

Kewin Niewiarowski

Material Passport and Material Bank:
An in-depth analysis of its capabilities and perspectives
for implementation based on selected case studies.

Enoncé théorique
Master - Architecture
Ecole Polytechnique Fédérale de Lausanne

Under the direction:
Prof. Corentin Fivet
Prof. Philippe Thalmann
Clemens Waldhart, EPFL master



2025 Kewin Niewiarowski
This document is made available under the terms of the Creative Commons Attribution License (CC BY <https://creativecommons.org/licenses/by/4.0>). Content from external sources is not subject to the CC BY license, and its use requires the permission of its author.

I'd like to thank all those who have contributed, directly or indirectly, to the realization of this work, Corentin Fivet, Clemens Waldhart and Philippe Thalmann for their guidance and advice, my family and friends for their support and Lukas Gschweidl who helped me with my research.

Table of content

Chapter I - Context of Material Passport and Material Bank

- 1. The need for a circular economy
- 2. Material without identity
- 3. Paradigm shift
- 4. Material Passport - concept explanation and advantages
 - 4.1 Transforming factor
 - 4.2 What is Material Passport?
 - 4.3 Concept of Material Bank
 - 4.4 Dynamic resource storage
 - 4.5 Financial benefits
 - 4.6 Challenges and problems
- 5. Why bring up the subject?
 - 5.1 Gap in Architecture, Engineering, Construction digitalisation
 - 5.2 Benefits and challenges of digitization
- 6. New stakeholders on market
 - 6.1 Place of the Architect

Chapter II - Working with existing

- 1. Urban mine - Felix Heisel's Ithaca Selective Sustainable Deconstruction Ordinance
 - 1.1 Preparation of the digital inventory
 - 1.2 LiDAR scanning
 - 1.3 Compilation of survey data with 3D Model
 - 1.4 Conclusion
- 2. Urban scale Material Bank
 - 2.1 Context
 - 2.2 Methodology
 - 2.3 Panelled deconstruction
 - 2.4 Results
- 3. Demolition and what comes next - Physical Material Banks
 - 3.1 Swiss context
 - 3.2 Matériuum
 - 3.3 Swiss market - macro picture
 - 3.3.1 Disassembly, evaluation, storage, distribution
 - 3.3.2 Knowledge and IT solution providers
 - 3.3.3 Research and university centers
 - 3.3.4 Architectural and construction offices involved in Reuse
 - 3.4 Realistic use of materials from Reuse
 - 3.5 Brakes of reuse
- 4. What can be done to improve the current state of Reuse?
 - 4.1 Technical details - web scrapping
 - 4.2 BIM Interface
 - 4.3 Conclusions

Chapter III - Material Passport in practice and in details

- 1. New Buildings - case study
 - 1.1 A model example of the new approach - Urban Mining and Recycling unit (UMAR)
 - 1.2 Design for disassembly on all scales
 - 1.3 Separation of biological and technical materials
 - 1.4 Reuse, recycling, composting
 - 1.5 Self-sufficiency in materials
 - 1.6 Product as a service

- 1.7. Conclusions
- 2. Information management systems
 - 2.1 Madaster
 - 2.2 Building explorer view
 - 2.3 Building process tab
 - 2.4 Circularity indicators
 - 2.5 Financial indicators
- 3. Proof of concept - application of Madaster tools on UMAR's case
 - 3.1 Methodology - data collection
 - 3.2 Methodology - data processing - obtaining indicators
 - 3.3 Results
 - 3.4 Conclusions
- 4. Material Passport - application and workflow in practice (how to really use it)
 - 4.1 BIM
 - 4.2 Standards and models
 - 4.3 IFC
 - 4.4 Export to Madaster - requirements
 - 4.4.1 Positioning in the coordinate system
 - 4.4.2 IFC units
 - 4.4.3 Unique GUID
 - 4.4.4 Material
 - 4.4.5 IFC-type
 - 4.4.6 SfB classification
 - 4.4.6 Base quantities
 - 4.4.7 Property Set
 - 4.4.8 2x3 export
 - 4.5 Generating material passport in practice
 - 4.6 Problems in exports
 - 4.7 Lessons and problems with Material Passport in practice

Chapter IV - Case studies

- 1. Temporary City Hall, Rau Architecten, 2011 Brummen, the Netherlands - a building designed as a Material Bank
 - 1.1 Design as a service
 - 1.2 CS1: Maximize material and energy efficiency
 - 1.3 CS2: Extend product value - standardization
 - 1.4 CS3: Extending the value of resources
 - 1.5 Relationships and cooperation between stakeholders
 - 1.6 Inter-industry cooperation - conclusions
 - 1.7 Conclusion
- 2. Triodos Bank Building - Material Bank?
 - 2.1 Materials - BREEAM shadow cost vs reuse potential
 - 2.2 Construction - Deconstruction
 - 2.3 Conclusions

Chapter V - Conclusion and reflection

- 1. Can architecture really be something dynamic? - Metabolism
- 2. What can be done to make Material Passport really work?
 - 2.1 Criticism of Material Passport
 - 2.2 Perseverance and readability of data in long perspective
 - 2.3 Lack of will for long time investments
 - 2.4 Lack of cases that will prove the idea's credibility
- 3. Conclusion
- 4. Master project opening

Abstract

This paper discusses the concept of the circular economy in relation to the Material Passport and Material Bank, which aim to sustainably manage resources in construction. It discusses innovative approaches to building design in the spirit of Design for Disassembly and the implementation of Material Passport with examples of completed projects of different nature. It analyses the role of tools such as BIM (Building Information Modelling) and digital platforms such as Madaster that enable material data management and the creation of building databases as dynamic asset stores.

