



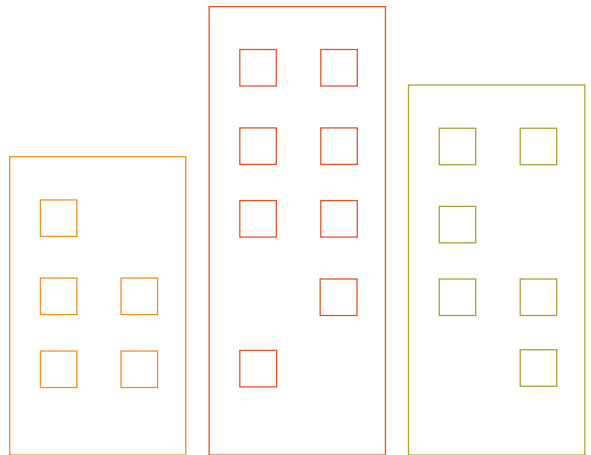
BAMB

BUILDINGS AS MATERIAL BANKS

SBE19 Brussels - BAMB-CIRCPATH: Building As Material Banks - A Pathway for a Circular Future

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Editor
Luis Bragança - University of Minho, Portugal





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SBE19 Brussels - BAMB-CIRCPATH: Building As Material Banks - A Pathway for a Circular Future

The BAMB Project Consortium



UNIVERSITEIT TWENTE.



Universidade do Minho



**SBE19 Brussels - BAMB-CIRCPATH:
Building As Material Banks - A Pathway
for a Circular Future**

Editor

Luís Bragança

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Foreword

The SBE19 Brussels - BAMB-CIRCPATH “Buildings as Material Banks – A Pathway for a Circular Future” held in Brussels on 5 to 7 of February 2019, is an initiative of the Consortium of the H2020 BAMB Project together with the Sustainable Built Environment (SBE) series of conferences.

Being within the SBE series, this event gathers the support of CIB – International Council for Research and Innovation in Building and Construction, iiSBE – International Initiative for a Sustainable Built Environment, the United Nations Environment Programme, and FIDIC – International Federation of Consulting Engineers. The goal of this series of regional and international conferences is to disseminate innovative policies and developments in the field of sustainable urban environment to a broad international audience of specialists in policy, design, construction and operation of buildings and related infrastructure.

BAMB is a EU funded project that brings together 16 partners from 7 European countries throughout Europe together for one mission - enabling a systemic shift in the building sector by creating circular solutions. BAMB has been developing and integrating tools that will enable the shift to a circular built environment: Reversible Building Design tools and Materials Passports – supported by new business models, policy suggestions, management, and decision-making models. In addition to testing developed BAMB tools, design, manufacturing, and construction innovations as well as the environmental and economic benefits of circular buildings have also been investigated through six real-life pilot projects.

BAMB-CIRCPATH as part of the worldwide prestigious SBE19 Conference Series intends to bring together researchers and industry experts from the entire world to exchange their ideas and research and showcase advanced technologies and innovative methodologies for the built Environment.

The main theme – Pathway for a Circular Future – is an important issue currently widely debated. It is consensual that building materials end up as waste when no longer needed, which can in turn harm ecosystems, increase environmental costs, and contribute to resource scarcity. Yet, buildings can also be seen as material banks located at every corner of urban areas. So, considering buildings as a resource is a first step towards creating value of otherwise worthless materials. From materials passports through reversible building design and circular business models to policy recommendations, in four years of activity BAMB has established a series of actionable tools to enable a transition towards a more circular economy.

Circular economy is a cyclical production and consumption approach. It emphasises the need to closed flow models, instead of the traditional linear one – extract-produce-use-dispose of. It promotes economic growth, by creating value to end-of-life products, being in line with the sustainability cornerstones.

The full potential value of the circular economy is embedded in the re-use, maintenance, refurbishment, and remanufacturing of materials and components, for as long as possible, demanding less resource and energy use and extending the life cycle of construction products. The more time a product stays in the loop the better.

Thus, BAMB investigated multi-disciplinary aspects from the building sector as the value chain at product and building level, assessed the cause of demolition of buildings, and the content of construction and demolition waste, as well as researched methods and means to promote reuse at product and building level, existing tools to promote flexible and demountable buildings. The research culminated in the development and implementation of six pilot case-studies, investigating and demonstrating new design, manufacturing, construction and maintenance approaches for dynamic and circular building.

So, this event aimed to enable sharing concerns, contributions and solutions between different stakeholders according three activities promoted: Industry Day; Site Visit; and Research Day.

The Industry Day was dedicated to share the BAMB tools and results with all innovation enthusiasts, stakeholders and industry players.

Site Visit promoted to visit the BAMB pilot Circular Retrofit Lab, that investigates and demonstrates how Reversible Building Design can prevent demolition waste when refurbishing existing buildings.

The Research Day promoted the exchange of ideas between researchers and industry experts, as well as sharing research and showcase advanced innovative technologies and methodologies for the built environment.

The conference topics include a wide range of current issues and the contributions received from participants reflect innovative research and best practices available in the field of a pathway for a circular economy. A total of 120 works were received, of which 76 articles were selected to be published in the conference Proceedings. All the works underwent a rigorous blind peer review process carried out by specialists.

The articles approved by the Scientific Committee were distributed according to the following topics:

- Management tools and supportive mechanisms for circular applications and business models;
- Strategies, tools and systems to promote circular economy in buildings;
- Design for adaptability, reconfiguration and high reuse potential;
- Environmental assessment and economic impacts for measuring circularity;
- Efficient waste and resources management;
- Barriers and opportunities for a circular built environment;
- BIM and digitalisation towards high reuse potential and circular economy.

The Organising Committee thanks all the authors who contributed with published articles, to all the reviewers whose efforts and hard work have ensured the high quality of all contributions to this event, and to the coordinators of all sessions that helped to promote the discussion around relevant issues about sustainable pathways for a better circular future.

On behalf of the Organising Committee,
Prof. Dr. Luís Bragança – University of Minho
Conference Chair



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University of Oporto, Portugal

Wim Debacker

VITO, Belgium



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Topic 1

Management tools and supportive mechanisms for circular applications and business models



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Capture and Control of Material Flows and Stocks in Urban Residential Buildings

Matthias A Heinrich and Werner Lang

Institute of Energy Efficient and Sustainable Design and Building, Technical University of Munich, Arcisstrasse 21, 80333 Munich, Germany

m.heinrich@tum.de

Abstract. To promote the circular economy and resource efficiency in the construction industry, information on material flows and stocks is needed. The work presented describes a holistic and dynamic model for the determination of material flows and stocks in urban areas triggered by the construction of residential buildings. In addition to the classification of material stocks (raw material cadastre for residential buildings), it is of central interest to identify future waste streams in order to forecast potential secondary raw materials, determine recovery strategies and control mechanisms. Furthermore, the supply of exploitable fractions must be matched with demand to identify the degree of self-sufficiency of selected areas in order to reduce the use of primary resources and necessary transports. The model developed in this work is validated on the basis of the district of Munich / Freiham, one of the largest urban developments in Germany. In this case study it has been shown that under certain conditions a self-sufficient supply of steel (from 2036 onwards) and recycled aggregate for the production of recycled concrete (from 2031 onwards) for residential building construction can be achieved.

Keywords: Urban mining, material flows, material stocks, residential buildings, urban systems, building materials



Existing databases as means to explore the potential of the building stock as material bank

B Gepts^{1,2}, E Meex¹, E Nuyts^{1,3}, E Knapen¹ and G Verbeeck¹

¹ Hasselt University, Faculty of Architecture and Arts, Agoralaan Building E, B-3590 Diepenbeek, Belgium

² Essencia, marketing agency specialized in construction, Beverlosesteenweg 114, B-3583 Paal, Belgium

³ PXL University College, Elfde-Liniestraat 24, B-3500 Hasselt, Belgium

bieke.gepts@uhasselt.be

Abstract. Awareness of the huge environmental impact of buildings has created more interest in resource efficiency and in the potential of circular economy. This is not only relevant for new buildings. Also the existing building stock represents a great amount of building materials, which could become available for reuse and recycling in the future. Currently, there is no database in Belgium that reflects the potential of existing buildings as material banks. Nevertheless, existing databases, e.g. the EPC (Energy Performance Certificate) database of the Flemish Energy Agency (VEA), contain valuable information on the material content in the existing building stock. Therefore, this paper explores the possibility of combining existing databases to reflect the (future) potential of the existing building stock as material bank. The two main databases under study are: 1) the EPC database of VEA which contains general building characteristics, such as building volume, building typology, floor area and information on the building envelope of more than 1 million buildings in the Flemish region and 2) the database of Essencia Marketing, a marketing agency specialized in the construction sector, which contains general building characteristics as well as geometrical and material data on almost 6000 new residential buildings spread all over Belgium (constructed between mid-2010 and mid-2017). The data in the databases are discussed and possible methods to combine data from both databases are explored.

Keywords: buildings as material banks, database extrapolation, estimation method, quantities of building materials



It's all about planning - pre-demolition audits to inform public calls for tender for enhanced resource management of building materials from deconstruction

Christina Ehlert¹, Carole Lacroix¹, Arno Biwer¹, Guillaume Dubois²

¹ Luxembourg Institute of Science and Technology, Environmental Policies, Environmental Research and Innovation, 41 Rue du Brill, 4422 Belvaux, Luxembourg

² Schroeder & Associés SA, 8 Rue des Girondins, 1626 Luxembourg, Luxembourg

christina.ehlert@list.lu

Abstract. Practical tools for the establishment of material inventories prior to demolition were developed to implement requirements of the Luxembourgish waste law. Pilot projects are accompanied to implement material inventories and encourage selective deconstruction to optimize material separation and resource exploitation. In one of the pilot projects, a test deconstruction of a representative unit of the building and a comprehensive material inventory served as basis for the public call for tender targeting the deconstruction. Both the material inventory of components and materials and the analysis of building contaminants during the early phase of the project allowed to define technical specifications and specific award criteria in the call for tender to reinforce state of the art methods for deconstruction and to channel resource management. An environmental assessment of the deconstruction of the building, based on the life-cycle assessment methodology, is currently undertaken to compare its environmental impacts versus those of a business-as-usual demolition scenario. The results will be used to further support the discussion with stakeholders how tender specifications can be adapted to reinforce environmental benefits of deconstruction and revalorization of materials and which steps have to be included in the planning process of deconstruction projects.

Keywords: selective deconstruction, pre-demolition audits, material inventories, green public procurement



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Improving the sustainability assessment method SBTool Urban – A critical review of construction and demolition waste (CDW) indicator

G Kamino¹, S Gomes² and L Bragança³

University of Minho, Department of Civil Engineering, Campus de Azurém, Guimarães 4800-048, Portugal

¹gustavokamino@gmail.com, ²gomesstefano@gmail.com, ³braganca@civil.uminho.pt

Abstract. Construction and demolition waste (CDW) are one of the biggest issues in waste generation that cities must deal. In EU, about 25% to 30% of all waste are derived from activities linked to construction and demolition. Such materials like concrete, bricks, wood, glass, metals, plastic and others, have high potential to be recycled or even reused in the process of urbanization. According to the Waste Framework Directive (2008/98/EC), by the year of 2020, a minimum of 70% (by weight) of CDW must be prepared for reuse, recycled or undergo other material recovery. Additionally, in Portugal, there is the Decree-Law n° 46/2008 that regulates the operations of CDW management, by prevention and re-utilization, and the process of collection, transport, storage, treatment, recovery, and disposal. Despite this, the level of CDW reuse varies greatly across the country. The SBTool-PT Urban Planning is an adaptation of the SBTool - international method of sustainability assessment - for use in urban projects into the Portuguese context. The methodology is divided into 3 dimensions (environmental, social and economic), each of them subdivided into categories (14 total) that have their own indicators. One of these indicators is called CDW, and it is related to how much of it is re-used and how it is treated. This study focuses on this indicator, reviewing his process of measurement and calculation, by comparing it with the existing rules, and others assessment methodologies. The findings of this study will validate its calculation process and indicate future developments.

Keywords: CDW, sustainability, assessment, urban, waste, indicator.



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Why invest in a reversible building design?

K WANG¹, S DE REGEL¹, W DEBACKER¹, J MICHIELS² and J VANDERHEYDEN²

¹ VITO (Flemish Institute for Technological Research), Boeretang 200, 2400 Mol, Belgium

² Groep Van Roey NV, Oostmalsesteenweg 261, 2310 Rijkevorsel, Belgium

ke.wang@vito.be

Abstract. Commercial buildings often have a much shorter service life compared to their technical life. Change in market needs is a leading reason for their premature demolition. “Reversible buildings”, which are capable of transformations in function and structure, are of high relevance for this building category. Reversibility starts with design. How can the investors be convinced to invest in a building with reversible design in the first place? The market value of commercial buildings is determined by the revenue they can generate through their service life. If the flexibility enabled by reversible buildings can be translated into higher market value, that could provide short-term incentives to invest in a reversible design. In this study, a quantitative financial model has been developed based on a real-life commercial office building in Flanders. The Net Present Value (NPV) of the building is calculated for both reversible design and conventional design. It was concluded that reversible design can deliver a more positive NPV compared to conventional designs, already with today’s available technologies and market conditions. The key value driver of reversible design is investment risk reduction. In particular, it reduces the risk of low return-on-investment or even loss due to early demolition. Stakeholder engagement (such as real estate investors and appraisal professionals) will be essential to validate such added value. Sensitivity analysis recommends future research and development of reversible buildings in reducing initial investment (design and build costs) and increasing use phase benefits.

Keywords: business case, financial model, reversible design, commercial building



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Can Material Passports lower financial barriers for structural steel re-use?

