Circular Economy in Nordic Architecture. Thoughts on the process, practices, and case studies.

Urszula Kozminska, Msc.Eng.Arch., PhD
Aarhus School of Architecture, Norreport 20, 8000 Aarhus, Denmark, uk@aarch.dk

Abstract. The principles of the circular economy change the existing practices in the construction sector. Designing for the future reuse requires extended research concerning the building's structure and the properties of materials. The circular design needs to investigate such aspects as the robustness of materials, reversibility of the structure, maintenance techniques, and reuse scenarios. This often requires extended knowledge and multiple consultations with experts. Thus, it results in a non-standard design trajectory. Therefore, the circular design process encounters multiple challenges related to the innovative character of architectural solutions, lack of knowledge, absence of adequate legal regulations and policies, ineffective business models, extended design phase, extra costs, or other socio-cultural determinants.

In this paper, selected case studies from the Nordic countries are analysed through literature reviews, field visits, and case studies analysis to define exemplary, architectural practices that close material flows and enable circular design and construction process. Analysed case studies (i.e., projects by Vandkunsten Architects, Lendager Group, Helen and Hard) demonstrate that research-based design process, life-cycle analysis, designing for disassembly, the use of local materials and techniques results in environmentally effective, high-quality, aesthetic, and sustainable architecture which not only functions well today but have a long-lasting character as it embraces the value of passing time. In the Nordic countries (Denmark, Norway), there are buildings that prove that the principles of the circular economy can be successfully incorporated in the built environment and serve as an inspiration for further development of circular architecture and sustainable cities.

1. Introduction

UN Sustainable Development Goals promote sustainable cities and communities which are characterised by the reduced environmental impact and which efficiently use clean and renewable resources. Thus, the SDGs are strictly linked with the concept of circular economy and its integration in the construction sector. This paper analyses how this transition may be addressed in the architectural design and sustainable construction process by reducing the environmental impacts of cities through optimisation of construction waste management and pro-environmental building design.

This article explains the concept of circular urban metabolism and the principles of circular architecture by conducting literature review and case study analysis of Danish and Norwegian examples. Moreover, it juxtaposes the main challenges for the circular design process with the specific situation in the Nordic countries. The paper concludes with the general findings concerning Nordic circular architecture.

2. Background: circular urban metabolism of sustainable cities and communities.
In 2030, cities will be inhabited by 80% of the human population (5 billion people). The urban metabolism of cities is constantly increasing [1]. The material-consumption of urban areas is accelerating [2]. The amount of waste is rising. The construction sector contributes significantly to global waste production as construction waste constitutes 36.4% of all waste generated in Europe [3]. Moreover, further extraction of materials from natural resources will increase raw material consumption by 2050. Hence, due to the rapid urbanization process, it is necessary to revise the current approach to urban planning and building design. Future, sustainable cities and communities (UN Sustainable Development Goal no. 11) should aim for minimised consumption of raw materials, sustainable management of construction waste and reduced pollution during construction processes, buildings’ performance, and their end-of-life scenarios. This can be achieved through a circular design - a long-lasting design, which favours adequate maintenance and repairing, reusing, or recycling practices in the built environment.

The circular design originates from the circular economy, a regenerative economic model that surpasses the European Waste Management Hierarchy as it reduces the consumption of finite resources through their effective use, reuse, closing material flows and innovation. The circular economy in cities embraces the concept of urban metabolism [4], which is understood as “the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste” [5]. The fast growth of cities accelerates the urban flows of building materials and construction waste, often negatively affecting the environment. Thus, the needs of continually expanding urban areas cannot be met in a standard linear process that uses non-renewable resources and expels waste. Currently, sustainable cities and communities will develop more circular systems which depend on the low consumption and the reuse of urban flows [6].