The article analyses what I consider to be the most important buildings and projects for the Material Passport concept that have been developed to date, such as the Catherine Commons Deconstruction Project - an experimental project in Ithaca (NY, USA), the Urban Material Bank in Ithaca - a digital material database for more than 11,000 residential buildings, UMAR - Urban Mining and Recycling Unit, Brummen City Hall and the headquarters of Triodos Bank. The selection of examples was not left to chance as all these buildings represent a different approach to the problem. Many other concepts and theoretical experiments relating to the issue under study were also analysed.

The paper highlights key challenges, such as the lack of standardised standards, difficulties with long-term maintenance and data interoperability, and the need to adapt new technologies in a conservative building industry. It also identifies the potential of the circular economy to reduce waste, carbon emissions and material costs, making it a viable solution both environmentally and economically.

Résumé

Ce document aborde le concept d'économie circulaire en relation avec le passeport des matériaux et la banque des matériaux, qui visent à gérer durablement les ressources dans la construction. Il aborde les approches innovantes de la conception des bâtiments dans l'esprit de la conception pour le désassemblage et de la mise en œuvre du passeport des matériaux, à l'aide d'exemples de projets achevés de nature différente. Il analyse le rôle d'outils tels que le BIM (Building Information Modelling) et de plateformes numériques telles que Madaster, qui permettent la gestion des données sur les matériaux et la création de bases de données sur les bâtiments en tant que réserves d'actifs dynamiques.

L'article analyse ce que je considère comme les bâtiments et les projets les plus importants pour le concept de passeport de matériaux qui ont été développés jusqu'à présent, tels que le projet de déconstruction Catherine Commons - un projet expérimental à Ithaca (NY, USA), la banque urbaine de matériaux à Ithaca - une base de données numérique de matériaux pour plus de 11 000 bâtiments résidentiels, UMAR - Urban Mining and Recycling Unit, l'hôtel de ville de Brummen et le siège de la banque Triodos. La sélection des exemples n'a pas été laissée au hasard, car tous ces bâtiments représentent une approche différente du problème. De nombreux autres concepts et expériences théoriques liés à la question étudiée ont également été analysés.

Le document met en évidence les principaux défis, tels que l'absence de normes standardisées, les difficultés liées à la maintenance à long terme et à l'interopérabilité des données, ainsi que la nécessité d'adapter les nouvelles technologies dans un secteur de la construction conservateur. Il identifie également le potentiel de l'économie circulaire à réduire les déchets, les émissions de carbone et les coûts des matériaux, ce qui en fait une solution viable tant sur le plan environnemental qu'économique.

1. The need for a circular economy

Earth is a system characterized by closed-loop operation, the exchange of matter between our planet and the rest of the cosmos is marginal. The only significant resource in the positive balance of exchange is solar energy, which does not contribute to gains in mineral or water resources. Everything we are able to find here is here and will stay here forever. It is therefore logical to conclude that the resources given to us on earth must be used in the manner of a closed cycle. So in order to continue the development which is the basis for the existence of most of our communities and economic systems, at some point it will be necessary to manage more responsibly the resources which today we consider as waste. The resources of our planet can thus be seen as a finite number of matter where each unit has a finite value.¹

Current economic systems are based on growth models that assume infinite sources of raw materials. This seems an understandable oversimplification and very characteristic of humanity planning only for the immediate future. No matter how hard we try, at some point the reuse of raw materials will be necessary for further development and postponing this into the distant future will only make this task more difficult.² This is also compounded by the current status of pollution because some raw materials are classified as waste in advance and most new buildings and products are designed in advance to be non-degradable and impossible to reuse easily.

A good example would be the markets for fossil fuels or rare earth metals. Both of these types of raw materials are extremely important elements for our economies. In the long term, however, they may run out, or become less available, for example, as a result of the difficulty of exploiting inaccessible deposits. In the face of such constraints, the concept of a closed-loop economy where waste is minimized and reuse of raw materials is minimized seems very reasonable. Time may show that such a change will not only be a measure to improve the quality of the environment and protect the planet, but also a sensible and good solution for the economy.³

¹ Commoner, Barry. *The Closing Circle: Nature, Man, and Technology*. New York: Knopf, 1971.

² Daly, Herman E. *Beyond Growth: the Economics of Sustainable Development*. Boston: Beacon Press, 1996

³ Raworth, Kate. *Doughnut Economics: Seven Ways to Think Like a 21st-Century Economist*. White River Junction: Chelsea Green Publishing, 2017

2. Material without identity

"Waste is material without an identity".
~ T. M. Rau

Like other products of human production, buildings have a definite life cycle, from design through construction, use and demolition. When their life is nearing its end, they are abandoned or dismantled, and their components usually end up as waste. Buildings erected on valuable land are dismantled and materials segregated depending on local regulations. Where land is not valuable, they are simply abandoned. In most cases, this is also because the materials they are made of are not known to us, and it is too costly and time-consuming to catalog and consider their reuse. Thus, it can be said that a material that becomes waste is a material without identity that is not worth segregating.