Anse Smeets¹, Ke Wang¹ and Michał P Drewniok²

¹ VITO (Flemish Institute for Technological Research), Boeretang 200, 2400 Mol, Belgium

² University of Cambridge, Department of Engineering, Trumpington Street, Cambridge, CB2 1PZ, UK

anse.smeets@vito.be

Abstract. The building and construction sector is responsible for more than half of global steel consumption. Recycling is common practice. Yet, this is an energy intensive process, even when using the best currently available technology. A strategy that avoids energy use for remelting and significantly reduces negative environmental impacts is re-use. Steel element re-use is technically feasible and economically attractive in certain cases. However, re-use rates in the UK remain low. Cost and timing are identified to be among the main barriers for re-use across the structural steel value chain. Re-used steel is estimated to be about 8-10% more expensive than new steel, taking into account all required reconditioning processes. This study investigates how data/information services like BAMB Material Passports can facilitate structural steel re-use in the UK by lowering financial barriers. It shows that relevant data has the potential of reducing costs in sourcing, testing, reconditioning and fabrication, ranging from 150-1000 £/t, depending on the re-use path followed (remanufacture or direct re-use of elements/structures). Key stakeholder groups are stockists and fabricators, which will be both the suppliers and customers of the data. It should be noted that data alone is not sufficient to overcome all barriers. Next to shortening or vertical integration of the supply chain, value redistribution across the chain can align incentives of different stakeholders. Regulations and perceptions (on quality) also play a key role. Finally, reversible design/design for dismantling can be a game changer in the transition towards more structural steel re-use, since it can significantly reduce deconstruction costs.

Keywords: business case, structural steel re-use, material passports, data.



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Fixotek: Implementing and Testing Urban Reuse and Repair Centers in Sweden

I Ordonez and S Hagy

¹ Department of Industrial and Materials Science, Chalmers University of Technology, 412 96, Gothenburg, Sweden

² Department of Architecture and Civil Engineering, Chalmers University of Technology, 412 96, Gothenburg, Sweden

shea.hagy@chalmers.se

Abstract. The Fixotek project is testing if dedicated community spaces in residential areas could help encourage residents to fix, lend, swap and recycle consumer products, thereby preventing waste generation and recovering resources locally. Four Fixoteks have been developed, in districts with different socioeconomic conditions in Gothenburg, offering regular open hours and events. The idea has been very well received by the community, with differences in how easily it has been taken up in some of the locations. Two of the Fixoteks engage local volunteers and have developed closer to local initiatives, while in the other two more efforts are needed to engage the local community. Non the less, the locations have allowed residents to reuse and repair beyond what was possible before. The project has been implemented with a multi-stakeholder consortium, which has given it a holistic approach to the implementation, but makes decision taking slow.

Keywords: Reuse Centers, Repair Centers, Knowledge Sharing, Circular Economy



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Circular planning: the case of Amsterdam

L Kootstra¹, E Keijzer¹, S Errami² and C Bogaards²

¹TNO Climate, Air & Sustainability, Post box 80015, 3508 TA Utrecht, The Netherlands

²EIB, Economic Institute for Construction and Housing, Koninginneweg 20, 1075 CX Amsterdam, The Netherlands

lucinda.kootstra@tno.nl

Abstract. Circularity is an increasingly often mentioned ambition of governments of various levels, yet the translation into concrete plans and policies is limited. The Metropole Region of Amsterdam (MRA) is a pioneer in this field, initiating a research for circular rebuilding of a neighbourhood in 2016 and the development of a roadmap for circular urban development in 2017. This year, the port of Amsterdam and the municipalities of Amsterdam and Haarlemmermeer together commissioned the analysis of the effects of circular construction on material flows, transport movements in the MRA, and land use in the harbour area. These effects were analysed by means of a building material model (BOB), combined with logistic models and construction and demolition forecasts of the Economic Institute for Construction and Housing (EIB). The results showed a mismatch between the supply of secondary building materials and the construction demand, ranging from factor 7 (more demand than supply) in the coming years to a factor 4 in the period 2041-2050. An evaluation of circular construction concepts revealed high potential for the reuse of structural elements, leading to a 20% decrease of material need for new buildings, 21% less transport kilometres and 20% less land use. The concept of demountable constructions was calculated to have no impact on total material use between 2018-2050, while increasing the transport kilometres and land use. Several concrete recommendations were given, for example on the interaction between logistics and land use and need for a more in-depth comparison of a variety of circular strategies.

Keywords: construction and demolition waste, circular economy, built environment, urban planning, urban metabolism, transformation strategies



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Decarbonizing the cement and concrete sector: integration of the full value chain to reach net zero emissions in Europe

A.Favier^{1,3}, K. Scrivener² and G. Habert¹

¹Chair of Sustainable Construction, ETH Zurich, Switzerland

²Laboratory of Construction Materials, EPF Lausanne, Switzerland

³ faviera@ethz.ch

Abstract. The construction sector represents a major share of greenhouse gas emissions related to industrial activities. The sector is mainly driven by one main material; cement. Most of the building stock in use in Europe today will last until 2050, meaning most building stock that will standing in 2050 has already been built. The same applies for the needed production capacity infrastructure in Europe. When opting for decarbonising the sector, this will have to consider looking at decarbonisation technologies and pathways. The objective of this study is to propose scenarios that can significantly reduce emissions by reducing the necessary investment. In order to achieve a significant reduction, the deployment of a major investment in carbon capture and storage is often the only way envisaged. We show that it is possible to achieve the objective of “2 degrees” of the Paris Agreement by involving all stakeholders and enhancing the digitalization and circular approach. We are also discussing the incentives that must be taken at European or national level in order to achieve the decarbonisation of the sector.

Keywords: policies, decarbonisation, scenarios, integrated value chain, circular economy



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Mapping a Resource-Based Design Workflow to Activate a Circular Economy in Building Design and Construction

Ahmed K. Ali, Ph.D.

Texas A&M University, Texas, United States

ahali@tamu.edu

Abstract. This paper introduces an innovative restructuring of the traditional Design-Bid-Build (DBB) project delivery method in the AEC industry, that enables the creative reuse of building materials and components. The restructuring intends to transform the DBB method into an Integrated Project Delivery approach by including building materials reuse stakeholders in the early phases of the design process. The model was developed by capturing the critical expert knowledge using a Delphi research protocol and the Business Process Modelling and Notation standards (BPMN). The proposed business process workflows are integrated with the BIM Project Execution Planning Guide. The study also identifies the critical decision nodes within the proposed process maps and suggests a decision-support framework that aid architects and building professionals when integrating sustainable building solutions regarding reusable building materials and components. The Knowledge Capturing Process (KCP) utilized in this study was applied using a qualitative method and a modified Delphi research protocol with the research participants. Triangulation with literature and built case studies were checked and the results were integrated in an illustrated detailed blueprint set of BPMN workflow maps, which were then used to reach consensus with the industry stakeholders research participants.

Keywords: Circular Economy, Process mapping, Resource-Based Design, BPMN, Materials Marketplace



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Green Supply Chain Management in the Construction Industry: A literature review

G L F Benachio¹, M C D Freitas¹ and S F Tavares¹

¹Department of Civil Construction Engineering, Federal University of Paraná, Centro Politécnico, Curitiba, PR, zip code 81531-980, Brazil.

gabrielfbenachio@gmail.com

Abstract. The Construction Industry is considered one of the biggest waste generators in the world, and to tackle this problem, the concept of environmental sustainability in the construction sector can act in different areas, as waste reduction, carbon emissions reduction, better selection of materials and others. These areas involve several stakeholders during a life cycle of a project, therefore the implementation of a Green Supply Chain Management (GSCM) can help the sustainability aspect of constructions. The concept of GSCM has been already implemented with success in other industries, however the construction industry has its particularities that demands a specific methodology of implementation of these concepts, taking in consideration the differences between the sectors. To address this issue, a systematic literature review was conducted to find how the concept of GSCM can be implemented in the construction industry. This review covered 26 peer reviewed or proceeding papers in the last 10 years about the use of GSCM practices in the construction sector. The results were divided into four distinct areas of research: supply chain relationships, market competitiveness, life cycle and waste management. The biggest findings from this research is that to obtain better sustainable results, these practices must be implemented in the full life cycle of the construction, mainly on the design phase, when the selection of materials happen. Also, most studies found that government incentives are needed to make it more viable for companies to implement GSCM into their operations.

Keywords: green supply chain management, construction industry, construction life cycle, waste reduction, sustainable construction.



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Topic 2

Strategies, tools and systems to promote circular economy in buildings



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Assessing buildings' adaptability at early design stages

Joana B Andrade¹ and Luís Bragança¹

¹ University of Minho, Centre for Territory, Environment and Construction, Guimarães, Portugal

joana.andrade@civil.uminho.pt

Abstract. Buildings should be able to change and be adaptable according to newer requirements; otherwise, premature demolition can occur. The adaptability or lack of it in buildings affects the environment, society, and economy. If existing buildings are better-taken care of and re-used, their life expectancy extends, and fewer resources are used. Flexible and adaptable buildings enable not just recycling and reusing existing buildings, they allow upcycle of these buildings into urban regeneration projects. Additionally, buildings' early design phases are critical for their sustainability. If adequate measures are taken at these stages, sustainability concerns are overcome in a much easier, faster, economical, and efficient way. This paper describes the importance of addressing sustainable criteria during early design, with special attention to adaptability criteria. Based on the concept of open building and aiming to promote ease of dismantling and adjustability, the evaluation proposed comprises two sub-indicators: flexibility provision and (ii) adaptability capacity. The first accounts for design strategies to accommodate change, through the transformation capacity. The second aims to quantify the availability of space to be changed and adapted according to the occupiers' needs, following the open building concept by accounting the built area available to be transformed. By considering these aspects at the early design, it is possible to obtain buildings that live longer with lower environmental impact. Higher transformation ability means buildings can easier accommodate new requirements; greater disassembly potential can be achieved enabling replacement, reuse or recycling for the buildings' materials and components, thus promoting buildings' sustainability and resilience.

Keywords: Sustainability, early design, adaptability, flexibility, buildings



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Cradle-to-Cradle in Building Services

K Jurkait¹ and J Stiglmaier²

¹ Arup Deutschland GmbH, Speditionsstraße 9, 40221 Düsseldorf, Germany

² Freelance Researcher, Jagowstrasse 12, 10555 Berlin, Germany

E:Mail: karsten.jurkait@arup.com and johannes.stiglmaier@posteo.de

Abstract. While the concept of Cradle to Cradle (C2C) is reasonably covered in building construction and finishes, it is rather ‘uncharted area’ in the building services – MEP engineers struggle to define what a C2C design for their discipline could look like, and only a few manufacturers have ventured into offering C2C-certified or -inspired products. The authors set out to change this by providing a comprehensive guidance for MEP engineers on how to design a C2C building in their discipline; they cover design criteria, system selection, system sizing, design for de-construction, and material / product selection for all of the main MEP disciplines (water and drainage, heating, cooling, ventilation, electrical installations, IT & data, vertical transport, fire protection, controls). In addition, the document sets out a number of criteria by which the ‘C2C aptness’ of a design can be measured, providing minimum criteria and a specific ‘C2C vision’ for each discipline; these criteria could form the basis for a future assessment tool for C2C buildings.

Keywords: C2C, guideline, criteria, MEP, building services



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Superuse and upcycling *through* design: approaches and tools

P Altamura and S Baiani

Department Planning, Design and Technology of Architecture (PDTA), “Sapienza” University of Rome, Via Flaminia 72, Rome, 00196, Italy

paola.altamura@uniroma1.it

Abstract. In Italy, first EU Country to have made Green Public Procurement (GPP) one hundred per cent mandatory, the recovery of construction and demolition (C&D) waste, the use of recycled materials and design for disassembly have been mandatory in public building projects since 2015. Nevertheless, in Italy, the renovation and substitution of existing buildings, not conceived to be easily deconstructed, generates 53 million tons/year of C&D waste (80% mixed inert waste) while the recovery rate is limited. Since 2012, the research team has been engaged on the increase of resource productivity in the building sector with two focuses. With the Atlante Inerti Project, co-funded by the EIT Climate-KIC, the team has experimented the upcycling of aggregates from the recovery of inert waste in prefab concrete design products for the building and outdoor furniture industries, testing innovative production techniques (large scale additive 3D printing). Simultaneously, the main research focus is the integration of adaptive reuse of buildings with superuse of components and materials: strategies inherent to the preservative Italian approach, complementary and preferable to recycling according to the EU Waste Hierarchy, still underestimated by the Italian legislation. The team has experimented the process of scouting construction/industrial waste materials at the local scale, with the application of the harvest map tool, to complex urban districts in Rome, in order to demonstrate how superuse and upcycling can represent reliable technical options widely replicable on a supply chain scale for increasing resource productivity in the building sector.

Keywords: superuse, upcycling, harvest map, recycled aggregates, design for disassembly, Italy.



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REBUILD: Regenerative Buildings and Construction systems for a Circular Economy

Atta Ajayabi¹, Han-Mei Chen², Kan Zhou³, Peter Hopkinson^{1,4}, Yong Wang² and Dennis Lam³

¹Exeter Business School, University of Exeter, United Kingdom

²School of Mechanical, Aerospace and Civil Engineering, University of Manchester, United Kingdom

³School of Engineering, University of Bradford, United Kingdom

⁴Author to whom any correspondence should be addressed

p.hopkinson@exeter.ac.uk

Abstract. Buildings and construction have been identified as having one of the greatest potential for value creation and capture from the application of circular economy principles. To achieve this requires a fundamental transformation in the recovery, remanufacture and re-use of end of service life structural products such as steel, bricks, concrete which make up the largest proportion of materials. At the same time these products must be re-used in new buildings and infrastructure designed for subsequent deconstruction and disassembly. REBUILD is a 3 year way UK research project to address this challenge. Initial findings on quantifying the material intensity of buildings (stock and flow assessment) are presented based on one of our case study cities. Results from new techniques to separate and reclaim bricks from cement mortar shows technical feasibility and ability to retain structural performance. Details on the next stage of scaling this work and techniques for separating and reclaiming steel and concrete are briefly described. Subsequent stage of life cycle assessment, value stream mapping and creating products for new forms of circular building and construction systems are also described. The paper concludes that whilst there are considerable challenges in reclaiming structural products that re-designed circular building and construction system could transform the value of end of service life buildings and the offers new opportunities for circular innovation and the circulation of materials and products at their highest value for the longest period.