In architecture, circular metabolism is directly linked with the regenerative design concept of Cradle-to-Cradle [7], which perceives cities, buildings, and materials as parts of continuous biological and technological cycles. The circular design uses such concepts as Upcycling or Superuse [8], which aim to create value for discarded building elements and materials. What is more, Superuse intends to optimize urban flows through detailed environmental assessment and linking the materials, their sources, processing facilities, and construction sites (Harvest Map concept). Furthermore, circular architecture is associated with the 3R Theory [9], which reduces the design and construction process to indispensable activities, or with the Theory of Layers [10], which organises buildings in layers according to the function and lifespans of their elements. The circular economy in built environment embraces the principles of sustainable building model [11], design for disassembly [12], life cycle assessment [13], reversibility of construction [14] and adaptable, flexible, open architecture.

3. Circular Economy in Denmark and Norway – mapping challenges and incentives for the construction sector.

Urban metabolism is influenced by the amount of generated waste [15] and depends on urban typologies, density [16], [2], function [17], buildings’ lifespans, forms, technical state and aesthetic conditions [18], [5], [15], [6]. Material flows within the cities are impacted by multiple organisational, infrastructural, economic, environmental, and social determinants [18], [2], [1], [6]. Closed circulation of building materials is influenced by such macroeconomic aspects as the country's level of economic development and the demand for reused or reusable materials [19] as well as by the microeconomic issues, e.g. the cost of the material. Material flows remain in correlation with their environmental impacts i.e., air pollution, energy, and water consumption [19], [20] during the whole process of the extraction, transportation, processing, performance, and end-of-life treatment of building materials. Circular fluxes of construction waste are influenced by materials' recycling potential and their impact on human health. What is more, shrinking natural resources and the necessity to reduce CO₂ emissions may modify materials’ sources and their ways of extraction [14]. Finally, closed material loops require effective and well-connected processing infrastructure which includes selective waste collection.
points, processing facilities, adequate organisation of demolition companies, online platforms and databases informing about the market of reused and reusable materials [19], [20], [21], [6].

In Nordic countries, the construction sector generates one-third of all waste [22]. The total amount of construction and demolition waste generated in Denmark constitutes 2.7 million tonnes per year, in Norway – 2.5 million tonnes per year [22]. These numbers include such waste streams as wood, gypsum, asphalt, glass, plastic, insulation, concrete, bricks, and metals. It is estimated that the reduction of 20% in the consumption of these resources in Denmark and Norway may result in a decrease in potential gas emissions by 1.872 million tonnes yearly [22]. Currently, Denmark recovers 90% of construction and demolition waste, Norway – 71% [3]. However, the circular material use rate, which measures the share of the material recovered and fed back into the economy (saving extraction of primary raw materials), is significantly lower - it is 8.2% in Denmark [3]. Denmark has the ambition to improve the quality of recycling material from the construction sector and to increase direct reuse rate. Norway aims to improve the quantity of recycling to 80%.

3.1. Policies and incentives

The circular design and construction process may be hindered by ineffective infrastructure, faulty disassembly procedures, contamination of secondary resources, unstable properties, undefined content, lack of standards, and regulated procedures as well as by the unfavourable economic and environmental conditions. However, mentioned challenges may be addressed and prevailed by pro-environmental and holistic policies, development strategies, and urban planning, as well as by adequate legal acts and a flexible approach to regulations and codes. Moreover, circular metabolism depends on an effective business model framework and suitable support from the authorities [23]. Circular metabolism may be facilitated by the presence of economic incentives [20] and supporting instruments (e.g., national or regional innovation programmes, extended producer responsibility strategies, voluntary agreements for SMEs, pro-environmental taxes, green investments, sustainable procurement or eco-design). Such support helps to offset the increased cost of the circular design process, disassembly procedures [23], or non-standard architectural solutions [6].