This "identity" if known beforehand could help determine the value and sense of considering dismantling a building instead of demolishing and then reusing the item or recycling it (not only because of land prices but also the value of the material to be recovered). This poetic-sounding term is actually a very pragmatic idea referring to the knowledge of the origin, composition properties and history of a given raw material. This is a very important part of a closed-loop economy system because it enables efficient resource management and waste minimization. Awareness of the identity of materials also allows for accurate tracking of raw materials at each stage of a building's life and allows for their management for future projects.⁴

⁴ Durmisevic, Elma. "Transformable Building Structures: Design for Disassembly as a Way to Introduce Sustainable Engineering to Building Design & Construction." PhD diss., Delft University of Technology, 2006.



fig. 3

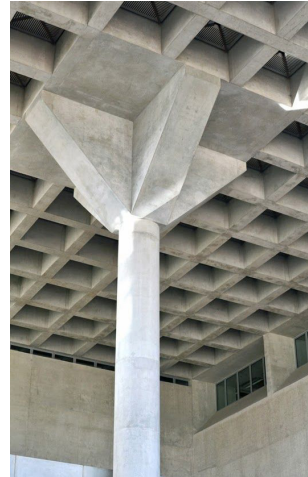


fig. 4. XX century concrete slab
(source. evimshahane.com)



fig. 5. XXI century concrete slab
(source. albau.com.pl)

3. Paradigm shift

Human nature actually always leads us to easier and less energy-intensive solutions. In the biology of our body, all functions are geared toward optimal energy use and our habits if not subjected to personal strong constraint, they will evolve toward the easiest and least energy-intensive activities for the body. The same has historically been true of building. Often, people finding themselves in new eras instinctively rebuilt structures left behind by predecessors or dismantled them to obtain materials for current building purposes. Recycling building materials and adapting existing structures was a natural choice, especially during periods of resource scarcity. A good example is the Middle Ages where the ruins of Roman buildings provided a valuable source of materials for new construction. This was due not only to practical considerations but mainly to economics where it was simply cheaper to obtain already worked stones or beams than to produce new ones.⁵ Architecture was thus often a continuous story and the previous era literally built the next.

A similar logic continued for centuries until the industrial revolution. We can see a clear change only at the beginning of the 20th century when the ratio of labor costs to the price of materials began to change. Prior to that, architects and designers sought to save as much as possible on materials at the expense of more complex construction. This is well illustrated by the example of the complex forms of concrete structures that we can often see in old buildings, requiring considerable skill and labor but saving valuable material.⁶

A marked change in this trend is observed only at the end of the second half of the 20th century where, thanks to mass production and the progressive radical industrialization, material prices are falling below the cost of labor. Modern construction is all about time efficiency and simplicity of execution. What matters is the rapid erection of buildings without much emphasis on the ability to dismantle the material or its minimal consumption. With rising labor costs, saving manpower has become a priority.⁷ Consequently, the end of a building's life often marks the end of the useful life of the materials used, as the high labor intensity required for material recovery and reuse often makes such efforts economically unfeasible. By not thinking about this phase, they are usually very difficult to recover which hinders effective waste management and prevents reuse. So how can the idea of reuse gain traction again and the former balance restored?

⁵ MacDonald, William L. *The Architecture of the Roman Empire: An Urban Appraisal*. New Haven: Yale University Press, 1986.

⁶ Kostof, Spiro. *A History of Architecture: Settings and Rituals*. New York: Oxford University Press, 1995.

⁷ Schneider, Tatjana, and Jeremy Till. *Flexible Housing*. Oxford: Architectural Press, 2007.

4. Material Passport - concept explanation and advantages

4.1 Transforming factor

The construction sector is one of the largest consumers of natural resources in the world and so its transformation will play a key role in shaping a sustainable future. Current raw material consumption statistics reach 40% for AEC (Architecture, Engineering, Construction) and the industry itself is responsible for almost 35% of all waste⁸ which poses a serious environmental and economic challenge. The linear economic model assuming an inexhaustible amount of resources and unlimited ability to create waste is slowly becoming untenable and the shrinking amount of resources and the difficulty of recycling is realistically wasting resources, energy and financial resources.