Keywords: Circular Economy, Buildings, Stocks, Structural products, Re-use



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Demolition versus Transformation, “mortality of building structures” depending on their technical building properties

R Blok¹ and P M Teuffel¹

¹ Department for the Built Environment, Eindhoven University of Technology, Netherlands

r.blok@tue.nl

Abstract. This paper describes the assessment of 60 multi-story buildings in the Netherlands, the followed approach and the main results. The 60 buildings have been assessed on their technical building properties to see which building parameters could be influential on the probability of an elongated Service Life for the building structure. The buildings, (of which 40 buildings have been given a “Second Life” through Transformation and 20 buildings have been demolished) have been assessed, initially on 64 different parameters. The number of parameters has then been reduced to 20, more or less influential parameters. A “quick scan” of building structures has been derived from these parameters. This quick scan uses an aggregated value expressing the re-use potential in a single adaptability/flexibility score. In a similar approach as often is used in medical survival analysis, the “Mortality of Buildings” have been calculated for different Flexibility Scores. Further elaboration will make it possible to assess building structures and then give an indication on their probability for (future) transformation. This is important, not only to assess our existing building stock but also to improve elongated Service Live’s for new buildings. By optimizing the Service Life of buildings structures, negative material impacts can be further reduced and the Re-use and Transformation on building level, rather than on material level, can be improved. More realistic Service Life Estimations will make comparisons of different solutions with different levels of Flexibility much more feasible.

Keywords: Service Life, Circular Building, Mortality, Reuse of building Structures.



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Measuring reuse potential and waste creation of wooden façades

Renata Androsevic^{1,3}, Elma Durmisevic^{1,2} and Maurizio Brocato³

¹ Sarajevo Green Design Foundation, 71000 Sarajevo, Bosnia and Herzegovina

² University of Twente, Department of Design Production and Management, Faculty of Engineering Technology, 7522NB Enschede, The Netherlands

³ Paris-Est University, GSA Laboratory – Geometry-Structure-Architecture, National Graduate School of Architecture Paris-Malaquais, 75006 Paris, France

¹ renata@sarajevogreendesign.com

² e.durmisevic@utwente.nl

³ maurizio.brocato@paris-malaquais.archi.fr

Abstract. Building industry produces 38% of total waste and 40% of total CO₂ emissions and uses 50% of all natural resources (EIB 2015). Taking this into account, decreasing the waste from any part of the building will help reducing total waste during the building life span. In this paper we will showcase the indicators for measuring of the waste creation from building façade upon transformation. Façade should follow transformations of the building without waste creation or without causing large financial or environmental impacts. The planning of building industry waste management begins in the design phase, as the waste prevention is the preferred option, and reuse, recycling, and other types of recovery are a second option according to EC. (Directive 2008/98/EC 2008). This paper will show the comparison between the conventional façade system made of wood and the prototype of GDC (Green Design Center) reversible façade system addressing the waste elimination. The reversible façade has been designed using design protocol for designing of low waste façade system for the future circular construction industry developed by Durmisevic 2017 as part of EU BAMB project. The protocol contains a rulebook with tools to measure the waste production during the transformation of building façade. This strategy aims to extend functional lifespan of external envelope of buildings and its components and materials, which would reduce the amount of consumed resources and generated waste during the lifespan of the façade. The contribution of this paper will also be in the field of connections in the building industry, as the importance of type of connections in the façade system with high reuse potential is noticeable.

Keywords: Reuse Potential, Transformation, Reversible Building Design, Building Waste Management, Environmental impact.



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Proposal of a building material passport and its application feasibility to the wood frame constructive system in Brazil

M R Munaro¹, A C Fischer¹, N C Azevedo¹ and S F Tavares¹

¹ Department of Civil Construction Engineering, Federal University of Paraná, Centro Politécnico, Jardim das Américas, mail box 19.011, zip code 81531-980, Curitiba - PR, Brazil

munaro.mayara@gmail.com

Abstract. Implementing practices for a circular economy transforms the way companies do business. Obtaining and processing systematized and optimized information facilitates decision making in order to innovate, create value and adopt measures to promote energy efficiency and sustainability in construction. Building Materials Passports (BMPs) are tools for inserting circular economy in buildings. They can be crucial in managing and providing information to stakeholders in industry value chains, with the aim of promoting the construction of more sustainable and resilient cities, where materials are identified in a database, removed and reused in order to maintain, recover or even increase value and useful life. This paper presents a proposal of a BMP applied to the wood frame system in Brazil, introducing the following guidelines: general information, safety, sustainability, use and operation, assembling directions, reuse and product service history. A case study was developed in a Brazilian company in order to test the application feasibility of the tool to the system. There were some barriers found in the development of the BMP regarding LCA data, as well as the end of life information of the material. This attempt to implement the BMP encourages practices of circular economy in the construction industry and, associated with the expanding use of wood frame in Brazil, contributes to flexible and renewable buildings. In addition, the main challenges for the introduction of BMP are discussed, emphasizing the need for joint action based on political initiatives and regulations that allow and facilitate circular practices in construction.

Keywords: building material passport, wood frame, circular economy, bank of materials, built environment.



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How to design buildings with Life Cycle Assessment by accounting for the material flows in refurbishment

R Castro^{1,2} and P Pasanen¹

¹Bionova Ltd., Helsinki, Finland

²rodrigo.castro@bionova.fi

Abstract. This paper will analyse and present a detailed overview of ways to design buildings in a circular economy by using Building Life Cycle Assessment and will be based on hundreds of case studies and years of practical experience in the building sector. The theoretical framework is defined by Life Cycle Assessment methodology and indicators and will focus on why performing an LCA is a necessary step to assess sustainable material choices and make design choices that ensure circularity and lower carbon emissions and other environmental impacts through the whole lifecycle of the building. Moreover, the focus will be on integrating Life Cycle Metrics with BIM and other design tools in order to enable making choices in the design stage and taking better decisions on the basis of alternative design suggestions. Finally, the paper will propose actionable, realistic strategies to perform carbon footprint and other LCA-related calculations in a fast, reliable, and cost-effective way. The paper will cover the whole lifecycle of a building, with a strong emphasis on disposal and reuse in a cradle to cradle perspective.

Keywords: life-cycle assessment, low-carbon design, decarbonization, circularity.



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City as Material Bank – Constructing with Reuse in Musicon, Roskilde

Anne-Mette Manelius, Søren Nielsen, Jan Schipull Kauschen

Vandkunsten Architects, 14 Krudtløbsvej, DK-1439 Copenhagen K

am@vandkunst.dk

Abstract. Roughly 90% of building materials for an 880sqm construction project were made from reused material components, existing structures and old shipping containers, and designed for disassembly. The paper is a case study that introduces the implementation of reuse in the project, a recently completed transformation of *Hal7*, a former industrial building. Two other ongoing projects are also introduced. These have not yet been completed but contain reused materials at the current stages, a series of *Recycling Centers* and the housing project *Indfaldet*. All three projects are part of the urban development of a former industrial area. Selected themes and courses of events are summarized from interviews with the project architects to list particular conditions in these cases with successfully implemented circular ambitions. End-user engagement is introduced to highlight a method to prioritise when maintaining a low budget. It is the argument that the city, represented by an individual employee, plays a central role to catalyse the implementation of reused materials and circular economy in construction. The city can guide to local resources to be mined, as well as provide the facilities and organization to handle the logistical issues when resources go from being waste to be built-in.

Keywords: Reuse, implementation, reversibility, collaboration, architecture, construction



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Woodscraper - highrise according to the circular economy

J Finkbeiner¹, K Günter¹, J Meissner¹, C Merz², F Stahl³, D Kruse⁴ and M Ernst⁵

¹ Partner und Partner Architekten – Reichenbergerstr. 124D/ D-10999 Berlin

² Merz kley partner ZT GmbH, Sägerstraße 4/ A-6850 Dornbirn

³ IFB Ingenieure GmbH, Wielandstraße 2/75385 Bad Teinach-Zavelstein

⁴ Dehne, Kruse GmbH & Co. KG, Major-Hirst-Straße 5-11/ 38442 Wolfsburg

⁵ Hochschule Ostwestfalen-Lippe (HS-OWL) Emilienstraße 453/2756 Detmold

mail@partnerundpartner.com

Abstract. shortages, climate change and population growth with associated urbanization pose immense challenges to the construction industry. The question of sustainable building construction raises the need for innovative concepts, which address the increasing scarcity of raw materials, energy efficiency as well as space efficient construction to protect our climate. strategies become more and more the focus also of social interest So far, buildings are usually built and operated according to the take-make-waste principle[1]. This means that finite resources are no longer available for new uses through downcycling processes. The Woodscraper examines by way of example how far fully circulatable buildings are already possible today. Therefore the concept of Woodscrapers is based on the principles of Cradle-to-Cradle, Circular Economy and AktivPlus. As part of the “Deutsche Bundestiftung Umwelt (DBU)” -funded project, strategies for circular construction have been developed and implemented in the project through an integrated planning process, involving the competences of a planning-team, the early involvement of the authorities, as well as specialist planners and manufacturers. Synergies between construction, materials and building services have been identified and implemented meaningfully. A life cycle analysis ran in parallel, to quantify those potentials. The Woodscraper visualizes this added value in the construction and makes it perceptible through comprehensive lifecycle analysis during operation over its entire life cycle.

Keywords: Circular Economy-Principles, Building as Material Bank, design for disassembly, resource-positive approach, BIM/Lifecycle analysis.



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Infozentrale auf dem Vollgut – Circular Construction for a Post-Fossil Society

E Roswag-Klinge¹, N Pawlicki¹, M Crabbe¹ and S Sommer^{1,2}

¹ Natural Building Lab, Technische Universität Berlin, Institut für Architektur, Sek. A44, Straße des 17. Juni 152, 10623 Berlin, Germany

² Building Cycle Collective, Infozentrale auf dem Vollgut, Am Südhaus 3, 12053 Berlin, Germany

crabbe@tu-berlin.de

Abstract. The “Infozentrale auf dem Vollgut” was designed and realised by a group of 36 students as part of the BUILDinG CYCLE design studio from the Natural Building Lab at the Technische Universität Berlin. In co-operation with the research project RE4 [1], a building embodying circular construction principles was realised from waste materials as a DesignBuild project, offering an answer to questions relating to resource-positive construction in an urban context and embodies a new method of architectural production for a post-consumer society. In the opening weeks of the project the student groups undertook a material research, where innovative low-tech constructive elements were created using a wide range of waste materials. Through this research the groups established a network, through which they were able to source larger amounts of the waste materials used for the building – recovered timber and cardboard. The load bearing structure of the building is formed from timber recovered from local demolition sites and a dismantled architectural installation from the International Garden Festival 2017, thus providing a second usage cycle for this valuable resource. The 5.5m x 7.0m roof structure is formed by a pre-stressed grid of layered and interlocking re-used timber beams with reversible connections designed for disassembly. For the wall elements an experimental system was developed utilising stacked upcycled cardboard fruit boxes filled with shredded paper as insulation and covered with recovered large format posters and plot drawings – common waste materials within the architecture faculty. The project embodies circular construction principles and serves as a prototype for a LowTech post-fossil architecture based on the realities of resource scarcity and climate change.

Keywords: Community based trans-disciplinary design, DesignBuild, Building from Waste, Circular Construction, Timber, LowTech



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Rebeauty – Artistic Strategies for Repurposing Material Components

Anne-Mette Manelius, Søren Nielsen and Jan Schipull Kauschen
Vandkunsten Architects, 14 Krudtløbsvej, DK-14439 Copenhagen K

am@vandkunst.dk

Abstract. A cross-disciplinary method has been developed to transform discarded material components to new designs and applications. It is the thesis that discarded material resources in construction represent a triple capital related to energy, economy, and culture and is the aim of the method to support decision-makers and stakeholders with data and physical prototypes in the transition to Circular Construction. The method has been applied to produce 19 full-scale material prototypes designed for disassembly and includes six repeatable steps: Market survey of volumes and availability of components, ideation and analysis matrix, material concept development, material and process prototyping, assessment in terms of 9 criteria representing market, culture, technicality, and environment, and finally dissemination or implementation in the market. For five cases, tools, times and prototyping procedures were documented in Flow-diagrams as the foundation for the assessment of concepts in regard to economy and energy. Results support the hypothesis as LCAs show a lower potential environmental impact for concepts for brick, glass, metal, and wood but not for concrete; architectural visualizations and striking 1:1 prototypes have directly inspired the construction sector and users to further development and implementation; commissions confirm the cultural and commercial potential. The concept of Rebeauty is introduced to summarize the artistic strategies.

Keywords: Architecture, Reuse, LCA, Reversible construction, Beauty, Collaboration



A new Evaluation Method for the End-of-life Phase of Buildings

H. Figl¹, C. Thurner¹, F. Dolezal¹, P. Schneider-Marin² and I. Nemeth³

¹ IBO – Österreichisches Institut für Bauen und Ökologie GmbH, Alserbachstraße 5/8, 1090 Vienna, Austria;

² Institute for energy efficient and sustainable planning and building, Ingenieur fakultät Bau Geo Umwelt TUM, Arcisstraße 21, 80333 Munich, Germany;

³ Hochschule Ansbach, Nachhaltigkeit - Schwerpunkt Bauwesen, Residenzstraße 8, 91522 Ansbach, Germany;

hildegund.figl@ibo.at

caroline.thurner@ibo.at

franz.dolezal@ibo.at

patricia.schneider@tum.de

isabell.nemeth@hs-ansbach.de

Abstract. Waste from building and construction sector makes up for about half of the total waste. In order to reduce waste, future buildings shall be constructed in a way that they leave little to no waste behind at the end of their life time. In this work a new method to characterize buildings with respect to their deconstruction and recycling potential at the end of their life time is described. An index of recovery is deduced, which enables planners to optimize buildings in the design phase. The new assessment method provides a science-based automated system. It is based on an inventory of building components, which are virtually disassembled into “minimal blocks”, i.e. the smallest possible entities which cannot be further disassembled by economically reasonable efforts. For all possible minimal blocks the algorithm provides tabularised scores, depending on current waste-treatment practice including the efforts required for separation and processing. Additionally, waste-treatment methods in development, including their technological stage of maturity and economic readiness for market are considered. Each building is decomposed into minimal blocks rated by this scheme. All rates are then weighted by the thickness of the respective minimal block and aggregated to a building indicator taking into account the area of the components. The new method promises to deliver selective results, which can be applied for the optimisation of building components. In a follow-up project the method shall be implemented as criterion “disassembly, separation and recycling” (4.1.4) in the BNB (Bewertungssystem Nachhaltiges Bauen) assessment system for the sustainability of buildings.



