified workers or demolition companies. The analysis of gathered data concerning available reused materials often requires verification of the initial project. Next – if the assessment of the location of previously selected reused materials, their amount, availability and technical properties is positive – the detailed project is prepared. In case of the negative evaluation, it is necessary to redefine the sources, to adapt the project and to store alternative materials. Only afterward the detailed project is developed, the construction process begins. Furthermore, it is important to account that modifications of the project may happen during the whole design and construction process.



**Figure 1.** Standard design and construction process. Source: own illustration based on [9].



**Figure 2.** The design and construction process in which reused materials are implemented. Source: own illustration based on [9].



**Figure 3.** The design and construction process which enables future reuse of building materials. Source: own illustration based on [9], [10].

The project which enables the future reuse of building elements after the end of their lifecycles (Figure 3) is also developed in a non-standard design work sequence. Similar, extended introductory phase of the design process should include specialist consultations and material tests. Sometimes it is necessary to conduct research to find optimal, architectural solutions for the future reuse of building materials. It is often helpful to consult the project with the experts from selective demolition companies, contractors or other specialists in reusing. Their knowledge and experience may help in defining resource effective and economically feasible reusable building materials. Furthermore, the experts provide information on optimal building forms and reversible joints. The interdisciplinary collaboration with experts should be continued during the preparation of the project documentation and the construction process. The specialist knowledge is also necessary to develop the guidelines for future users of the building, for its maintenance and disassembly. The project specification should also define future waste streams and optimal ways of the future reuse of building materials. Furthermore, the design process should encompass the lifecycle of the material [10].

**Table 1.** Reuse and design for reuse (DfR) in comparison to the standard design process

Introductory design phase	Reuse and DfR: elongated time framework, additional data collection, research, consultations, interdisciplinary collaboration, environmental goals definition
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	<u>Reuse</u> : materials sourcing, storing, testing and processing; application for permits for the use of non-standard solutions and materials <u>DfR</u> : future waste streams definition; disassembly and reuse scenarios plan
Project and specification	<u>Reuse</u> : flexible and modifiable cost plan, project schedule and specification <u>DfR</u> : identification and signage of material content; identification of waste streams, disassembly procedures and reuse scenarios; guidelines for maintenance, servicing and disassembly
Education	<u>Reuse and DfR</u> : necessary educational programmes (university level) and reuse-oriented training for professionals
Absence of standardised processes and construction methods	<u>Reuse and DfR</u> : necessary development of standardised tools and technologies for materials sourcing, processing and construction <u>DfR</u> : definition of future sourcing, processing and construction methods

### 3. Challenges

The main challenge concerning the reuse of building materials is a lack of data about their availability, amount, quality and ways of sourcing or processing. The designers are rarely educated in the reuse of construction waste and designing for the reuse. Moreover, there is no demand for such projects among the general public [11]. The collection, segregation, and processing infrastructure is often ineffective or insufficient. The reuse of building materials is also hindered by inadequate disassembly procedures, contamination of secondary resources, unstable properties of reused materials, lack of material certification, difficult identification of their content and debatable aesthetic. Furthermore, the longer, non-standard design and construction process usually results in a higher cost of construction as the use of reused materials often requires additional tests and consultations to obtain necessary certificates and permissions. The higher complexity of disassembly in comparison with the standard demolition often blocks the reversible design process as it is regarded as a more expensive solution [11].

But circular design depends also on multiple economic, environmental, social and infrastructural determinants [12], [13], [14], [15]. Spatial and pro-environmental policies and urban planning influence the way materials are used. Flexible and holistic approach to regulations and codes as well as an adequate business model framework is crucial for circular design process [11]. Buildings and their forms, dimensions, volume, age, technical and aesthetic condition affect the use of materials [12], [15], [16], [17]. Circulation of building materials depends on their properties, on urban typologies, density [13], [18], function [19] and time [15]. These aspects affect the amount of waste, the frequency of renovation, the way of deconstruction and the lifespan of a building. Moreover, reuse practices are influenced by the processing abilities of a region and the quality of transport and infrastructure necessary to collect and process waste [15], [20], [21], [22]. Environmental impacts also play a role: such aspects as air pollution, energy, and water consumption during the whole process of the extraction, transportation, processing and performance of materials facilitate or constrain the implementation of circular solutions in a construction sector [21], [22]. Another important factor determining the reuse of materials is their impact on human health and their recycling potential. Not every material can be environmentally effectively recycled [19]. Furthermore, the reuse of building materials depends on such economic aspects as the country's level of economic development, the demand for reused materials, the presence of economic incentives [21], [22], [23] and a higher cost of material [15]. Reusing practices are also strongly influenced by social determinants, including human customs, behaviours and daily practices, environmental awareness, social perception, authorities' awareness, social status and engagement [12], [16], [24], [25], [26].