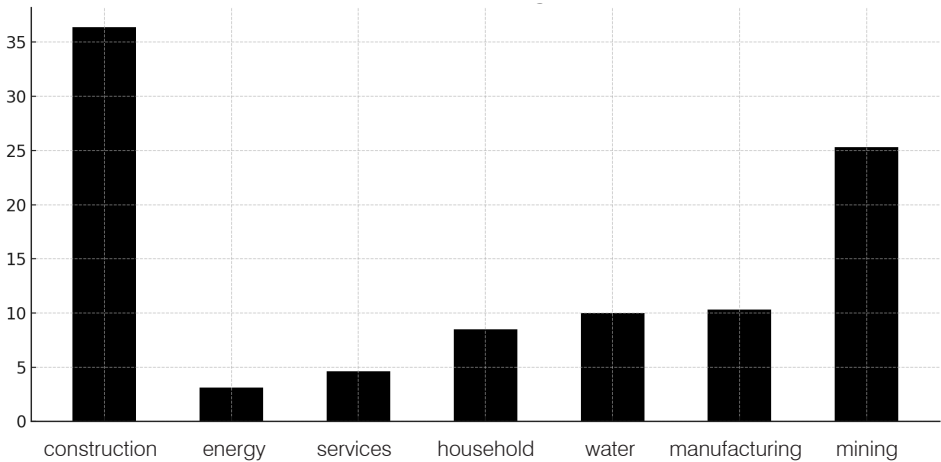


fig. 6. percentage of waste in different market branches

A kind of solution to these problems can be the Material Passport concept, which completely changes the way we think about materials. For they cease to be disposable components which once used in a building remain forever a conglomerate, but a resource, a reusable raw material. The idea would be that the life cycle of a material could be counted, which would far exceed the life cycle of a building. Currently, after demolition we are left with a pile of rubble, in the case where each material already had its identification we would be dealing with a bank of materials which the building becomes after the end of its useful life.⁹

4.2 What is Material Passport?

Material passport is a concept, but in the industry we can meet it as a digital document - most efficient when it is assigned to the BIM (Building Information Modeling) model of its component, making detailed informa-

⁸ Durmisevic, Elma. "Transformable Building Structures: Design for Disassembly as a Way to Introduce Sustainable Engineering to Building Design & Construction." PhD diss., Delft University of Technology, 2006.

⁹ MacArthur, Ellen. Towards the Circular Economy: Economic and Business Rationale for an Accelerated Transition. Cowes: Ellen MacArthur Foundation, 2013.

tion about the materials used in a given project easy to manage. It acts as a digital identity for each raw material, allowing it to be identified, tracked and evaluated for potential reuse.¹⁰ Key data include: chemical composition of the material, physical properties, technical characteristics, durability, weather resistance, safety of use, fire class, carbon footprint and energy efficiency data¹¹ and reusability assessment and disassembly instructions

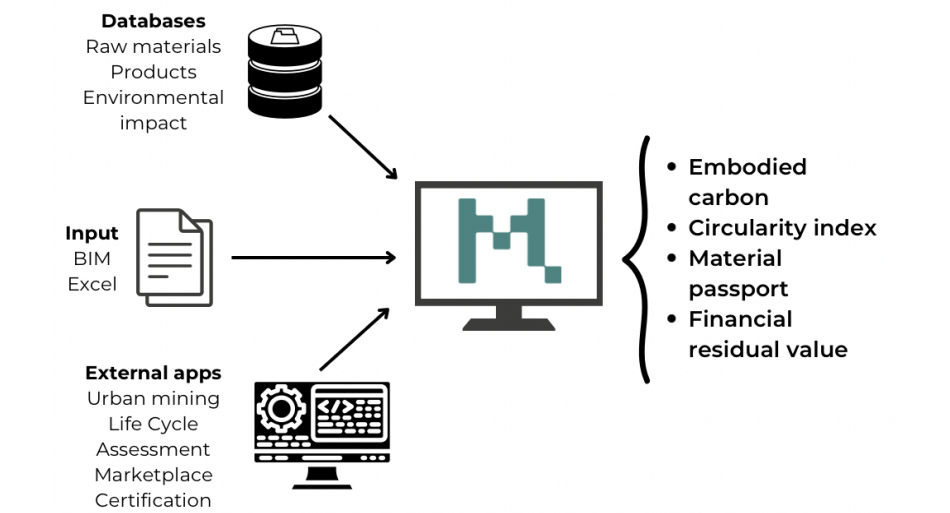


fig. 7. Simplified data flow for Material Passport creation (source. Madaster 2019a)

There are many forms of Material Passport. As it is an idea, it can be represented at least as an Excel table but also as a complete BIM model of a building, a distributed system based on blockchain¹², a SQL (Structured Query Language) database accessible through third-party web platforms or even an index in a paper book. The most useful, of course, are digital models like BIM or databases because they allow for advanced information management and thus effective management of the life cycle of a building and its assets. Just like a label on a product contains information about the components, however, the whole state-of-the-art is the ability to have all this information in one place and the aforementioned ability to manage it. Collecting such detailed information is a major challenge, but at the same time offers a huge opportunity. Thanks to the increasing complexity of the data, material passports offer the possibility of a deeper understanding of the resources inside a building and their value from an economic, social and environmental perspective. Collecting such detailed information is a major challenge, but at the same time offers tremendous opportunities. With the increasing complexity of the data, material passports offer the possibility of a deeper understanding of the resources inside a building and their value from an economic, social and environmental perspective.

¹⁰ Heisel, Felix, and Philip Rau-Oberhuber. "Designing for Disassembly and Circularity: Case Study of a Transformable Building Prototype." Journal of Cleaner Production 245 (2020): 118-121.

¹¹ Adams, Katherine T., Michael Osmani, John Thorpe, and Charles Thornback. "Circular Economy in Construction: Current Awareness and Challenges." Proceedings of the Institution of Civil Engineers - Waste and Resource Management 170, no. 1 (2017): 15-24.