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Topic 3

Design for adaptability, reconfiguration and high reuse potential



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The reuse of load-bearing components

Jan Brütting¹, Catherine De Wolf¹ and Corentin Fivet¹

¹ Structural Xploration Lab, Swiss Federal Institute of Technology Lausanne (EPFL), smart living lab, Passage du Cardinal 13b, 1700 Fribourg, Switzerland

jan.bruetting@epfl.ch (J Brütting)

Abstract. Load-bearing systems of buildings are poorly valued when they reach functional obsolescence. Still, they contribute the most to the material weight and embodied impacts of buildings and infrastructures. The reuse of structural components therefore offers great potential to save materials, energy and resources. While historic and contemporary projects highlight the environmental, time or cost benefits of building with reclaimed elements, many technological challenges remain. This paper gives an overview of buildings that efficiently reuse structural components as well as a review of current research efforts addressing structural reuse. The first case study is the design process of an elastic gridshell made from reclaimed skis. This project demonstrates the potential of ensuring structural performance while working with uncharacterized and heterogeneous materials. In general, designing structures from a stock of reclaimed elements entails reversing the conventional structural design process. The synthesis of structures has to follow the availability of elements and their mechanical and geometric properties. Developed tools that facilitate such design from reused elements while minimizing embodied environmental impacts are presented in this paper. A second case study demonstrates the relevance of such tools through a conceptual train station roof made from electric pylon elements. Lastly, some key challenges related to the design of structural systems from reused elements are presented. These research initiatives constitute a first step to understand and support the design of load-bearing systems from reused elements and hence to bring the construction industry closer to circular economy.

Keywords: Building structures, load-bearing systems, component reuse, circular economy, case studies, structural design, optimization



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Design of composite flooring systems for reuse

M P Nijgh and M Veljkovic

Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands

M.P.Nijgh@tudelft.nl

Abstract. Composite floor systems are frequently used for high-rise buildings and multi-storey car park buildings, mainly because of the competitive combination of the steel beam and the concrete deck. Traditionally, composite beams are cast in-situ and shear interaction between the concrete and steel beam is provided by welded headed studs. The application of welded headed studs prevents the non-destructive separation of the composite beam, which leads to a very low scoring in the sustainable assessment in terms of the reuse of structural components. An alternative to welded headed studs are bolted shear connectors, which allow for demountability and reusability of a (prefabricated) composite floor system. A key challenge for demountable and reusable composite beams consisting of prefabricated elements is to provide sufficient tolerances to allow for easy execution and demounting, but also to achieve a stiff and strong shear connection under live loads. The required tolerances can, for instance, be obtained by using large bolt-to-hole clearances. The, at first glance, contradictory requirement of a large hole clearance in the execution phase and high stiffness under live loading conditions was solved by using injection bolts. The goal of this paper is to demonstrate how the demountable and composite structures fit in the circular economy framework, and to show that such a demountable and reusable structure was successfully erected and demounted under laboratory conditions. In addition, a cost assessment will be addressed using a simple methodology based on estimated service life (ESL) factors to estimate the annual environmental costs of a composite floor system.

Keywords: Composite structure; reusability; demountability; sustainability, shear connector; resin-injected bolted connection



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Adaptable skin systems

Omar Zalloum

Chalmers University of Technology, Department of Architecture and Civil Engineering, Gothenburg, Sweden

omar.zalloum.93@gmail.com

Abstract. Most buildings are continuously changing. Renovation, layout modifications, and other physical changes are usually complicated processes associated with losses in materials and assets. The building industry is responsible for a vast amount of the global waste. Therefore a shift towards circular solutions is crucial to minimise this negative environmental impact. This paper is based on the master thesis, *A Tale of Layers*, completed in spring 2018 at Chalmers University of Technology, and provides further discussion on the results. The thesis developed a set of design strategies for adaptable skin systems, and focused on a design proposal of 'the connection' which is a reversible connection system between the structure and the skin of a building. The aim of 'the connection' is to increase the building's adaptability and the circular use of materials. It allows transformations in the skin with minimal effects on the structural system to preserve its quality and value. The design strategies and 'the connection' can be applied in different contexts, while the skin systems alternatives presented are specific for the extension of Snäckeback School in Ronneby, Sweden. Separating the different building systems and following standard dimensions and modular systems make buildings easy to repair and adjust according to the changing demands and increase the possibility for materials reuse. However, they can limit the buildings' shape and form. Creating skins with variable U-values is an additional benefit of separation, allowing the skin to be one factor that contributes to optimising the building energy performance in some climates.

Keywords: adaptability, skin, systems separation, reversible, circular economy, variable U-value.



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Dismountable Flooring Systems for Multiple Use

Christoph Odenbreit and András Kozma

University of Luxembourg, ArcelorMittal Chair of Steel and Façade Engineering,
Luxembourg-Kirchberg, Luxembourg

christoph.odenbreit@uni.lu

Abstract. Steel shapes our modern world as an integral part of the global construction economy. In the last decades, the sustainability of steel grew and turned from a linear to a circular business, where the material is fully recovered and recycled after use. The RFCS Research Project “REDUCE” of the European Commission goes one step beyond the mere material recycling and investigates, how the circular economy’s philosophy can be used to reduce the carbon footprint furthermore. On that basis, one target of the research was to develop basic modular and standardised structural load bearing elements which can be adapted in the building or assembled, properly disassembled and partly or entirely be reused again in a subsequent building. This paper presents the respective research results of demountable flooring- and beam systems: 15 large scale push-out tests and two large scale composite beam tests as well as numerous finite element simulations with ABAQUS have been performed at the Laboratory of the ArcelorMittal Chair of Steel and Façade Engineering. The suitability for dis- and re-assembly as well as the strength, stiffness, slip capacity and ductility have been determined. The investigated systems included pre-stressed and epoxy injected systems, as well as solid slabs and composite slabs with profiled decking. The results showed sometimes higher resistances and smaller displacement capacities than conventional systems. The numerical simulation results were presented as well as the results of the laboratory tests. First assessments were given about the respective consequences and about how these consequences could be considered in the layout of future steel composite structures.

Keywords: Demountable flooring systems, composite structures, shear connectors, experimental study, finite element simulation



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Energy retrofit scenarios: material flows and circularity

E Gobbo¹, S Trachte¹ and C Massart¹

¹Architecture et Climat, Faculty of Architecture, Architectural Engineering, Urban Planning (LOCI), Université Catholique de Louvain (UCL), Place du Levant 1 L05.05.04, Louvain-la-Neuve, Belgium

emilie.gobbo@uclouvain.be

Abstract. Cities are fast growing and are becoming more and more dependent on external services and supplies to meet their demands. In this context, the building industry can play a major role to reach European and regional targets of low-energy construction and circular design, particularly if considering the need of improving the energy standards and performance of the existing stock. On these premises, this paper presents the findings from recent research and discusses upcoming challenges, in particular: what are the consequences of retrofit operations on material flows, and their impact on circularity and low carbon objectives? In other words, which energy retrofit strategies are being implemented in buildings that could contribute to the production of building' waste or secondary resources today, but also in the future? The purpose of this paper is to analyse the impact of different retrofitting scenarios on the energy performance of material flows. These scenarios can directly influence the nature and quantity of the materials used (inflows) and discarded (outflows) by upgrading or renewing the existing building stock. They can also lead to different environmental impacts and vary the embodied potential (through reuse or recycling) of resources. The analysis focuses on selected case studies representative of the housing stock in Brussels (Belgium). The overall objective is to inform, sensitize, and lead various stakeholders to responsible and conscious choices when retrofitting a building by adding concerns of resources efficiency while focusing on reducing energy demands.

Keywords: energy retrofit scenarios, material flows analysis, urban mining, circular economy, resource efficiency



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The architecture of reuse

Mark Gorgolewski

Ryerson University, Toronto, Canada

mgorgo@ryerson.ca

Abstract. The starting point for designers in a circular system will often be identifying an inventory of potential second use materials and components. They then develop their design ideas around the tectonic characteristics of the materials. This can be seen as a restriction or a positive inspiration for creating meaningful ecological architecture suitable for the circular economy. Since availability of reclaimed materials and components is currently less predictable, flexibility in design and tolerance to alternatives by the project team and owner are important. The building design community needs to review and adapt conventional practices to increase demand for, and effectively integrate, reclaimed materials and components. This paper considers the architectural process implications and opportunities from reuse. As design teams adopt strategies to increase use of reclaimed materials and components, it is likely that the standard project management stages used by design teams may need to be adapted to facilitate a process better suited to circular strategies. New partnerships need to be formed, and new tools developed. Learning from existing projects a series of strategies are reviewed.

Keywords: Reuse, circular design, closed-loop architecture, resource efficiency, sustainable design.



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Design of Load-Bearing Systems for Open-Ended Downstream Reuse

Corentin Fivet

Structural Xploration Lab, EPFL, Switzerland

corentin.fivet@epfl.ch

Abstract. This paper discusses the design of load-bearing systems for buildings with regard to their current lack of open-ended reusability. The reason for dismantling load-bearing systems today tends to be less related to material degradation than to a loss of functional fit with an evolving building program. It can therefore be expected that load-bearing components are reused in other systems, which extends their service life and avoids the manufacture of other components. Common design strategies to ensure the actual reusability of components consist in guaranteeing that the assembly is durable, versatile, modular, reversible, and adaptable. This paper (a) reviews these features, (b) illustrates by means of case studies that, without minimum threshold, they do not guarantee the repurpose of components into different, unforeseen systems, and (c) describes opportunities and challenges related to the design of more open-ended sets of load-bearing elements, i.e. sets whose element types allow for a substantially large number of diverse assemblies, in terms of floor plans, spans, loads, support layouts, connection types, architectural language, and integration with other building systems.

Keywords: load-bearing system, reuse, design-for-disassembly, circular economy



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From Temporary to Permanent; A Circular Approach for Post-disaster Housing Reconstruction

R Askar ^{1,3}, A L Rodrigues ², L Bragança ¹ and D Pinheiro ¹

¹ Centre of Territory, Environment and Construction, University of Minho, Guimarães, Portugal

² School of Architecture, University of Minho, Guimarães, Portugal

³ rand.askar@hotmail.com

Abstract. Housing crisis is an evitable outcome of most of post-disaster scenarios due to the massive destruction they usually produce. Therefore, the reconstruction process and particularly in terms of housing is considered as an evident prerequisite in handling disasters' aftermaths. Temporary accommodation alternatives have been widely assumed in a variety of post-disasters cases as a primary step of the reconstruction process. Yet despite this fact, they have been broadly criticized for being unsustainable and resource-consuming. This matter can negatively affect the recovery process of the disaster-affected communities at different levels. Those effects can be even more serious when hitting developing countries, turning them more vulnerable. Still, there is an insistent need to find a rapid action to accommodate the disaster-affected people following their displacement while reconstructing their permanent homes. This paper proposes an incremental housing strategy which could form a key part of a proactive strategy that has not been offered by conventional methods. It provides time-efficient housing construction approaches while responding to the immediate large-scale interventions. Likewise, it bridges over the two phases of temporary and permanent housing in one integral transformable process that relies on efficiency and adaptability. The paper also discusses the sustainability aspects of executing the incremental strategy and examines its qualitative outcomes that contribute to a circular built environment in disaster-disrupted communities.

Keywords: Temporary accommodation, post-disaster reconstruction, incremental housing strategy, resources efficiency, adaptability.



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

Urszula Kozminska

Aarhus School of Architecture, Norreport 20, 8000 Aarhus C, Denmark

uk@aarch.dk

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, dismantlable 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



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A workflow for retrofitting façade systems for daylight, comfortable and energy efficient buildings

Bruno Bueno and Fatma Özceylan

Fraunhofer Institute for Solar Energy Systems ISE, Heidenhofstrasse 2, 79110 Freiburg DE

bruno.bueno@ise.fraunhofer.de

Abstract. The building façade not only provides the aesthetic signature of a building, but also important functions, such as daylight provision, glare protection, solar gain management and visual contact with the outside, which make the building usable and energy efficient. These functions often oppose each other, so the selection and design of façade systems and their control for a certain building application should depend on those functions that the designer wants to promote to the detriment of the other functions. In the context of the H2020 RenoZEB project, this paper presents a workflow for the conceptual planning of façade systems as applied to building retrofitting. The proposed workflow consists of analysing the space from the point of view of the functions of its façade. In a first step, the analysis of the case study leads to the definition of the design requirements, i.e. the relevance of the different façade functions and their priorities. The second step involves the selection of a suitable fenestration system and control strategy for the retrofit solution. In this step, an optimization process for the control strategy is proposed based on state-of-the-art thermal and daylighting simulations. In a third step, the annual performance of the retrofit solution is evaluated in order to check if the requirements are fulfilled. The proposed workflow is illustrated with a case study, in which the automation strategy of a retrofitted façade system is optimized for two different applications: a residential and an office building in Bilbao (Spain).

Keywords: retrofit, façade, comfort, energy efficiency, building simulation, daylight.



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Topic 4

Environmental assessment and economic impacts for measuring circularity



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A greenhouse that reduces greenhouse effect: how to create a circular activity with construction waste?

A Romnée¹, C Vandervaeren², O Breda³ and N De Temmerman²

¹ Belgian Building Research Institute, Sustainable Development Laboratory, Brussels, Belgium

² Vrije Universiteit Brussel, Architectural Engineering, Brussels, Belgium

³ DZeroStudio architects, Brussels, Belgium

ambroise.romnee@bbri.be

Abstract. Frontrunner small companies are nowadays developing locally new circular business models with construction resources. This paper presents the genesis, the potential environmental impact, and the business model of producing and marketing greenhouses made of salvaged materials according to the industrial symbiosis principles and the economy of functionality. A designer has recuperated formwork wood on a construction site and glass from reclaimed windows on a demolition site to reuse them in the production of a greenhouse. After cleaning, the wooden elements are calibrated, then assembled to create the greenhouse. Thanks to reversibility and standardization, the greenhouse can be easily repaired, extended and disassembled. In addition to the high recycled content of the greenhouse, all these characteristics make the greenhouse circular by design, and from 3.7 to 8 times potentially more environmental-friendly than a greenhouse in aluminium, as shown by a comparative life cycle assessment (LCA). According to the principle of the economy of functionality, the greenhouse is marketed as a tool to allow its users to reach an objective and not only be sold as a product. In some cases, the greenhouse could remain the property of the producer, while the users receive support to grow fruits and vegetables. The project shows that developing new business activities and reducing the environmental impact of construction sites are goals that can be achieved in parallel in a circular economy approach. We expect that this project will convince other entrepreneurs that innovative construction waste treatment can provide large practical, economic and environmental advantages.