In Denmark, the European action plan for the Circular Economy (2015) and the Circular Economy Package from 2018 are interpreted in Danish resource and prevention strategies, which aim to reduce waste generation and ensure more efficient use of resources. The circular economy goals are also formulated in the recommendations of the Advisory Board for the Circular Economy, established in 2017. They target the construction sector by promoting increased resource efficiency, creating new markets, and circular business models [22]. The recommendations mention Green Deals, new standards, and updated building regulations to remove barriers for the circular design. Moreover, the circular economy is promoted by the National Strategy for Circular Economy, which was announced in 2018 and which targets the recirculation of materials and products. The strategy advocates for i.e., adequate design, establishing the market for waste and reused goods, and gaining more value from buildings [24]. The Danish public procurement targets the purchase of circular goods and services by the public sector. Furthermore, since 2012, the Central Denmark Region has been developing the Circularity City Project, which uses the circular economy as a driver for sustainable business development. The project’s objective is to find new urban solutions by establishing value chains, material recycling, digitisation, modular fabrication and construction, defining new materials, construction methods, and models for collaboration. The Danish Design Council runs a project on circular design for SMEs and Danish companies are integrating such circular strategies as circular supply, resource recovery, life extension, sharing platforms and product as service. What is more, the Innovation Competition ‘Circular Challenge’ (organised by philanthropic foundation Realdania) awarded three prizes of 130 000 euros to test and develop circular solutions for the built environment.

In Norway, the government issued a white paper on waste policies in the circular economy to increase reuse and recycling in 2017. The Norwegian waste strategy ‘From waste to resource’ establishes the target for the recycling rate to 80%, but there are no specific documents or strategies
promoting circular economy in the Norwegian construction sector. However, Norway introduced in the building regulations the requirement to prepare the waste plan for new buildings when they are renovated or demolished [22]. It is also necessary to set an environmental assessment plan before the demolition to separate hazardous waste. At least 60% of construction waste should be sorted on the construction site. Additionally, the structure of the Norwegian business sector is well-suited for circular economy collaboration as there are many concentrated industrial clusters with expertise, little hierarchy, and high level of trust.

3.2. Social context
Finally, circular metabolism and architecture remain in strong correlation with such social determinants as human customs, behaviours and daily practices as well as society’s environmental awareness, social perception, social status, and engagement [18], [15]. In the Nordic countries, the environmental awareness of society historically rates high. Moreover, 46% of Danes and 40% of Norwegians are familiar with the term ‘circular economy’, 88% of Danes and 83% of Norwegians are in favour of the idea to reduce their overall consumption, and the majority feels responsible for the transition towards circular economy [25]. More than 65% is open to the concept of adequate tax shifts. What is more, Danes and Norwegians developed positive attitudes towards repairing, recycling, and second-hand purchases: 36% of Norwegians and 32% of Danes repairs items, and 21% of Danes bought second hand items more than 10 times in 2019. Finally, Nordic societies, ‘most economically equal nations’, create ‘certain preconditions (…) that are conditional for full implementation for the circular economy’ [25:63]. The report [25] shows that further integration of circular economy requires adequate education and open-access platforms.

4. Circular Economy in Nordic Architecture – process, requirements and case studies
4.1. Process
The circular design is developed in the interdisciplinary and flexible process which includes the collaboration of experts from diverse disciplines who contribute with knowledge concerning optimal ways of materials’ sourcing, processing, and reusing, their environmental impacts, disassembly methods and cost calculations of related processes [26], [27], [28]. To define the optimal way of reusing construction waste, it is necessary to conduct the detailed, specialist assessment of its technical properties, current state, previous modes of use, durability, chemical composition, environmental impact, toxicity, contamination, and other defects [26], [8]. It is often necessary to research and consult optimal architectural solutions for the future reuse of building materials. The collaboration with the experts from selective demolition companies, contractors, or waste management companies may help in defining sources of materials or resource-effective and economically feasible reused or reusable building materials as well as finding optimal building forms and reversible construction systems. What is more, the specialist knowledge may contribute to the guidelines for future users of the buildings, for their maintenance and disassembly techniques as well as to the projects’ specifications which should define future waste streams and their optimal ways of reusing as the circular design process encompasses the whole life-cycle of the material [29].