¹² <https://www.metabolic.nl/news/circular-economy-materials-passports/>



fig. 8

4.3 Concept of Material Bank

In previous paragraphs, the term Material Bank has often been mentioned, but what exactly is it? With a complete Material Passport database for a building or multiple buildings, a catalog of materials available at the end of a building's life cycle can be created. An organized system of information collection that can enable the creation of local and regional material databases.¹³ Imagine a scenario in which a building at the design stage received a full implementation of Material Passport. After 50 years, the next generation of architects receives a catalog of objects and elements with full 3D representation and complete information and is ready to create a new design based on fully reusable materials. Architects and developers could also plan new developments based on available resources that could prove much cheaper to use than new materials. It could also contribute to the realization of the 0km construction site concept. An accurate model could serve as a tool for planning the deconstruction and construction of a new building on the same plot of land.



fig. 9 Estimating material mass in urban scale Material Bank, city of Ithaca (source: F. Heisel).

4.4 Dynamic resource storage

The most interesting thing about this is the ability to plan and manage these resources even before demolition. The biggest problem with reuse today is that you have to dismantle the building, assess the condition of the materials, take the necessary parameters and then still transport, store and sell the item. This is an incredibly complicated process that significantly increases costs and consumes valuable time. This is one of the many reasons why reuses today are a curiosity rather than a common

¹³ Dufresne, A. 2014. Recycled Building Materials for a Sustainable Construction Industry. *Construction and Building Materials* 68: 124-133.

approach to construction. Simply shortening the cycle by collecting the information (which would already be included in the passport) and storing and repeatedly transporting it from place to place could make reuse something cost-effective and much more attractive to designers, builders and investors.

4.5 Financial benefits

According to a study for the Amsterdam Metropolitan Area, it showed that the 2.6 million tons of construction materials released each year during renovation and demolition in Amsterdam are worth \$688 million¹⁴. These are significant numbers that are now being dumped in landfills every year. So what can be done to access these resources? This raises an important question: why do business entities dispose of materials of such apparent value? Is it because they are unaware of their value, legal or logistical barriers prevent their reuse or the materials have little practical value after all? Understanding these dynamics is central to determining how to effectively access and reuse these resources

fig. 10 Steel maximum concentration in the Urban Mines of Amsterdam, (source: code.waag.org)

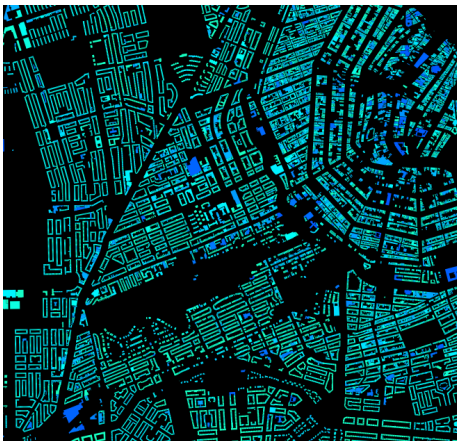
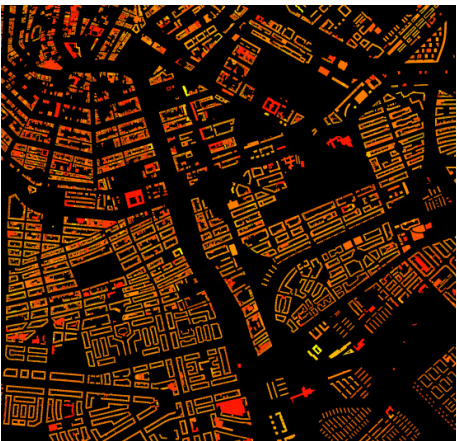


fig. 11 Copper minimal concentration in the Urban Mines of Amsterdam, (source: code.waag.org)



First, the current transition from a conventional linear economy to a circular economy is not efficient. Its main drivers are government regulation and the willingness of individual private actors to act in an environmentally friendly manner. The change should be driven by positive factors, such as a clear message: we catalog materials and design in a way that makes closed-loop circulation both cost-effective and easy with digital catalogs. Fully implementing Material Passport into the design process can bring numerous financial benefits to investors, developers and the industry as a whole.

One of the most interesting financial benefits is the ability to estimate

14 Metabolic. "Materials Passport for a Circular Economy," November 25, 2019. <https://www.metabolic.nl/news/circular-economy-materials-passports/>.

the potential value of materials as early as the building design stage. The materials used, both structural elements and finishes, are recorded and evaluated for reuse and potential for future sale. The easiest thing to imagine is the dismantling and reuse of structural elements, steel or wooden beams are elements that are also commonly reused today. But what if all parts of a building suitable for this had such potential including trim, detailing, doors, bathroom fixtures, plumbing, etc.? This could be a serious argument for investors to turn to solutions with greater recycling and reuse potential because these materials will become their asset. The large expense of construction will be partially offset by the potential sale not only of the land but also of the building elements in the future and the demolition itself may cease to be a nuisance. Finally, there is also an argument for buyers. Having full documentation can convince the customer more easily, it increases trust and facilitates transactions.¹⁵

So the obvious conclusion from the above also seems to be savings for investors of newly constructed buildings. A greater supply of recycled materials should significantly reduce their price. Developers and investors can therefore take advantage of cheaper materials available on the secondary market¹⁶. It would also be an interesting argument to compare the efforts and costs of extracting materials through the mining process to recycling. How many cycles would a material have to go through to make it significantly cheaper than those that have to be mined from scratch and then transported?¹⁷

Beyond this, there can be a number of other benefits from using Material Passport. Indirectly, by saving more raw materials, energy demand can be reduced and the carbon footprint of their extraction can be reduced - The processes of extracting, processing and transporting construction materials are energy-intensive. In addition, in the context of rising energy and raw material prices, efficient resource management is becoming increasingly cost-effective. This array of multidimensional benefits could ultimately lead to an increase in the attractiveness of sustainable investments. Investors would be more likely to turn to buildings that meet the criteria of non-linear economics in search of higher rates of return or more stable investments with a guaranteed return of some funds at the end of the building's useful life.