Keywords: construction waste, industrial symbiosis, environmental impact, economy of functionality.



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Cradle to Cradle and Whole-Life Carbon assessment – Barriers and opportunities towards a circular economic building sector

N Futas¹, K Rajput² and R Schiano-Phan¹

¹Architecture and Environmental Design, University of Westminster, 35 Marylebone Road, London NW1 5LS, UK

²ChapmanBDSP, 40 Gracechurch Street, London EC3V 0BT, UK

noemi.futas@gmail.com

Abstract. The general awareness of climate change has been increasing steadily while buildings continue to be the main contributors to greenhouse gas emissions. To address the need for change in the building industry and transform its hazardous impacts on the environment to a positive footprint, circular economic design approaches and Whole-Life Carbon (WLC) assessment have been introduced. This paper analyses the main barriers for a successful implementation of the regenerative Cradle to Cradle (C2C) concept and WLC evaluation, identifying the lack of unified and measurable framework along with the deficiency of detailed case studies and post occupancy evaluation. In the context of the increasing demand for carbon accounting, obtaining comprehensive information on embodied carbon in buildings is challenging despite the existing Life Cycle Assessment structure. To link theory with practice, the paper discusses the London School of Economics Centre Buildings Redevelopment by RSH+P as case study. It reveals barriers and opportunities for WLC evaluation as well as the potential of life cycle cost optimization in environmental and economic terms.

The paper concludes with a reflection on how the certification of materials through material passports may not only achieve a higher transparency but lead to a circular economic building industry by comprehensive WLC assessment and a closer implementation of reversible building design corresponding to the C2C principles. The potential of combining WLC evaluation with C2C strategies and translating them into a comprehensive, unified assessment framework for a circular building sector is identified.

Keywords: Reversible Building Design, Cradle to Cradle, Materials Passport, Whole-Life Carbon, Embodied Carbon, Circular Building Sector



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New Methods for Sustainable Circular Buildings

J Andrade¹, C Araújo¹, M F Castro¹ and L Bragança¹

Department of Civil Engineering, University of Minho, Guimarães, Portugal

joana.andrade@civil.uminho.pt

Abstract. Cities can and should be an open field to sustainable circular guidelines since its scale complexity becomes an impact (positive or negative) over the environment as deep as its dimension. On this scenario, construction industry aims to develop products that fulfil also functional requirements and at the same time safety and durability during all the life cycle phases, promoting reversible buildings to avoid constructions obsolescence and recourses' waste. Most of the Building Sustainability Assessment methods require detail in the input data, hampering their usability at early design stages. So, the paper presents two complementary methods that are being developed to promote early stage sustainability through both sustainability design decision-making guidance and assessment of investment willingness and affordability. The first method enables project teams to compare design alternatives and verify which is the most sustainable choice and alerts them how sustainability concerns are linked to all design criteria, constraints and decisions. The second method is a cost-benefit analysis method to analyse and compare building solutions that consider the stakeholders' investment willingness and market availability. These new approaches can lead to a more sustainable built environment and contribute to more circular economy since it allows thinking on reversible and transformable buildings since the early design stages choosing solutions closer to the building stakeholders' investment willingness and the users' affordability.

Keywords: Early Stages Design, Integrated Design Process, Investment Willingness and Affordability, Sustainable Building Solutions.



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Product data and building assessment – flow of information

T P Lützkendorf¹

¹ Chair for Sustainable Management of Housing and Real Estate, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany

thomas.luetzkendorf@kit.edu

Abstract. The design, realisation and operation of buildings should be based on the principles of sustainable development, and consequently on the goal to conserve natural resources as a critical aspect of it. To this end, improving the resource efficiency in all building-related activities – from design to end-of-life – is necessary. Yet, such an effort cannot be fully successful if not based on comprehensive information. On the architects' side, there is a need for information on construction products to be fed into the assessment of building design variants. The exchange of information between product and building level is a topic dealt with in European (CEN TC 350) and International (ISO TC59 SC17) standardization. However, the demand on product information goes beyond the content of an Environmental Product Declaration (EPD). It is therefore necessary to discuss what are the additional needs for product information and how to provide this information to be practical for a building assessment. Finally, it is necessary to discuss how buildings should be documented along their life cycle to provide useful information for third parties. Third parties are – among others - valuation professionals, facility managers or demolition/dismantling companies. An approach to building files/building information packs will be presented, where information on the physical composition of the building and its material flows in the life cycle (material inventory) becomes an integral part. With regard to standardization, how to determine and present a recycling potential of a building will be discussed. Current research projects in Germany will inform the discussion.

Keywords: Building file, construction product, flow of information, actors, assessment



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Comparing life cycle assessment modelling of linear vs. circular building components

L Eberhardt¹, H Birgisdottir¹ and M Birkved²

¹ Danish Building Research Institute, Department of Energy Efficiency, Indoor Climate and Sustainability, Aalborg University, A. C. Meyers Vænge 15, 2450 Copenhagen SW, Denmark

² SDU Life Cycle Engineering, Department of Chemical Engineering, Biotechnology and Environmental Technology University of Southern Denmark, Campusvej 55, 5230 Odense-M, Denmark

lcl@sbi.aau.dk

Abstract. As the construction industry consumes vast amounts of natural resources and in return produces large waste quantities, interest in circular economy has emerged as the means to reduce sector specific environmental impacts meanwhile ensuring continued economic growth. Life cycle assessment is a scientifically based and ISO standardized method for assessing resource consumptions and environmental impacts of products, systems or services over its entire life cycle and has been increasingly used in the construction industry and in some recently published circular economy studies. However, circular economy brings about 'rethinking' present well established building systems as well as the future life cycle scenario of these. Hence, this also means rethinking how life cycle assessments are performed on these building systems as it is suggested by some that life cycle assessment is a linear environmental impact assessment approach that misfits the circular economy idea of multiple product life cycles. The paper at hand aims at visually demonstrating variations in life cycle environmental impacts and material flows when supplying buildings with linear components compared to prospective circular designed building components for reuse and recycling and how they are modelled in life cycle assessments.

Keywords: Life cycle assessment (LCA), Design for Disassembly (DfD), Circular Economy (CE), buildings, environmental performance, reuse



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Upcycling and Design for Disassembly – LCA of buildings employing circular design strategies

FN Rasmussen¹, M Birkved² and H Birgisdóttir¹

¹Danish Building Research Institute, Aalborg University, Copenhagen SW

²Life Cycle Engineering, University of Southern Denmark, Odense

fnr@sbi.aau.dk

Abstract. Within the ReSOLVE framework, the concept of 'Looping' materials in an efficient way is a crucial theme to ensure environmental sustainability of circular economy. This paper investigates how current calculation practice of building LCA from the EN 15804/15978 standards affects the global warming potential (GWP) of building designs where material loops have been in focus. In this study, we calculate the environmental potentials of circular building design based on two cases; 1) a building constructed from primarily upcycled materials, and 2) a building constructed with principles of design for disassembly (DfD). Results from the two cases point to the significance of the EN standards' allocation approach in which a system's use of recycling/reuse is merited, rather than meriting a system providing recyclable/reusable materials. Hence, the upcycling strategy results in lower GWP, especially from the production stage, whereas the DfD strategy does not realize an environmental advantage within the framework of the EN standards. Results further shows that even though concrete elements are notable components of the DfD building, developing DfD-solutions for these exact elements might not be the preferred focus for optimizing the environmental benefits provided by the building. Instead, DfD focus could be on shorter-lived elements of high benefit potentials.

Keywords: Upcycling, Design for Disassembly, Circular Economy, Buildings, Allocation, LCA



Comparison of eco-effectiveness and eco-efficiency based criteria for the construction of single-family homes

S Lindner^{1,2}, M Braungart¹ and N Essig²

¹ Leuphana University of Lueneburg, Lueneburg, Germany

² Munich University of Applied Sciences, Munich, Germany

sara.lindner@hm.edu

Abstract. The built environment faces diverse sustainability challenges concerning the ecological, the economic and the sociocultural dimension. However, common construction practices mainly focus on the reduction of environmental impacts, especially the energy consumption in the usage phase. Despite their long tradition of implementation, these eco-efficiency based strategies can only be regarded as a useful and groundwork lying step and opportunity to reduce the ecological impact in the short-term, but are insufficient for addressing the need for fundamental redesign of buildings in the long-term. In contrast, the cradle to cradle concept offers a model for fundamental redesign of buildings allowing positive interaction with the ecosystem based on the eco-effectiveness approach. The paper will analyse and compare eco-efficiency and eco-effectiveness based criteria for the construction of single-family homes with the help of guidelines and assessment methods for buildings and materials. The analysis serves the aim of identifying learnings from the long-term experience in the field of eco-efficiency and benefitting from it for the future implementation of eco-effectiveness based strategies. Single-family homes are chosen as typology as they represent the most popular housing type in Germany, but show numerous disadvantages regarding the ecological, economic and socio-cultural dimension compared to other forms of housing. Representing the smallest but worst typology from a sustainability point of view, they offer an ideal starting point. In a next step, the results can be transferred and expanded to other typologies.

Keywords: eco-effectiveness, cradle to cradle, eco-efficiency, positive footprint, single-family homes, Germany



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Financial assessment of reusing materials in buildings: comparing financial potential of wood, concrete, and glass reuse

Julia LK Nußholz¹ and Katherine Whalen¹

¹International Institute for Industrial Environmental Economics, Tegnérsplatsen 4, 223 50 Lund, Sweden

Corresponding Author, julia.nussholz@iiee.lu.se

Abstract. Buildings are responsible for a third of global greenhouse gas emissions, with much of their life cycle impacts resulting from embodied impacts of building materials. One solution to reduce embodied emissions is to use of secondary materials such as by-products and waste materials for producing building materials (in this study referred to as reuse solutions). While this is reported to have positive environmental and economic impact, many financial barriers to economic application remain, centering on labor-intensive recovery processes, low end-of life value, fluctuating material volumes and qualities. This paper aims to advance understanding of the financial potential to reuse different end-of-life materials for building materials by presenting a cost structure analysis of three reuse solutions developed by a Scandinavian case company for wood, glass, and concrete. Findings indicate that profit margins differ considerably by material stream and application. Expenditure for production processes (i.e. cutting wood to planks, assembling glass into windows, mixing aggregates to new concrete) was a significant cost driver in all three reuse solutions. Costs for purchasing end-of-life materials also differed significantly in each case, reflecting the differences in residual value of each material stream. Future research is needed to expand the financial assessment to consider the upscale potential and effect of economies of scale for each case. In addition, we suggest to investigate other dimensions of value such as economic aspects (e.g. job creation and societal costs savings from environmental impacts), as well as the environmental improvement to advance understanding of the relevance of material reuse for buildings.

Keywords: Circular economy, circular business models, sustainable buildings, life cycle management, embodied emissions, financial assessment



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

E Kakkos¹, F Heisel², D E Hebel² and R Hirschier¹

¹ Technology & Society Laboratory, Empa, Lerchenfeldstrasse 5, 9014, St. Gallen, Switzerland.

² Sustainable Construction, Faculty of Architecture, Karlsruhe Institute of Technology, Englerstrasse 11, 76131 Karlsruhe, Germany

efstathios.kakkos@empa.ch

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



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Comparative Life-Cycle Analysis of Building Materials for the Thermal Upgrade of an Existing Building

C Piccardo^{1,3}, A Dodoo^{2,4}, L Gustavsson^{2,5} and U Y A Tetey^{2,6}

¹ Department of Architecture and Design, University of Genoa, 16123 Genoa, Italy

² Department of Built Environment and Energy Technology, Linnaeus University, Växjö, SE-35195, Sweden

³ chiara.piccardo@arch.unige.it, ⁴ ambrose.dodoo@lnu.se, ⁵ leif.gustavsson@lnu.se,

⁶ uniben.tetey@lnu.se

Abstract. The existing building stock is estimated to need major renovations in the near future. At the same time, the EU energy-efficiency strategy entails upgrading the energy performance of renovated buildings to meet the nearly-zero energy standard. To upgrade existing buildings, two main groups of measures can be adopted: thermally-improved building envelope and energy-efficient technical devices. The first measure usually involves additional building materials for thermal insulation and new building cladding, as well as new windows and doors. A number of commercially-available materials can be used to renovate thermal building envelopes. This study compares the life-cycle primary energy use and CO₂ emission when renovating an existing building using different materials, commonly used in renovated buildings. A Swedish building constructed in 1972 is used as a case-study building. The building's envelope is assumed to be renovated to meet the Swedish passive house standard. The entire life cycle of the building envelope renovation is taken into account. The results show that the selection of building materials can significantly reduce the production primary energy and associated CO₂ emissions by up to 62% and 77%, respectively. The results suggest that a careful material choice can significantly contribute to reduce primary energy use and CO₂ emissions associated with energy renovation of buildings, especially when renewable-based materials are used.

Keywords: building renovation, alternative building materials, life cycle, primary energy use, CO₂ emissions, energy-efficiency.



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Energy and carbon balance of materials used in a building envelope renovation

C Piccardo^{1,3}, A Dodoo^{2,4}, L Gustavsson^{2,5} and U Y A Tetley^{2,6}

¹ Department of Architecture and Design, University of Genoa, 16123 Genoa, Italy

² Department of Built Environment and Energy Technology, Linnaeus University, Växjö, SE-35195, Sweden

³ chiara.piccardo@arch.unige.it, ⁴ ambrose.dodoo@lnu.se, ⁵ leif.gustavsson@lnu.se,

⁶ uniben.tetley@lnu.se

Abstract. Construction and demolition waste (CDW) are a priority waste stream in EU's polices, accounting for about 30% of all waste generated. At the same time, according to the EU energy-efficiency directive, existing buildings subject to significant renovation need to be upgraded in their thermal building envelope in order to meet higher energy performance standard. This involves additional building materials and hence increases the CDW generation. This study investigates the energy and CO₂ emission balance of building envelope renovation when using different building materials, taking into account the production and end-of-life stages. The study is based on a Swedish case-study building assumed to be upgraded to the passive house standard. Benefits from waste recovering are considered, including construction and demolition wastes. The results show that the selection of building materials can significantly affect the primary energy and CO₂ emission balances. Depending on the material alternative the end-of-life primary energy use and net CO₂ emission can be reduced by 5%-21% and 2%-24%, respectively, compared to the initial primary energy use and net CO₂ emission. Therefore, a careful material choice at the design stage, as well as an efficient waste management, can contribute to reduce primary energy use and CO₂ emission associated with energy renovation of existing buildings.