In the circular design process, the designers need to analyse technical, aesthetic, economic, and social aspects when choosing the materials. Moreover, they are often responsible for ensuring the required properties of reused materials to procure adequate certifications and permits [26]. Therefore, the introductory phase of the design process is extended due to additional research activities, specialist consultations, material tests, and experiments. It often results in a longer and more expensive design and construction process. Furthermore, the unpredictable market of reused materials, their limited availability, problems with sourcing, and the absence of regulated procedures and work methods require the flexible cost plan and the schedule of the project. It is necessary to account for the time needed 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. Thus, the
documentation of the project should be carried out during the entire process [30]. The alternations of the project may happen during the whole design and construction process [28].

Finally, it is crucial to define the main environmental goals (e.g., in the form of the amount of reused materials implemented or future recycling ratios) at the beginning of the project in the brief and specification. The implementation of environmental priorities should be monitored on every stage of the design and construction process. Therefore, it is necessary that the collaboration of mentioned stakeholders starts early in a conceptual phase of the design process to enable a better understanding of design priorities and integration of circular solutions. Moreover, all stakeholders involved in the circular design process should use new business models based on cooperation, and partnership which ensure a positive financial return for all parties involved [30].

4.2. Requirements
Aside from the differences in the design process, the use of reclaimed materials and designing for the future reuse of building elements requires multiple modifications in the way materials are sourced, and the buildings are shaped. These changes can be presented as general guidelines [27] for the circular architectural design, which demands that materials should be chosen adequately to the climate conditions, way and time of usage, as well as their technical, chemical, and aesthetic properties. What is more, the properties of selected materials should ensure their recyclability [30]. Thus, monomaterial, non-toxic, healthy, safe, aesthetic, local materials with identified content are preferred [12]. Detailed specifications and material passports can be used to facilitate the identification of materials. For future reuse, optimal materials are light, long-lasting, modular, prefabricated, changeable, easy in mounting and disassembly, standardised, recyclable, with planned way and period of usage as well as a defined reuse scenario. The composite materials should be avoided. It is advised to use certified materials and construction systems that enable repeated use [30].

Moreover, circular architecture considers the entire lifespan of the building elements, their functions and time of usage, as well as ways of transportation, mounting, maintenance, repair, disassembly, and reuse. It is important to embrace the technical, environmental, and aesthetic properties of reused or reusable materials when choosing adequate construction methods. In the case of reused materials, it is recommended to exchange existing and broken connections. To facilitate future disassembly and the reuse of building elements, it is advised to use mechanical, reversible, non-destructive and indirect joints (e.g., bolts, velcros, tongue and groove connections instead of adhesives and nails) and limited coating and finishing of materials (e.g., heat treatment instead of chemical impregnation) [12], [30]. The circular design prefers simple, adaptable, modular, and aesthetic forms with free plan and section, regular grid, and hierarchical, easy access to all building’s parts to facilitate their maintenance and repairs. It can be achieved by separating structure from other elements or by the reduced number of used types of materials, joints, and components. Furthermore, standard, and accessible materials and construction methods that fit into a ‘larger and coherent’ system are favoured [30].

The detailed guidelines for the circular design are related to the type of the building material as each building material and type of construction waste require different treatment, processing, and adaptation method for a new function.