4.6 Challenges and problems

Having presented the topic from the best side, it is important not to forget the problems that still afflict both the Material Passport concept and the entire segment of the reuse industry. I would like to outline the main prob-

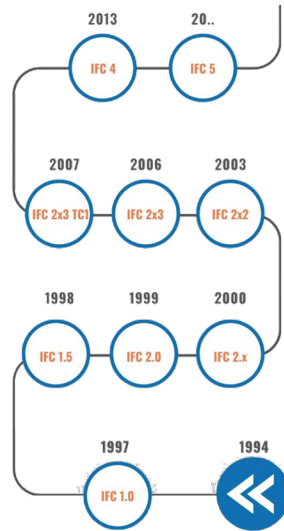


fig. 12 IFC format evolution over the years (source: bimcorner.com)

16 MacArthur, Ellen. Towards the Circular Economy: Economic and Business Rationale for an Accelerated Transition. Cowes: Ellen MacArthur Foundation, 2013.

15 Adams, Katherine T., Michael Osmani, John Thorpe, and Charles Thornback. "Circular Economy in Construction: Current Awareness and Challenges." Proceedings of the Institution of Civil Engineers - Waste and Resource Management 170, no. 1 (2017): 15-24.

lems of this technology before proceeding with a proper critique in the second part of the paper. Digital cataloging can certainly be a watershed moment for modern construction, but for it to come to fruition it must spread on a very large scale.

Scale primarily requires unified tools and standards. I mentioned earlier that Material Passport can take different forms. Currently, many entities are developing their own documentation systems which differ in their structure or data storage format. The need to translate data into another format is associated with additional costs, complexity and loss of some information during the translation process. This is a well-known problem that the IFC (Industry Foundation Classes) standard faced for a long time. The same example also shows that over time there has been a natural unification of the data structure and the mentioned format has today become a standard for inter-industry cooperation in the AEC.

Time may also prove to be a problem. Over time, formats will evolve, and no one can predict whether today's files will be usable and readable in 50 or 70 years.

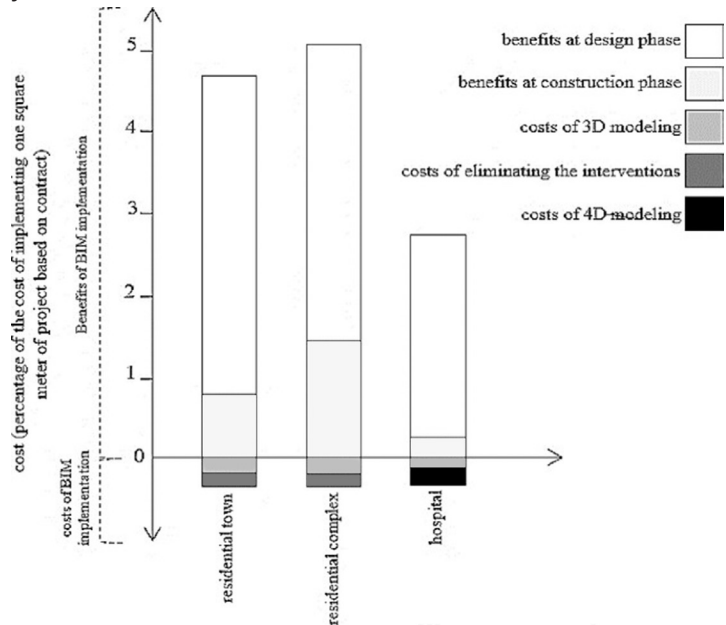


fig. 13 Costs and benefit from BIM implementation - to compare with potential Material Passport implementation (source: "Cost-benefit analysis of building information modeling implementation

Besides, despite the numerous financial benefits overall, a massive financial investment is first required to update and restructure current material databases. Each manufacturer would have to build its own database, moreover, based on a unified standard that would be simple, readable by the most popular programs and stand the test of time. It could also turn out that existing digital databases require constant maintenance.

As with PDF (Portable Document Format) and IFC, the big question is security and intellectual property rights. This type of comprehensive set of building information should remain private. In an increasingly digital world, however, this may not be easy. The key is to create clear rules regarding privacy and the sharing of information contained in passports. The data contained in the directory must remain reliable and vulnerable to malicious modification. Subsequent owners of a building must be assured that the data on materials and supply chains has not been previously altered and that the owner was not misled when purchasing the property. There is a similar issue with sharing this data. This requires the existence of a new stakeholder, intermediary or platform where such information would be stored, blockchain technology comes to mind, which makes it possible to modify the digital footprint.