Keywords: building renovation, construction and demolition waste, end-of-life, primary energy, CO₂ emission.



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Incompatible trends - Hazardous Chemical Usage in Building Products Poses Challenges for Functional Circular Construction

Martha Lewis

Henning Larsen Architects, Vesterbrogade 76, Copenhagen, 1620 Denmark

mle@henninglarsen.com

Abstract. Based on a review of 2012 and 2016 data in the Nordic chemical database, SPIN, this paper is an assessment of the usage of REACH's Substances of Very High Concern (SVHC) and Denmark's List over Undesirable Substances (LOUS) chemicals in the building industry in Denmark. The paper is a status update of the 2016 Danish Environmental Agency's report of the usage of hazardous substances in sustainable buildings, based on 2012 data from SPIN. The analysis focuses on change in tonnage of usage of chemicals found in twelve different construction product categories in SPIN, crosschecked with substances from the SVHC and the LOUS lists. The usage of some hazardous substances in certain usage categories has reduced from 2012 to 2016. There is an overall trend indicating an increase of undesirable chemical in construction articles and preparations, which poses serious challenges for a functioning circular built environment. Findings indicate which construction categories and which chemicals are of particular concern for the current construction market in Denmark. The results underscore the essential need for transparency in building product content, in order for design professionals and contractors to make decisions that support the future use of the material or building element.

Keywords: material health, hazardous chemicals, sustainable design, circular built environment



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Effect of environmental assessment on primary energy of modular prefabricated panel for building renovation in Portugal

Manuela Almeida, Ricardo Barbosa¹ and Raphaelae Malheiro

Centre for Territory, Environment and Construction, Department of Civil Engineering, University of Minho, Campus Azurém, Guimarães, Portugal

ricardobarbosa@civil.uminho.pt

Abstract. While facing increasingly strict regulations regarding energy efficiency, the construction sector should also adopt sustainable solutions in terms of new constructions and renovations of buildings. In particular, energy renovation of existing buildings has specific technical and economic constraints that are generally addressed through implementation of new materials and building integrated systems, whose environmental impact should be considered when assessing the most adequate solution. Within the context of the More-Connect Project, which aims to develop modular prefabricated solutions for energy renovation of buildings, several renovation scenarios for a pilot building in Portugal were assessed using a methodology to compare the cost-effectiveness of renovation measures. The article explores the use of lifecycle assessment to analyse the effect of considering embodied primary energy in cost-effectiveness calculations.

Keywords: Cost-effectiveness, energy efficiency, More-Connect, building renovation, Life Cycle Assessment.



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Circular (de)construction in the Superlocal project

Michiel Ritzen¹, John van Oorschot¹, Michelle Cammans¹, Martijn Segers², Tom Wieland³, Pieter Scheer⁴, Bart Creugers⁵, Nurhan Abujidi¹

¹ Zuyd University of Applied Sciences, Research group SURD, Heerlen, the Netherlands

² HEEMWonen, Kerkrade, the Netherlands

³ Jongen Construction, Kerkrade, the Netherlands

⁴ Dusseldorp, the Netherlands

⁵ SeC Architects, the Netherlands

Michiel.ritzen@zuyd.nl

Abstract. Worldwide, the concept of the circular economy is gaining momentum. Different strategies are investigated for the construction industry to become circular as it is a major player concerning resource consumption, both energy and material related. One of these strategies focusses on qualitative re-use of building components and building materials. To assess the circularity of different re-use scenarios of building components and materials, we developed and applied a circularity assessment concept in the European Urban Innovation Actions (UIA) project 'Super Circular Estate' (Superlocal). In this project, a 10-floor high 100-apartment building block is deconstructed and its components are re-used in new building objects; 1 pavilion, 4 detached dwellings with different floor areas and 12 terraced dwellings. In the model the environmental impact of different circularity scenarios is expressed in embodied energy, embodied CO₂, and carbon pricing. Besides the material and energy aspects, other qualities and former social structures are re-used within the project area, boosting the local economy and creating a high-quality and desirable urban environment, resulting in Europe's first super circular housing estate. In the baseline, the existing apartment block consists of 2.3E03 GJ embodied energy and 2.9E03 tons of embodied CO₂. The investigated pilot dwelling consists of 3.35E02 GJ embodied energy, of which 65% is embodied in re-used materials, and 4.62E01 tons of embodied CO₂, of which 90% is embodied in re-used materials. This investigation indicates that re-using building components and materials significantly contribute to decreasing building related embodied energy and embodied CO₂, and should be considered a key step in closing materials loops to make the built environment circular.

Keywords: Circular deconstruction, Re-use of building components, Circularity assessment model



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Topic 5

Efficient waste and resources management



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

F Heisel^{1,3}, D E Hebel^{1,3} and W Sobek^{2,3}

¹ Sustainable Construction, KIT Karlsruhe, Englerstr. 11, 76131 Karlsruhe, Germany

² Werner Sobek Design GmbH, Albstr. 14, 70597 Stuttgart, Germany

³ Werner Sobek with Dirk E. Hebel and Felix Heisel, Stuttgart / Karlsruhe, Germany

felix.heisel@kit.edu

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



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Reuse of resources in the use phase of buildings. Solutions for water

Carla Pimentel-Rodrigues¹ and Armando Siva-Afonso^{1,2}

¹ANQIP – Associação Nacional para a Qualidade nas Instalações Prediais, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal

²University of Aveiro/RISCO, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal

anqip@anqip.pt

Abstract. Circular economy can be considered not only in relation to building construction materials, but also in relation to resources that are used in the use phase of buildings, such as water, energy or even nutrients. On the other hand, some constructive solutions are becoming increasingly important in the current scenario of climate change, taking into account the need to increase the resilience of the urban environment and the mitigation of emissions. This is the case, for example, of green roofs and living façades, which are an alternative to traditional grey infrastructure, offering many benefits to both citizens and cities. Beyond the ability to improve environmental conditions and quality of life, they can augment the energy efficiency of buildings, reduce flood risks in urban areas and be combined with rainwater harvesting systems. So, taking into account these trends for constructive solutions in the future, this paper analyses the possibilities of a circular use of water in buildings, aiming to create in the future "zero water" buildings. Particular attention is given to the compatibility between new green roofing solutions and rainwater harvesting systems in buildings, but the reuse of grey water and the possibility of nutrient recovery in buildings, such as urine (phosphorus) - which can be used in the building itself on green roofs - living facades or urban agriculture, are also referred to.

Keywords: Circular economy, zero-buildings, water, energy, nutrients



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Use of seagrass fibres in adobe bricks

E Olacia^{1,2}, A L Pisello^{2,3}, V Chiodo⁴, S Maisano⁴, A Frazzica⁴ and L F Cabeza¹

¹ GREiA Research Group, INSPIRES Research Centre, Universitat de Lleida, Pere de Cabrera s/n, 25001 Lleida, Spain

² CIRIAF-Interuniversity Research Centre on Pollution and Environment Mauro Felli, Via G. Duranti 63, 06125, Perugia, Italy

³ Department of Engineering, University of Perugia, Via G. Duranti 67, 06125, Perugia, Italy

⁴ CNR - Istituto di Tecnologie Avanzate per l'Energia "Nicola Giordano", Via Salita S. Lucia sopra Contesse 5, 98126 Messina, Italy

lcabeza@diei.udl.cat

Abstract. The main aim of the present study is to measure the capability the “Posidonia Oceanica” as fibre reinforcement for adobe bricks. This sea-plant is distributed in the Mediterranean coast, considered as a solid marine by-product. To analyse the performance, prismatic earthen specimens with seagrass fibres were compared with the most traditional additives for this purpose; straw fibres. Both fibres were included with different lengths and quantities. Previously, in order to understand their behaviour, the fibres themselves were evaluated. Tensile strength and water absorption tests were performed. Meanwhile bricks themselves were subjected to mechanical tests. Concerning the biomass fibres, results show that straw fibres present higher tensile resistance than the seagrass leaves while they are more fragile to breakage than seagrass; on the other hand, they have higher water absorption than seagrass. Mechanical results show variations depending on their fibre content and length. Nevertheless, bricks with long seagrass fibres present a characteristic good behaviour in terms of flexural and compressive strength. Generally, adobe bricks with both types of fibres achieve similar mechanical properties, generating favourable results in terms of comparison between them.

Keywords: Earthen bricks, compressive strength, flexural strength, biomass, seagrass, straw



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Strategies for circular, prefab buildings from waste wood

A Klinge¹, E Roswag-Klinge¹, L Radeljic¹ and M Lehmann²

¹ZRS Architekten, Schlesische Strasse 26, 10997 Berlin, Germany

²ZRS Ingenieure, Schlesische Strasse 26, 10997 Berlin, Germany

klinge@zrs-berlin.de

Abstract. This paper presents a strategy how to maximise timber elements and materials from existing buildings for the reuse or the recycling for new construction. The EU funded project RE⁴ develops a new concept for disassembly to reuse or recycle timber elements from existing buildings for manifold application (structural and non-structural) and aims to bring waste wood back into the building cycle. Furthermore, an innovative design concept for fully reversible, prefabricated, multi-story residential buildings constructed from waste wood has been established to extend the buildings-life cycle through robust but flexible and adaptable design. Reversible connections, reusable elements and recyclable materials shall minimise future waste when buildings reach their end of life. A two-story prototype shall proof the concept and deliver figures for easy installation, dismantling and future reuse. The research aims to show how current practice can be overcome and design for disassembly can be achieved.

Keywords: Timber reuse and recycling, prefabrication, adaptable design, circular construction, reversible connections, demonstrator



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What are the barriers affecting the use of earth as a modern construction material in the context of circular economy?

JC Morel¹ and R Charef¹

¹ Centre for Research in the Built and Natural Environment, Coventry University, United Kingdom

ac0969@coventry.ac.uk

Abstract. One path to decrease the impacts of construction is to switch from the current take-make-dispose extractive industrial model, to a circular economy scheme. Building with prime materials and especially with earth (locally available soils containing clay), is a way to foster the circularity of the materials because the unstabilised earth is 100% infinitely reusable. Earth architecture involves different modern and ancient techniques of construction like rammed earth or compressed earth block masonry. However, the development of new earth building is still limited to a niche in spite of its high circularity potential in a modern context. We have performed a review of the barriers that may affect the uptake of the earth as a building material. We have studied journal papers and some findings are based on the experience of the authors as practitioners and researchers. The identified barriers can be classified in Steering mechanisms, Process, Economics, Client understanding and Underpinning knowledge. We have discussed the barriers and reviewed some possible paths to smooth the existing obstacles to the development of earth architecture.

Keywords: barriers, earth building, Circular Economy, sustainable building.



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WIM project: wood flow analysis in Heyvaert district

V Ooghe^{1,3}, A Athanassiadis¹, M Van der Linden², J Hermesse² and P Bouillard¹

¹ Building, Architecture and Town Planning, Université Libre de Bruxelles (ULB), 50 Av.F.-D. Roosevelt, Brussels, 1050, Belgium

² Laboratoire d'anthropologie prospective, Université catholique de Louvain (UCL), Place Montesquieu 1, Louvain-la-Neuve, 1348, Belgium

³ victor.ooghe@ulb.ac.be

Abstract. Wood is a natural material, largely used in the construction sector and for a number of daily life uses to make furniture or tools. Its stock is concentrated in urban area where are the majority of population and human activities [1]. In Brussels, wood represents the third important material used in construction sector [2]. Wood presents diverse circular advantages as a removable assembly, diversity and ease of use. Wood in Molenbeek” (WIM) project (2017-2020) is a multi-disciplinary research project in Molenbeek’s district (Heyvaert) where social and environmental issues are encountered. The aim of the project is to perform a wood material outflow and stock analysis and to assess if a local wood valorisation can be a circular solution in the regional waste management and the resilience of the district. This wood valorisation model is created with the inhabitants. Consequently, the model evolves with their remarks and ideas. The quantification is realized with a bottom-up approach to present more accurate information than regional data. Indeed, local quantification illustrates some invisible flows by using census, observations, discussions with inhabitants, social and economic actors. The bottom-up approach gives the opportunity to work with local actors to build a “circular” network in a district.

Keywords: Urban Metabolism, Material Flow Analysis, wood waste, co-create, circular economy.



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Market analysis of recycled sands and aggregates in North-West Europe: drivers and barriers

S Delvoie¹, Z Zhao¹, F Michel¹ and L Courard¹

¹Urban and Environmental Engineering Research Unit, University of Liege, Quartier Polytech 1, Allée de la découverte 9, B-4000, Liege, Belgium

s.delvoie@uliege.be

Abstract. Construction and demolition wastes (C&DW) are estimated at one third of total wastes generated in the European Union (EU) and represent the main flux in volume. Inert materials (e.g. concrete, bricks, tiles and ceramics) constitute the largest fraction of construction and demolition wastes. These wastes can be recovered as secondary raw materials after a recycling process resulting in the production of recycled sands and aggregates (RS&A). The market for RS&A is however complex and sensitive. It can be affected by many parameters and may be very variable from one region to another. A quantitative analysis of some market variables is carried out in five NW European countries: Belgium, France, Germany, Luxembourg and the Netherlands. For achieving this analysis, attention is paid to the following data/parameters: generation of inert construction and demolition wastes, production of RS&A and production of natural sands and aggregates. Since the market of recycled products is also governed by transportation costs, the study has compiled data on the density of recycling plants for construction and demolition wastes, the density of pits and quarries extracting natural materials, the density of inert landfills and taxes applied for C&DW landfilling. National/regional legislation and requirements are also included in the analysis. Based on the compiled data and objective reasons, the market of RS&A is more developed and more suitable in the Netherlands and in Flanders (North of Belgium) than in the other investigated countries/regions.

Keywords: market, construction and demolition wastes, recycling, sands, aggregates, Europe.