4.3. Case studies
The ongoing research concerning circular architecture in the Nordic countries aims to verify if favourable socio-cultural, economic and organisational conditions result in an integration of circular economy principles in the construction sector in Denmark and Norway. Therefore, multiple recently finished and currently developed architectural projects in those countries were analysed through literature review, Internet-based research method, the projects’ documentation examination, and field visits. The case study analysis, apart from basic data collection (incl. building’s typology, size, location and date of completion), investigated the integration of selected circular strategies, e.g., adaptive reuse, material reuse, design for disassembly, 3R, Theory of layers, flexibility, Cradle-to-
Cradle, and circular urban metabolism principles. The evaluation assessed buildings’ structure, joints, materials, and other circular solutions. This analysis identified 22 examples of circular architecture in Denmark and 8 in Norway. It is important to mention that the Danish examples are consciously labelled as circular buildings, whereas the Norwegian ones mention more specific circular strategies, e.g., material reuse, design for disassembly, etc. The analysis also showed that such circular design strategies as adaptive reuse or material reuse have been introduced in Nordic sustainable architecture since 2008 or earlier, whereas more complex circular projects, which address multiple circular strategies, have been appearing since 2012 and are gaining popularity in recent years.

In Denmark and Norway, there are circular projects of diverse scales and functions: from masterplans (Resource City in Naestved, 60 000sqm, 2017 or UN17 Village in Copenhagen, 35 000sqm, ongoing by Lendager Group), through public space (Geopark in Stavanger, 2008 by Helen and Hard), offices (Powerhouse Kjøbenhavn in Bærum, 5200sqm, 2014 by Snohetta), educational (Marthagaarden Kindergarten in Frederiksborg, 2013 by Lenager Group), cultural (Green Solution House in Rønne, 4500sqm, 2015 by GXN), and sport facilities (Gymnasium for Street Sports in Gentofte, 1000sqm, 2015 by Vandkunsten Architects) or services (Nordhavn Recycle Centre in Copenhagen, 400sqm, 2016, by Lendager Group), to hotels (Pulpit Rock Mountain Lodge, in Strand, 1260sqm, by Helen and Hard), multi-family housing (Lisbjerg Hill Housing in Aarhus, 4100sqm, 2018, by Vandkunsten Architects), single-family houses (Villa Albert in Aarhus, 168sqm, 2013 by Loop Architects) and prototypes (Circle House in Valby, 2017, GXN, 3XN, Vandkunsten Architects, Lendager Group). Analysed buildings are developed using such circular design strategies as adaptive reuse (Musicon, HAL 7 Makers Corner in Roskilde, 2017 by Vandkunsten Architects), material reuse (Upcycle House in Nyborg, 2013, by Lenager Group), design for disassembly (Bjergsted Financial Park in Stavanger, 2019, by Helen and Hard), 3R (Apartments in the Constable School in Copenhagen, 2015 by Vandkunsten Architects), Theory of Layers (Seaweed House in Læsø, 2013, by Vandkunsten Architects), flexibility (Upcycle Studios in Copenhagen, 2018 by Lendager Group), Cradle-to-Cradle (Circle House in Valby, 2017, GXN, 3XN, Vandkunsten Architects, Lendager Group) and circular urban metabolism principles (Resource Rows Housing in Copenhagen, ongoing, by Lendager Group).