### 4. Case studies

#### 4.1. Villa Welpeloo, Enschede, the Netherlands

Villa Welpeloo (Figure 4) is a 312-sqm single-family house designed by Superuse Studios and built in 2009. In this two-storey building reused, locally sourced materials constitute 60% of all used materials. The building's façades were finished with reused, thermally impregnated wooden planks extracted from cable reels from the neighbouring factory. The structure of the building was made out of steel elements from the textile machine. Insulation reused old polystyrene panels sourced from a dismantled production plant in the vicinity. Moreover, other reused materials were used for finishings (e.g., recycled plastic wall cladding, recycled glass, reclaimed road signs). Materials were minimally processed and the project was developed in a way which aimed to enable the reversibility of construction [27], (e.g., the use of mechanical joints or reversible splines for mounting the façade cladding). It was estimated that the use of reused materials for façade cladding generated only 5% of CO<sub>2</sub> emissions which would be generated by the use of new materials. Similar reduction (12%) was caused by the use of reused structural elements [28]. The introductory phase of the design process was extended because architects needed to locate materials' sources (harvest map tool), to conduct research, material tests, and consultations. Moreover, the project was frequently modified during construction process due to unpredictable properties of reused materials (e.g., due to the toxicity of initially considered reused railway slabs for building's structure) or due to lack of standardised processing and construction methods.



**Figure 4.** Villa Welpeloo, Enschede. Source: U.Kozminska



**Figure 5.** Open-Air Library, Magdeburg. Source: U.Kozminska

#### 4.2. Open-Air Library Salbke, Magdeburg, Germany

The library (Figure 5), designed by KARO Architekten, was built in 2008-2009. The 488-sqm pavilion was located on a site left after the demolition of a local library in Magdeburg. The new pavilion was designed as a space to integrate local inhabitants and to revitalise deteriorated urban space. The project was developed in close collaboration with the local community (e.g., workshops, prototyping, collective construction process) to create an inclusive public space. The library centres around green urban square which is surrounded by the retro-futuristic façades made out of 550 modular, aluminium prefabricated elements sourced from a dismantled department store. Those prefabricated elements did not require any structural processing – they were cleaned, painted white with powder coating and mounted to the original rail structure with mechanical joints to enable future disassembly. During the introductory design phase, designers sourced reused materials, tested them and prototyped to find optimal technical solutions. The project was repeatedly consulted with the experts and authorities to obtain necessary permissions. The participatory design process extended the duration of the project but overcame one of the main challenges, which concern working with waste, their negative social perception.

#### 4.3. Plattenpalast, Berlin, Germany

Plattenpalast (Figure 6), is a 39-sqm duplex house which currently serves as an exhibition space in Berlin. The building was created in a research-by-design process conducted at TU Berlin in collaboration with Wiewiorra Hopp Architekten in 2009 to create a prototype of a sustainable dwelling made out of reused prefabricated concrete panels. The open L-shaped plan of the building with the

closed module, which hides the bathroom, is designed to adjust to the changing needs of its users. The pavilion is made out of 13 prefabricated concrete panels (popular WBS70 panel type) sourced from the disassembled housing estate and 12 aluminium window frames with characteristic golden glazing. Dismantled concrete panels underwent durability tests and were cleaned, shortened, cut diagonally, drilled and joined with reversible steel dowels. They were impregnated with anti-graffiti water-repellent on the external side and covered with the internal insulation and mineral plaster from the inside. New materials were used to protect the joints and insulation (e.g., self-healing concrete or carbon fibres to reinforce window openings and concrete lintels). This project, financed by a federal grant and private sponsors, addressed a fundamental issue of the circular design – the lack of knowledge about possible methods of transformation. The extended conceptual phase of the design process included research, multiple consultations, and material tests. The developed model serves as an example of a standardised construction procedure to reuse popular concrete elements and proves that close, subsidised collaboration of the designers and academics may lead to environmentally and economically efficient application of reused materials in the built environment.