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Estimation of building waste flows and adequacy with resources

Ingrid Bergogne¹, Mathilde Louërat¹, Sylvain Laurenceau² and Marie Lemagnant²

¹Université Paris Est, Centre Scientifique et Technique du Bâtiment (CSTB), Grenoble, France

²Université Paris Est, Centre Scientifique et Technique du Bâtiment (CSTB), Marne-la-Vallée, France

mathilde.louerat@cstb.fr

Abstract. Today, the flows of materials in the French building sector are poorly known, both in terms of quantities or types of recovery (reuse, recycling, energy recovery, etc.). Therefore, the aim of this study is to increase the knowledge about recovery of building products in France. A methodology is developed to identify the flows of materials resulting from the deconstructions of buildings. The volume of demolished buildings for each typology (individual house, apartment building, office building...) and constructive system (brick, concrete, wood...) is known from the state of the art. Moreover, the quantities of demolished materials are estimated for each building typology from a French database of building waste diagnosis. Then, the volume of waste can be calculated for all the building sector and the deconstruction flows can be crossed with an analysis of the existing types of recovery (projects of close development, recycling channels, ...). This analysis will present the distribution of the different ways of recovery for each type of material and the associated costs. This capitalization of data on waste flows and building resources will allow to question the adequacy between material needs and available resources.

Keywords: waste flows, recovery, deconstruction, resources



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The role of resource efficiency towards circular economy

Helena Gervasio

Department of Civil Engineering, University of Coimbra, 3030 Coimbra, Portugal

hger@dec.uc.pt

Abstract. The use of natural resources for building construction represents, in terms of mass, one of the biggest challenges in resource consumption. On the other hand, construction and demolition waste is one of the most important waste streams generated in the EU, about 25% - 30% of all waste generated in the EU, and consists of numerous materials with potential for recycling. Recently, a research project *EFIResources* was completed, which focussed on the development of a performance based approach for sustainable design, enabling to assess resource efficiency of buildings, in the early stages of building design, and supporting European policies related to resource efficiency and circular economy. Therefore, the main aim of this paper is to present the developed approach, which is based on the benchmarking of the environmental performance of buildings, in a life cycle perspective. Moreover, this paper includes a discussion of the different methods that are available for the allocation of credits and/or debits due to the recycling process, between the system producing the secondary materials and the system receiving them, in line with current EU policies.

Keywords: LCA, buildings, allocation, resource efficiency, benchmarks, circular economy.



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Topic 6

Barriers and opportunities for a circular built environment



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Obstacles and barriers for measuring building's circularity

K M Rahla^{1,2}, L Bragança^{1,2}, R Mateus^{1,2}

¹ Department of Civil Engineering, University of Minho, Guimarães, Portugal

² The Centre for Territory, Environment and Construction (CTAC), Guimarães, Portugal

k.m.rahla@civil.uminho.pt

Abstract. Applying circular economy principles in the built environment at different levels is considered as a future vital approach to reducing its environmental impacts along with huge economic benefits, which is generally explained by “decoupling resource consumption from economic development”. At the meso-level of the built environment, circular buildings have arisen as a more holistic approach to embrace circular economy thinking. This novel practice requires flexible and adaptable strategies to enable alteration and adjustment while avoiding material loss and keeping the value of products at the highest levels. Evaluating buildings circularity by means of standardized indicators is therefore primordial to implement a common language between all involved actors and monitoring the progress towards an eco-design. Still, the complexity of putting together such a methodology is far from being a mere task. To date, several studies have been more focused on assessing circularity for short-lived products while disregarding assessing long-lived products as buildings and their ability to be deconstructed and reassembled in a so-called “reversible design”. Unfolding a set of robust indicators to measure building circularity promises to be challenging in order to set up a flawless assessment tool which can summarise different aspects of the application circular economy at a building level. This paper intends to put an emphasis on the potential obstacles that can be encountered while developing metrics to quantify building circularity.

Keywords: Circular economy, built environment, circular buildings, Assessment tool, challenges.



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Building circular in Brussels: an overview through 14 inspiring projects

A-L Maerckx¹, Y d'Otreppe² and N Scherrier³

¹ Cenergie cvba, 2600 Berchem, Belgium

² Brussels Environment, Div. Energie, air, climat et bâtiments durables, Dpt. Stimulation Economique bâtiments durables, 1000 Brussels, Belgium

³ Brussels Environment, Div. Information, Coordination générale, Economie circulaire et Ville durable, Dpt. Déchets, 1000 Brussels, Belgium

¹ anne_laure.maerckx@cenergie.be

² ydotreppe@environnement.brussels

³ nscherrier@environnement.brussels

Abstract. The call for projects 'Be circular – Be Brussels' is held since 2016 and has already awarded 14 circular construction projects. On those projects, a focus is put on the better management of human and material resources. The companies in charge of the winning projects are freelances, very small businesses, SMEs and large companies. Each in its own way, applies circular measures, on site and inside its organization. Reuse, design for change and disassembly, training of workers and partnerships between companies are some of the measures implemented, which help highlight the current levers and obstacles to a circular economy in the construction sector. Many challenges still need to be addressed in order to generalize circular construction across the region, but the sector is moving and the signals it sends are positive. In particular, we notice a real transfer from investments related to the material resources (purchase of new materials and waste management) towards investments related to human resources (preliminary studies and on-site labor); this matches the regional ambition to put the human capital at the center of the work process. As practical cases, the (current and future) circular construction projects help to target the measures that should be implemented at regional and national levels, so that the circular economy becomes, indeed, the new economic model of Brussels.

Keywords: Be Circular, Brussels, material resources, human resources



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Case Study: Taiwan's pathway into a circular future for buildings

B J A van Bueren^{1,2}, M A A M Leenders³ and T E M Nordling⁴

¹ Department of Life Sciences, Circular NCKU, National Cheng Kung University, No 1 University road, Tainan, 70101, Taiwan

² Waterarchitect van Bueren, Geestweg 40a, Naaldwijk, 2671ED, the Netherlands

³ Graduate School of Business and Law, Royal Melbourne Institute of Technology, 124 La Trobe Street, Melbourne, VIC 3000, Australia

⁴ Department of Mechanical Engineering, National Cheng Kung University, No 1 University road, Tainan, 70101, Taiwan

bartvanbueren@gmail.com

Abstract. The aim of this paper is to explore successful paths and potential obstacles for introducing circular buildings to a region new to the strategy of Circular Economy (CE). For this, the process of circular buildings development in Taiwan is analysed. In 2016, the government of Taiwan passed an act that put a focus on CE. Taiwan entered this field with nearly no prior experience. This paper analyses three cases: The Holland Pavilion for the World Flora Expo Taichung; the TaiSugar Circular Village Tainan; and the CE Social Housing Taipei. Interestingly, Taiwan choose the Netherlands as a country for guidance on best practices and the path to implementation. Our analysis focuses on barriers and opportunities found in the initiation, commissioning, and the ongoing development process of these projects. Data is collected through interviews with 30 stakeholders, from government, industries and academia who are involved in the projects. International collaboration is shown to have speeded up the CE building innovation process in Taiwan.

Keywords: Taiwan, circular economy, circular buildings, innovation strategy, internationalizing, triple helix.



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Barriers and opportunities to reuse of building materials in the Norwegian construction sector

Anne Sigrid Nordby

Asplan Viak, Department of Energy and Resources, Sandvika, Norway

annesigrid.nordby@asplanviak.no

Abstract: In spite of ambitious goals regarding implementing circular economy, many well-intended projects fail in practice. One essential question is how reuse of building materials from demolitions can be realized at industrial scale in the high-cost country of Norway? The paper points to barriers and opportunities for reuse of construction products and technical installations in Norwegian buildings. The technical, legislative and market barriers are interrelated and linked to 1) An undeveloped market due to lack of economic driving forces, 2) Lack of information about used construction products and 3) Inexpedient legislation that is not adapted to the sale and use of used building materials. Proposals for measures to increase reuse are linked to the legal framework, economic incentives, competence, information system/ marketplace, technical control and certification procedures as well as risk management. It is recommended to clarify and adjust the regulations relating to both the trading and the use of reused construction products. Also, it may be useful to study how other EEA countries deal with the challenges presented by the Construction Products Regulation. The study will be further followed up by the NHP-network, consisting of 15 Norwegian building industry organizations.

Keywords: materials, reuse, policies, regulations, measures



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Connections and joints in buildings: Revisiting the main concepts on building materials life cycle's circularity

C Escaleira¹, R Amoêda² and P J Cruz¹

¹ University of Minho, School of Architecture, Guimarães, Portugal

² University Lusíada Norte, School of Architecture and Arts, Famalicão, Portugal

claudiaescaleira@entropiadesign.org

Abstract. Joining methods were set as a field of study and the state of the art on connections in buildings within building materials circularity was reviewed. The cross reference of fields of connections in buildings and resources and waste management has highlighted a set of constraints for implementing circularity strategies such as reversibility of connections: the gap between existing systematisation of knowledge on connections in buildings and the strategies and guidance to support their design, the divergent conclusions reached resulting from partial approaches on circularity and its strategies and, lastly, the questions raised by the consequences of adopting reversible solutions that are still open for discussion.

Keywords: reversible building's connections, irreversible building's joints, building's material life cycle, building's material recovery, building's deconstruction barriers.



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Current work on social sustainability in the built environment

N B Larsen¹ and L B Jensen¹

¹ Department of Civil Engineering, Technical University of Denmark, Kongens Lyngby, Denmark

nabl@byg.dtu.dk, lbj@byg.dtu.dk

Abstract. Sustainability is based on the United Nation's (UN) Brundtland Report, which defines economic, social and environmental factors that can ensure long-term economic viability while maintaining an environmental balance and showing commitment to socially desirable practices. Great focus has been on integrating environmental and economic factors into the project processes of construction. There is substantial potential in developing a strategic process to ensure that social sustainability is systematically incorporated into a project equally with economic and environmental factors. Research in the field is scarce and suggests that social sustainability is a secondary parameter even though it is integrated in building projects today. There is a tendency that decisions made regarding which social sustainability aspects is to be integrated in a project is based on experience from previous projects. There is a need of a strategic approach on how to handle and work with social sustainability that is based on more than experience. Can decisions be informed by quantifiable information about social sustainability as is the case with economic and environmental sustainability?

Keywords: Sustainability, social sustainability, economic sustainability, environmental sustainability, assessment tools, certification systems,



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European Union legislation for demand-side management and public policies for demand response

B Machado¹, M F Castro¹, and L Bragança

¹ University of Minho, CTAC, Guimarães, Portugal

a58600@alunos.uminho.pt

Abstract. Energy is now intrinsically linked to technological and social development, powering all such systems. The use of fossil fuels to supply the required energy is causing global environmental and health issues and is impacting on all life forms on the planet. Given the increasing energy use, anthropogenic greenhouse gas emissions are consequentially increasing. A critical and evolutionary way of thinking about the energy and resources demand management and supply is necessary because there is a clear concern about irreversible impacts on the world and a scarcity of the resources as well. At the same time, all the energy and resource use processes should be optimized to maximize the benefits, reduce the costs and promote stakeholders network, toward a circular economy. This could be the way to supply the demand without increasing the scarcity of the resources and to simultaneously achieve environmental benefits. At the same time, creating an educational grid is important to change the established paradigms, to promote critical thinking about the wasted resources and thinking holistically about overall consumption. This paradigm shift is changing the market, making it more competitive and reducing inefficiency by promoting the efficient use of resources. In the XXI century, legislation and public policies which consider sustainability approaches are constantly improving, trying to fix the pathways to avoid climate changes and achieve energy efficiency, but at the same time, the energy and resources demand still increasing to a no sustainable way to the social and environmental aspects.

Keywords: Demand Side Management, Demand Response, Energy Efficiency, Sustainability, Circular Economy, Public Policies.



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Circular economy and regeneration of building stock in the Italian context: policies, partnership and tools

S Giorgi¹, M Lavagna¹ and A Campioli¹

¹Department of Architecture, built environment and construction engineering, Politecnico di Milano, 20133, Milan, Italy

serena.giorgi@polimi.it

Abstract. The paper presents a part of research focused on the definition of circular economy models in the regeneration of existing building stock in the Italian context, identifying policies improvements, strategic partnership and environmental and economic life cycle assessment tools for supporting decision.

Through direct-interviews to operators (investors, designers, manufacturers, etc.), the paper analyses the typical relationships and dynamics among them in the Italian building regeneration process. The operators' opinions and requests towards circular strategies (reuse/recycling at building and material levels) are pointed out, in order to highlight the obstacles and levers of circular economy application. The paper shows the strengths and the weaknesses for the regeneration of building stock by the application of circular economy, the opportunities and the threats for circular economy by its application in the regeneration of building stock. In order to achieve circular requalification processes, avoiding waste and enabling practices of reuse and recycling, the change of relationships, policies and business models are defined. Moreover, the paper discusses on the importance of environmental evaluation of circular practices, identifying the decision steps and operators which, with the support of environmental and economic life cycle assessment tools, can select circular strategies towards sustainable requalification process.

Keywords: end-of-life, requalification process, buildings' regeneration, life cycle sustainability approach, policies improvements, stakeholder opportunities.



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Exploring material circularity opportunities for a construction-SME on small-scale projects in Ireland

M Kelly¹, K Burke² and J Gottsche¹

¹Department of Building and Civil Engineering, Galway-Mayo Institute of Technology, Dublin Road, Galway, Ireland.

²Carey Building Contractors, 6B, Liosban Business Park, Tuam Rd, Galway, Ireland.

Mark.Kelly@gmit.ie

Abstract. In Ireland, there has been a clear connection between construction output and construction and demolition waste production, with estimates of 17.8 million tonnes (Mt) in 2007 dropping to just over 3 Mt in 2014, which has mirrored the dramatic economic growth and subsequent sharp decline over that period. During this time of economy recovery and improving construction output, there is a unique opportunity to decouple this connection and rethink the traditional linear supply chain model to transition the sector towards nurturing resource efficiency and material circularity. This study explored opportunities to embed these principles within a construction-SME business model using an applied action research framework on selected case studies. A series of interventions (procurement protocols, sub-contractor engagement, auditing and benchmarking, source segregation and waste tracking) were piloted on two new-build construction projects ranging in a value from €1.5 to €2.8 million over a two-year period (2016-2018). The research is ongoing but initial results indicate that opportunities do exist in procurement/tendering, pre-construction planning and construction phases to improve resource efficiency practice and introduce material circularity principles into traditional construction-SME supply chain processes.