Nordic circular buildings use reversible structural and mounting systems, i.e., dismantable steel connections for prefabricated concrete elements (Peikko system in the Circle House in Valby), reversible wooden column-slab systems filled with CLT cassettes (Lisbjerg Hill Housing in Aarhus), structural timber Holz system connected with dowels (Vindmøllebakken Housing in Stavanger, 2018 by Helen and Hard), changeable steel mounting system Komproment (Circle House in Valby) or recyclable aluminium window system Velfac (Green Solution House in Rønne). Twenty, from 30 identified circular buildings in Denmark and Norway, use timber for structural elements (Bjergsted Financial Park in Stavanger), external cladding (Upcycled Summerhus in Odsherred, 2018 by Lendager Group) or interior finishing (Atrium Houses in Albertsund, ongoing, by Vandkunsten Architects). Moreover, such natural materials are implemented as eelgrass (for façade cladding and insulation in Seaweed House in Læsø), cork (façade cladding in Circle House in Valby) and local...
stone (granite in Greenhouse Solution House in Rønne). Furthermore, circular architecture in both countries reuses discarded materials, i.e., shipping containers (for structure in CPH shelter in Copenhagen, 2017 by Vandkunsten Architects), wooden offcuts (for exterior and interior cladding in Upcycled Summerhouse in Odsherred), building rubble (for parking structure in Green Solution House in Rønne), reclaimed window frames (for window systems in Upcycle Studios in Copenhagen), bricks (for façade cladding in Resource Rows Housing in Copenhagen), concrete (for façade elements in Pelican Self Storage in Copenhagen, 2015 by Lendager Group), steel elements (for foundations in Upcycle house in Nyborg), recycled glass (for pavements in Green Solution House in Rønne), plastics (for interior baffles in Powerhouse Kjobrø in Bærum), and furniture (in Marthagaarden Kindergarten in Frederiksberg) or industrial installations (petroleum machines for urban furniture in Geopark in Stavanger) and cables (for interior decoration in the Energy Hotel in Nesflaten, 2008 by Helen and Hard). Several buildings incorporate locally sourced reused materials, e.g., recycled concrete from the Copenhagen metro in Upcycle Studios or reclaimed bricks from Carlsberg Brewery in Copenhagen in Resource Rows housing. Such Cradle-to-Cradle certified materials are also implemented in Nordic circular architecture as Desso carpets (Green Solution House), Velfac window system (Green Solution House), or Mosa tiles (Villa Albert). 50% of analysed buildings is designed for disassembly to different extent: they use modular, prefabricated, and reversible systems or they develop a hierarchical building structure which ensures easy access to all building layers to enable their regular maintenance, repairs, and replacement as well as future dismantling. Investigated circular buildings are developed with open plan and section (e.g., Upcycle Studios), or they enable the further extension (Lisbjerg Hill Housing) to facilitate adaptation and modification of space according to the changing needs of the users. What is more, circular buildings are often designed according to the 3R principles. Therefore, they limit unnecessary construction activities to the minimum (Energy Hotel in Nesflaten), reduce finishing of existing structures (Apartments in Constable School), and new materials (untreated wood on the façades and interiors of Lisbjerg Hill Housing). Nordic circular architecture is also exemplary in introducing new co-living models (Vindmøllebakken Housing developed in the participatory design process and functioning according to the sharing economy principles) or in closing local energy, water and food loops in building design (biological water purification systems, monitored resource consumption and active indoor climate systems in Green Solution House).

5. Conclusions
Favourable socio-cultural context and the existence of policies and incentives supporting the circular economy in the Nordic countries result in exemplary circular architectural projects which use diverse circular design strategies and variously apply circular solutions and materials. Moreover, Nordic circular architecture develops new circular business models (e.g. in Green Solution House monetary revenue from the hotel funds the ongoing integration of new solutions), novel organisational structures of architectural offices (cross-disciplinary character of Lendager Group which consist of an architectural office, upcycled materials’ provider and circular economy experts) and research projects to explore possible circular solutions (Nordic Built Component Reuse, 2014-2015 or ongoing CIRCuIT - Circular Construction In Regenerative Cities conducted by Vandkunsten Architects). These research and pilot projects are often subsidised by European, national, regional, private and public foundations, and research programmes (e.g. Green Solution House, Seaweed house, Sunde Boliger, Upcycle House), which facilitate transition towards the circular economy in the Nordic built environment.