**Figure 6.** Plattenpalast, Berlin. Source: U.Kozminska



**Figure 7.** Warssawa Manufacture, Konstancin-Jeziorna. Source: Mech.build.

#### 4.4. Warssawa Manufacture, Konstancin-Jeziorna, Poland

The former food factory (130sqm, Figure 7) and the adjacent garage (90sqm) were adapted for the production of concrete tiles in 2016 by the architects from Mech.build. The modernisation project aimed to rearrange the functional layout and to improve the building's appearance. The existing external walls, clad with prefabricated gypsum elements, ensured good insulation but required vertical alignment. The new elevations of the production building were clad with, oiled wooden planks which remained from the renovation of neighbouring house. The garage was covered with recycled, seared wooden planks mounted to the substructure made out of welded steel elements from on-site roofing. The gate, doors, roofing and the new structure of the garage shed were built with reused elements from previous office containers and the old truss. The selective disassembly was defined as the main challenge in the construction process. The reused elements were processed on site and the project was iteratively modified during the construction phase. This flexible approach to the design process and collaboration with skilled and experienced construction workers facilitated efficient use of locally sourced reused materials.

#### 4.5. Housing on Lisbjerg Hill, near Aarhus, Denmark

The residential complex on Lisbjerg Hill (Figure 8) is a 4100sqm community housing designed by Vandkunsten Architects and developed in 2014-2018. The aim of the project was to create a flexible living space which would adapt to the changing needs of its inhabitants. The hybrid construction system consists of a concrete core and foundations, and prefabricated, laminated timber structure reinforced with steel elements and joined with reversible, metal joints to enable easy disassembly and the reuse of elements. The façades were covered with untreated wood and protected from rain with large, overhanging roofs. Interiors are also finished with untreated wood. The project rates high in energy

consumption, daylight conditions, carbon footprint and conservation of resources. It was developed by experienced designers who researched and verified multiple reuse methods in previous projects. Thus, this example proves that research-based design process and the adequately educated team have a competency to create economically efficient, aesthetic and circular buildings.

#### 4.6. Resource Rows, Copenhagen, Denmark

Resource Rows (Figure 9) is a housing complex located in a new urban area of Copenhagen – Ørestad. It was designed by Lendager Group in collaboration with Arkitektgruppen, the developer company NREP and engineering consultant MOE. The project, currently under construction, aims to create 9148sqm of living space enclosed in tree- to seven-storey buildings which surround the internal courtyard. The environmental goal of the project was to reduce the consumption of natural resources and to minimise CO<sub>2</sub> emissions caused by the construction process. This was achieved by using reused bricks for the elevation cladding. They were sourced from the old Carlsberg brewery in Copenhagen. The brick walls were cut and reinforced with the steel frames to create façade modules which were used as standard prefabricated façade elements. They were mounted directly to the insulated structural wall. This project shows how the interdisciplinary collaboration of diverse experts during the design process creates an innovative, pro-environmental and aesthetic architectural solution for easy in construction and efficient application of reused materials. The developed construction method addresses the problem of the absence of standardised processes for reused materials and parts with the common misconception that the use of such materials compromises the aesthetics of a building.



**Figure 8.** Housing on Lisbjerg Hill, near Aarhus. Source: U.Kozminska



**Figure 9.** Resource Rows, Copenhagen. Source: U.Kozminska

### 5. Conclusions: a changing design process and the role of the architect.

All presented case studies show that circular solutions in the construction sector are being successfully developed. The reused materials and the principles of design for disassembly are being implemented in new architectural designs. These developments happen despite multiple infrastructural, planning, legal, social, environmental and economic challenges which appear in a non-standard and iterative design and construction process. The architects are working with construction waste, or they design for further reuse despite limited access to related knowledge, data, and information. They educate themselves, source materials and experiment with them, consult architectural solutions with experts, participate in collaborative processes, learn from the engineers, contractors, demolition companies, or local artisans. They look beyond tested solutions and question standard practices. The emerging role of the architect, who participates in the circular design process, requires extended knowledge to negotiate between often contradicting circumstances without compromising the quality of created sustainable architecture.

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