Keywords: construction, resource efficiency, circular economy, waste



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Topic 7

BIM and digitalisation towards high reuse potential and circular economy



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A BIM-based theoretical framework for the integration of the asset End-of-Life phase

Rabia Charef, Hafiz Alaka and Eshmaiel Ganjian

Centre for the Built and Natural Environment, Coventry University, UK

charefr@uni.coventry.ac.uk

Abstract. Due to the migration of industry from the use of traditional 2D CAD tools to Building Information Modelling (BIM) process, and the growing awareness of Construction and Demolition (C&D) waste issues, researchers are interested in compiling the use of BIM for C&D Waste issues. BIM is commonly used for the Design, Construction and Maintenance phases of an asset; however, the use of BIM for the End-of-Life management is still in its infancy. This paper proposes to reconsider the asset lifecycle by incorporating a sustainable End-of-Life, as a phase, in BIM context. Recommendations are given to push the BIM potential up to the asset End-of-Life management. Based on the results of a literature review assessing the current use of BIM for the asset End-of-Life, a conceptual framework was drawn. A set of eleven stakeholders, involved in the asset lifecycle, from inception to deconstruction were interviewed to improve the conceptual framework. The research reveals the impacts and barriers for the integration of the deconstruction phase into the asset lifecycle. Consequently, a theoretical framework for the asset lifecycle from inception to deconstruction in BIM environment is created to change the linear system to a circular economy.

Keywords: Building Information Modelling (BIM), End-of-Life, Deconstruction, Demolition, Barriers, Circular Economy.



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BIM and Circular Design

A Aguiar, R Vonk and F Kamp

Rijnbout bv, Moermanskade 317, 1013 BC Amsterdam, The Netherlands

aguiar@rijnboutt.nl

ABSTRACT: Materials passport is a tool to promote circular design. BIM is an essential and powerful tool to create and manage digital information. As such, it can be used for materials passports. Which information is needed and reliable? How can we extract it from a BIM model? The current debate issues “which information is needed?” with the assumption that it will be all settled with BIM. Indeed, BIM has great potential when it comes to gain and share information, but what are the possibilities and how to maximise its potential? This paper clears the discussion by giving better understanding about BIM and circular design using the different phases of the lifecycle to get a grip on how information develops during the process. A circular economy requires a paradigm-shift: buildings as material banks. Each building will have a ‘materials passport’ and new buildings will be built reversible and reusable using BIM. A circular BIM model is needed and should be created with the least possible effort in order to maximise its potential on an affordable way.

Keywords: BIM, cooperation, affordability, reliability, effort



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A Preliminary Case Study on Circular Economy in Taiwan's Construction

Yun-Tsui Chang and Shang-Hsien Hsieh*

Department of Civil Engineering, National Taiwan University
6F., No.188, Sec. 3, Xinhai Rd., Da'an Dist., Taipei City 106, Taiwan

shhsieh@ntu.edu.tw

Abstract. After realizing the serious environmental problems caused by current linear economic model, designers, researchers and policy makers around the world started to look into the possibilities of a more sustainable model- circular economy. And the construction industry is no exception to this change. In recent years, not only in Europe, circular economy in the built environment has also become a key focus for public and private sectors in Taiwan. Several projects aiming at constructing circular buildings have been initiated. However, the understanding of circular buildings in Taiwan is very little. Furthermore, how Building Information Modeling (BIM), known as a powerful tool for circular buildings, contributes to these projects for building circularity is beyond exploration. Through one in-depth interview and case study, this paper aims at disclosing the current development, barriers and future potentials of circular economy in building sectors and related BIM applications in Taiwan. The current awareness of stakeholders, key challenges and enablers for circular economy in construction have been identified. How BIM is utilized for circular building design, and its benefits, limitations and potentials are also recognized.

Keywords: Circular Economy in Construction, Building Information Modeling, Case Study



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How close is the built environment to achieving circularity?

August P. Nazareth

University of Bradford, Bradford, England

augustnazareth@gmail.com

Abstract. To accelerate the built environment and construction industry's uptake of the circular economy, we can begin by highlighting and publicising the construction industry's closest circular project examples that seem to (unintentionally) utilise recommended circularity principles and frameworks. The Ellen McArthur Foundation's (EMF's) Toolkit for Policy Makers has an easy-to-follow ReSOLVE (REgenerate, Share, Optimise, Loop, Virtualise, Exchange) framework. There are many initiatives in the construction industry to create less wasteful and operationally efficient building lifecycles including BREEAM, LEED, and LEAN etc. as well as design for manufacture and assembly (DfMA), offsite and modular, scan to BIM (Building Information Modelling), Internet of Things (IoT), Virtual Reality (VR), Virtual Design Construction and Digital Twins. In addition, with innovative technologies and digitalisation it is now possible to not only design new buildings with facilities management efficiencies in mind at the onset, but it is also possible to digitalise older and even heritage buildings, built hundreds of years ago. However, whether these initiatives are "circular", remains fragmented in an industry that is unfamiliar with the "circular economy". This paper will extrapolate the EMF's ReSOLVE frameworks through the context of three examples in vastly different formats; a desert lodge in the NamibRand Reserve (Namibia) close to achieving circularity; the tallest modular building in New York City that completely negates notions that pre-fab is undesirable and unattractive; and a large supermarket chain that has used BIM and other digitalisation to increase its operational efficiency, reduce material waste and increase visibility into space availability.

Keywords: Offsite construction, prefabrication modular, circular economy, ReSOLVE, building-as-a-service, digital twin.



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Parametric design and BIM, systemic tools for circular architecture

C Dautremont¹, S Jancart¹, C Dagnelie² and A Stals¹

¹LNA, Faculty of architecture, Liège University, Belgium

²Quercus Architecture, Belgium

cdautremont@uliege.be

Abstract. The current change in societal model, from linear to circular, coupled with the digital transition, is changing certain architectural practices. The emergence of BIM (Building Information Model, Modeling, Management) generates an evolution of the work process and collaborative tools. However, the BIM tools hardly integrate digital information of the elements found during the material inventory. Moreover, these tools are not really adapted to the modeling of formally complex elements. The designers are thus led to appropriate new tools such as those of parametric design. Although for a long time reserved for "star-architects" projects, we will rely on a Belgian research showing that these tools are gradually appearing in architectural agencies. Our study has shown that the use of parametric design can be a lever of creativity in architectural practice as well as a springboard for the integration of reuse materials. We therefore ask several questions in this regard: What are the challenges of a circular architectural approach? How can digital tools be used in this process? Does parametric have a place in a reuse perspective? This contribution analyses how to include a form of circularity in architecture and mainly around the implementation of reuse elements. We propose a workflow between BIM and parametric tools as a means of valuing reuse in architecture. We will approach these questions with concrete examples illustrating the relevance of the link between parametric and reuse.

Keywords: BIM, Reuse, Parametric Modeling, Circularity



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Using BIM to optimise and assess the energy efficiency category of SBTool^{PT}-H

J P Carvalho¹, K Ridder¹, L Bragança¹ and R Mateus¹

¹ University of Minho, Civil Engineering Department, 4800-048 Guimarães, Portugal

jpcarvalho@civil.uminho.pt

Abstract. The current method for assessing the two indicators of the Energy Efficiency category of the Building Sustainability Assessment method SBTool^{PT}-H (P7: Primary energy, P8: In-situ energy production from renewables) is rather time-consuming. The assessment requires many values that need to be calculated manually or with specific spreadsheets, whenever a design is proposed. When a design alteration is introduced, the whole process needs to be repeated, which leads to designers to be discouraged to develop this task. This research explores the use of the Building Information Modelling (BIM) software – Autodesk Revit and Autodesk Green Building Studio (GBS) – to assess the Energy Efficiency category. The purpose is to find a more efficient assessing method, encouraging and supporting designers to optimise their projects. More efficient methods can contribute to more sustainable constructions and to decrease the construction industry's environmental impact. To explore if Revit and GBS can streamline the assessment of this SBTool^{PT}-H category, a case study was carried out. A reference building was created which complied with all the current Portuguese regulations. The reference building was then modelled in Revit and submitted to an energy analysis using GBS. The results showed for indicator P7, that the use of GBS and Revit streamlines the assessment by faster extraction of information thanks to the 3D-model and the energy analysis software. However, the assessment could be made even more efficient if the software and national regulations were more matched such as conformity of units and analysed parameters. Concerning indicator P8, the results showed clearly that using GBS is a rather efficient process.

Keywords: sustainable construction, SBTool, BIM, Building Sustainability Assessment, energy efficiency



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Concept for a BIM-based Material Passport for buildings

M Honic¹, I Kovacic¹ and H Rechberger²

¹ Vienna University of Technology, Institute for Interdisciplinary Building Process Management, Vienna, Austria

² Vienna University of Technology, Institute for Water Quality and Resource Management, Vienna, Austria

meliha.honic@tuwien.ac.at

Abstract. Minimisation of resources consumption belongs to the main concerns of EU, resulting in the development of strategies for maximizing recycling rates in order to minimize environmental impacts and energy consumption caused by extraction of primary materials. Detailed knowledge about the embedded materials as well as their characteristics of building stocks is crucial in order to enable high recycling rates and low environmental impacts of buildings. In this paper, we will present the results of the funded research project BIMaterial: Process design for a BIM (Building Information Modelling) -based Material Passport. The concept of the BIM-based Material Passport is used for evaluating the recycling potential and environmental impact of materials embedded in buildings. The BIM-based Material Passport assesses all materials including their quantitative and qualitative properties, thus significantly supporting recycling and reduction of environmental impacts. Further, the BIM-supported Material Passport serves as design optimization tool and enables the generation and comparison of variants thus supporting the decision making process. The main aim of this research is to generate a BIM-based Material Passport for the optimization of the building design regarding resources use and documentation of materials, thereby using Building Information Modelling as knowledge base for geometry and material properties and coupling to further databases for assessment of ecologic footprint and recycling potentials. Thereby a framework for modelling and the methodology for the semi-automated generation of the BIM-based Material Passport will be proposed.

Keywords: Material Passports, resources efficiency, recycling potential, BIM



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The Importance of City Information Modeling (CIM) for Cities' Sustainability

H S Dantas¹, J M M S Sousa² and H C Melo¹

¹ Civil Engineering Department, Instituto Federal de Minas Gerais, Rua Severo Veloso, 1880, Bela Vista, Piumhi, MG, 37925-000, Brazil

² Civil Engineering Department, Instituto Superior de Engenharia do Porto, Porto, 4200-072, Portugal

dantashiago@gmail.com

Abstract. The urban population growth has caused an increase of infrastructure systems' complexity and consequences of human activity to the environment. Therefore, it is essential that sustainability concepts are implemented in urban development. This paper presents a study of how City Information Modeling (CIM) can contribute to improve public services and the quality of life of citizens. In order to reach these goals, the authors analyzed the International Standard ISO 37120 (Sustainable development of communities – Indicators for city services and quality of life) and evaluated how data from Building Information Modeling (BIM) and CIM can be used to obtain data for the indicators of the ISO. The study concludes that BIM and CIM models can provide data for 53 of 100 existing indicators in a simpler and more accurate way. This approach can assist the city's managers to take assertive decisions and contribute to improve the evaluation of public services performance.

Keywords: Sustainability, ISO 37120, urbanism, urban planning, BIM, CIM.



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Integration of environmental life cycle information in BIM objects according with the level of development

V Durão¹, A A Costa¹, J D Silvestre¹, R Mateus² and J de Brito¹

¹ CERIS, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal

² University of Minho, Department of Civil Engineering, Guimarães, Portugal

vera.durao@tecnico.ulisboa.pt

Abstract. The construction sector is a major contributor to global environmental impacts. This is one of the reasons why there is a political trend towards a “greener” sector. One indicator of this trend is the progressive application of life cycle thinking approaches and life cycle assessment of products, assemblies and buildings. The digitalization of construction projects, namely the use Building Information Modelling (BIM), can constitute a support to the automation of the application of Life Cycle Assessment (LCA) at the building’s design stage. However, besides the complexity of LCA model and results interpretation, BIM models usually lack LCA data that allow environmental impacts calculation. Currently, few publications explicitly relate the integration of LCA and BIM with the specificities of distinct development stages in the design and construction process or Levels of Development (LOD) of BIM objects. This paper summarizes the possible sources of LCA information to include in BIM models and discusses the complexity of LCA information needed for distinct BIM objects’ LOD. A parametrization of environmental information is proposed, to be included in BIM objects, based on an evolutionary level of detail in LCA information for increasing LODs.

Keywords: LCA (Life Cycle Assessment), BIM (Building Information Modelling), LOD (Level of Development), building sustainability



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Implementation of City Information Modeling (CIM) concepts in the process of management of the sewage system in Piumhi, Brazil

H C Melo¹, S M G Tomé¹, M H Silva², M M Gonzales¹ and D B O Gomes¹

¹ Civil Engineering Department, Instituto Federal de Minas Gerais, Rua Severo Veloso, 1880, Bela Vista, Piumhi, MG, 37925-000, Brazil

² Information Technology Support Department, Instituto Federal de Minas Gerais, Fazenda Varginha, s/n, Zona Rural, Bambuí, MG, 38900-000, Brazil

humberto.melo@ifmg.edu.br

Abstract. The municipality of Piumhi, Brazil, lives with sewage system problems. Currently the model used by the SAAE (local Water and Sewage Public Provider) only provides corrective actions. The combination of the concepts BIM and GIS will allow the movement towards the City Information Modeling, seen in a promising way for public management. The purpose of this research is to develop a management model for the sewage network that focus on preventive actions, allowing a decision-making process based on accurate information. Meetings were held with the municipal autarchy, enabling a diagnosis of the current situation and the determination of strategies for dices collect. 1731 wells were surveyed, with the following data collected: depths, geographic coordinates, diameter, pipe's material and flow direction in each section. The wells in the sewage network were 1291 visible, 316 unseen and 64 non-precision coordinates. The wells in the sewage interceptors were 56 visible and 4 unseen wells. Due to the high percentage of unseen wells (18,5%) many alignments of the sewage network were no determined, what is recommended to be done as maintenance occurs in the existing infrastructure. A web management tool for QGis and tutorials will be, allowing SAAE to carry out the preventive management of the sewage network. The development of a reliable database will allow the identification of problems and the comparison of the conditions and characteristics of the existing networks, allowing the SAAE to define assertive actions to improve infrastructure performance and generate savings in financial resources, equipment and manpower.

Keywords: Building Information Modeling, City Information Modeling, Geographic Information System.



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