References
[1] Kennedy C Pincetl S and Bunje P 2011 The study of urban metabolism and its applications to urban planning and design Environ. Pollut. 159 8-9 1965–73
[2] Barles S 2010 Society, energy and materials: the contribution of urban metabolism studies to sustainable urban development issues J. Environ. Plann. Man. 53 4 439–55
[3] https://ec.europa.eu/eurostat/statistics-explained/index.php/Waste_statistics
[Accessed:15.12.2019]

[4] Wolman A 1965 The metabolism of cities Scientific American 213 3
[5] Kennedy C, Cuddihy J and Engel-Yan J 2007 The Changing Metabolism of Cities J. Ind. Ecol., 11 43-59
[6] Agudelo-Vera CM, Leduc WR, Mels AR and Rijnaarts HM 2012 Harvesting urban resources towards more resilient cities Resour. Conserv. Recy. 64 3–12.
[7] Braungart M and McDonough W 2002 Cradle to Cradle: Remaking the Way We Make Things. (London: Vintage)
[8] Hinte E Peeren C and Jongert J 2007 Supreme: Constructing New Architecture by Shortcutting Material Flows. (Rotterdam: Nai010 Publishers)
[9] Petzet M 2012 Reduce, Reuse, Recycle: Rethink Architecture. German Pavilion (Ostfildern: Hatje Cantz)
[10] Brand S 1994 How Buildings Learn: What Happens After They're Built. (New York: Penguin)
[11] Kiebert C 2012 Sustainable construction: green building design and delivery Hoboken: Wiley
[12] Crowther P 2000 Developing an inclusive model for design for deconstruction. Deconstruction and Materials Reuse: Technology, Economic, and Policy 266 (Wellington: CIB Publication)
[13] Curran M A 2016 Life-cycle Assessment Encyclopedia of Ecology 4 359-366
[14] Ruby A I 2010 Re-inventing construction. (Berlin: Ruby Press)
[15] Spoerri A Lang D Binder C and Scholz R 2009 Expert-based scenarios for strategic waste and resource management planning—C&D waste recycling in the Canton of Zurich, Switzerland Resour. Conserv. Recy. 53 592–600 22
[16] Deilmann C 2009 Urban Metabolism and the Surface of the City. Guiding Principles for Spatial Development in Germany German Annual of Spatial Research and Policy 23 1-16
[17] Hammer M, Giljum S and Hinterberger F 2003 Material Flow Analysis of the City of Hamburg Quo vadis MFA? Material Flow Analysis (Wuppertal: workshop 8-10.10)
[18] Andenberg S 1998 Industrial metabolism and the linkages between economics, ethics and the environment Ecol. Econ. 24 6 311–20
[19] Chong W and Hermreck C 2010 Understanding transportation energy and technical metabolism of construction waste recycling Resour. Conserv. Recy 54 26 579–590
[20] Zaman AU 2014 Measuring waste management performance using the Zero Waste Index: the case of Adelaide, Australia J. Clean.Prod.66 407–419
[21] Brunner PH 2011 Urban Mining. A Contribution to Reindustrializing the City J. Ind. Eco. 15 3 339-349
[22] Høibye L Sand H 2018 Circular Economy in the Nordic construction sector Rosendahls: Nordic Council of Ministers
[23] Debacker W and Manshoven S 2016 D1 Synthesis of the State of the Art. Key Barriers and Opportunities for Material Passports and Reversible Design in the Current System (H2020 BAMB project)
[24] Ministry of Environment and Food 2018 Strategy for Circular Economy. More value and better environment through design, consumption and recycling. (Copenhagen: Ministry of Environment and Food)
[25] https://www.sb-insight.com/sb-reports [Accessed:15.12.2019]
[26] Addis B 2006 Building with Reclaimed Components and Materials (London: Earthscan)
[27] Kozminska U 2017 Architektura, Ekonomika i Srodowisko Jednostki Miejskiej. Materialy Worne w Budownictwie (Warsaw: Warsaw University of Technology)
[28] Gorgolewski M 2018 Resource Salvation.The Architecture of Reuse (Oxford: Wiley Blackwell)
[29] Goens H Capelle T Henrotay C and Steinalge M 2018 D13 Prototyping Feedback Report. Testing BAMB Results Through Prototype and Pilot Projects (H2020 BAMB project)
[30] Guldager Jensen K 2016 Building a Circular Future. (Denmark: GXN Innovation)