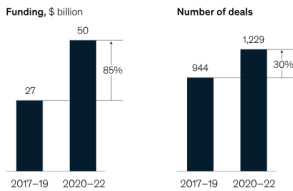


fig. 16 Global investments in AEC tech grew to \$50bln 2020-2022 (source: McKinsey Global Institute)



fig. 14 Circular Economy Action Plan cover (source: Publications Office of the European Union)

fig. 15 BAMB report, Framework for material passport cover (source: EPEA Netherland BV, SundaHUS i Linköping AG)

A final problem would be the differing standards and laws across countries. Currently, the lack of uniform regulations and standards is a major barrier to MP development. In the European Union, for example, recycling guidelines alone are not standardized, not to mention such elaborate concepts as Material Passport. While there are a number of initiatives such as Level(s), a European system for assessing the sustainability of buildings, or Circular Economy Action Plan¹⁸, an initiative to create a legal framework to support sustainable construction, they do not yet regulate Material Passport or even create a framework for its operation

¹⁷ European Commission. Level(s) - A Common EU Framework for Sustainable Buildings. Brussels: European Commission, 2020.

5. Why bring up the subject?

5.1 Gap in Architecture, Engineering, Construction digitalisation

The architecture, engineering and construction (AEC) sector is one of the largest and most influential in the world. According to the McKinsey Global Institute, its market value in 2022 was \$8 trillion, and is projected to reach \$16.5 trillion by 2030. Despite generating about 6% of global GDP, AEC is one of the least digitized industries - ahead of only agriculture. Moreover, only 1.5% of the sector’s revenue is invested in digitization, which is a serious barrier to its growth.¹⁹ With the sector’s obvious raw material and energy needs, we can easily imagine the correlation of these numbers to environmental impacts.



fig. 17 McKinsey Global Institute industry digitalisation index (source: McKinsey Global Institute)

The large underdevelopment of the sector’s digitization naturally seems to be creating new opportunities for growth to come. The digitization potential of AEC is increasingly recognized as a transformative force and the revolution that is coming has been predicted for many years by experts.²⁰ Historically, this branch of the economy has always lagged behind in terms of implementing new solutions. It has relied mainly on traditional practices that have naturally slowly evolved over the years in the complex value chain of the construction industry. Recent trends, however, indicate a change. Demand for infrastructure is growing rapidly and is even reversed by a decline in skilled labor²¹ resulting in an urgent need for increased work efficiency and the need for data transparency.

²⁰ McKinsey Global Institute. Reinventing Construction: A Route to Higher Productivity. McKinsey & Company, 2017.

5.2 Benefits and challenges of digitization

The revolution that has been rumored for years and still hasn’t arrived this time may turn out to be a real phenomenon. Between 2020 and 2022, the sector saw a surge in investment in AEC technology, with late-stage venture capital reaching some \$11.5 billion, more than triple the amount in the previous three years.²² In addition, the COVID-19 pandemic acted as a catalyst, accelerating the adoption of digital technologies and highlighting their critical role in ensuring project continuity and collaboration in a rapidly changing environment.²³ This investment boom means a dramatic increase in the need for digital tools to improve efficiency and facilitate management. With the right positioning with sustainable solutions such as Material Passport, it is possible to change the face of the industry in the coming years. The changes that are taking place today, the companies and institutions that are responsible today for creating digital passports and material databases are likely to set the first standards that, over time, will become constituted as common in use by architects and engineers worldwide.

So it is crucial that the format of these changes include environmental aspects such as Material Passport. As can easily be seen from the earlier statement, changes from the construction industry happen very slowly so the window that opens is certainly a rare opportunity to make changes.

Digitization is, of course, also a number of other benefits that I indirectly touched on earlier. Material Passport and the Material Bank concept also means more effective communication and collaboration through digital platforms that allow teams to better coordinate activities, thus minimizing the delays and misunderstandings that often plague traditional project management methods. In addition, the adoption of advanced analytics and data-driven decision-making can optimize resource allocation and project schedules, leading to more predictable and successful project completions and influencing better risk management.

Of course, there are also obstacles and difficulties. A major challenge is existing business models and the lack of digital strategies. Combined with overly assertive leadership and a lack of consolidation of ideas, it is difficult to make such solutions standard for the time being. In addition, the focus on short-term construction projects geared toward quick returns and “forgetting the issue” discourages experimentation with long-term investment prospects.²⁴

²¹ “AI And Digital Transformation for AEC Executives: A More Practical View,” n.d.

²³ Hall-Cotton, “Overcoming Resistance to Digital Tools in Construction: A Path to Modernisation &Rsquo; Commnia,” June 17, 2024.

²² <https://www.bcg.com/publications/2022/the-challenges-of-a-sustainability-transformation>

fig. 18 Benefits from Material Passport implementation (source: Madaster)



The human nature factor cannot be underestimated either, resistance to change among professionals complicates the task. People who have educated themselves for years and honed their skills while practicing are not eager to make new changes that often require additional effort, further training and sometimes a complete change in thinking. It is also worth remembering that in-service training may not sufficiently emphasize the need, potential and means of circularity and teachers themselves may also not be as eager to change their teaching practices. They fear (not unfoundedly) for the security of their jobs and the need to re-brand themselves when changes would require too much effort.²⁴ This resistance can significantly hamper efforts to innovate and adapt to the changing landscape of the AEC industry

²⁴ Saeid Kalantari, "Transforming the AEC Industry: a Closer Look at Digitalization Challenges," May 3, 2023, <https://www.linkedin.com/pulse/transforming-aec-industry-closer-look-digitalization-saeid-kalantari/>.

6. New stakeholders on market

This therefore provides natural opportunities for the emergence of new entities in which the role is not yet fully defined. In many professions, including the architectural profession, we can see fragmentation into increasingly specialized fields. This is because as we grow, our work is becoming more complex and one person is no longer able to lead the entire design of a modern building as it might have been in the past. Today, the term "master architect" refers to entire offices which then outsource individual tasks such as, for example, designing interior lighting or providing proper acoustics to other entities....

Material Passport is no different. Managing such large and complex amounts of data requires sophisticated IT systems that architects or civil engineers can no longer handle. Companies specializing in technology management offer platforms for cataloging building materials and tracking their lifecycle, and they also claim to provide readability and data protection over the lifecycle of a building. One such company is Madaster. Through its platform, it allows the management of materials data by offering the ability to calculate Life Cycle Assessment, store Material Passport, create asset balances or estimate costs and losses when reusing materials. The platform synchronizes with the model with an IFC file exported from the architect's or engineer's BIM program and allows for "useful" data visualization.

6.1 Place of the Architect

With the development of such technologies come new opportunities. Architects, too, may gain a new strategic role in this process. According to the American Institute of Architects (AIA), Architects in the new reality of AEC will be required to acquire many new competencies.²⁵ The principals of the architect's traditional role have been modified many times in the past, including in an era of increasing accumulation of knowledge and growing sustainability demands, his tasks will also include responsibility for efficient resource management and minimizing the carbon footprint of buildings. Designers are already responsible for the selection of materials that meet both technical requirements, have the potential for reuse and the final shaping of materials in accordance with the Design for Disassembly concept.²⁶

The ability not only to operate programs but also to create software for one's own use may also prove crucial. Something that today seems niche and abstract with advancing digitization may become essential.



fig. 19 In the literature, professional fragmentation and specialization is called "skill stacking" (source: photo by Maël BALLAND on CC)

²⁵ "Harnessing Innovation: How Technology Is Reshaping Architectural Design," theconstructor.org, October 18, 2023, <https://theconstructor.org/architecture/architectural-design/harnessing-innovation-how-technology-is-reshaping-architectural-design/573308/>.

²⁶ Heisel, Felix, and Philip Rau-Oberhuber. "Designing for Disassembly and Circularity: Case Study of a Transformable Building Prototype." *Journal of Cleaner Production* 245 (2020): 118-121.

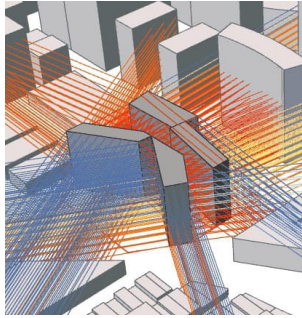


fig. 20 Building form optimisation for best visibility in Galapagos (source: architosh.com)

Most engineering professions have already undergone this transformation, and no one is surprised that an engineer who has nothing to do with IT has basic programming skills. Often they are no longer able to function without it, writing simple programs and scripts that crank them out in the most repetitive tasks can make their work much easier. We can also meet this in architecture, many people have heard about the capabilities of the Grasshopper plug-in for Rhinoceros 3D thanks to which, when used correctly, we can greatly optimize our design activities - make our work more efficient. Such solutions, although still niche, are becoming more and more common in modern architectural studios. Knowledge of programming allows architects to automate design processes, optimize construction and make better use of resources. Also, the development of modules in the BIM environment makes it possible to create personalized solutions and integrate material passports with digital building models²⁸

This helps not only in spatial design but also in data management. It should be remembered that material passport are concepts based on the collection of large amounts of data. This information is very difficult and time-consuming to process by a human being who wants to obtain the desired conclusions. Adequate data visualization can be very useful for design and greatly facilitate informed decision-making,²⁹ especially now when Material Passport standards are not yet generally accepted and data often have different structures requiring adaptation before use. The combination of multiple platforms can also be a fascinating prospect. Assuming we have a parameterized model compatible with Rhino+Grasshopper and a readable database combined with a combinatorial plug-in (e.g. Galapagos), we could generate thousands of design variations with different material options and then simply select the most optimal one. So digital tools give us amazing possibilities, but they require taking time and taking risks.

²⁸ Burry, Mark. *Scripting Cultures: Architectural Design and Programming*. Hoboken: John Wiley & Sons, 2011.

²⁹ Davis, Daniel. "Modeled on Software Engineering: Flexible Parametric Models in the Practice of Architecture." *Design Studies* 34, no. 6 (2013): 753-773.

1. Urban mine - case study

Felix Heisel's Ithaca Selective Sustainable Deconstruction Ordinance

So far, mainly ideas for improving Reuse for new buildings that are yet to be built have been discussed, but can the Material Bank concept also be applied to existing buildings? Admittedly, most of them are facing a major change in the future. Most of the buildings we know today will someday reach the end of their usefulness and will be demolished or thoroughly revitalized. The deconstruction and cataloging of materials from the house at 206 College Avenue in Ithaca (NY, USA) undertaken by Felix Heisel's team is an example of implementing the ideas of Reuse and Material Bank for existing old buildings. The whole undertaking is an experimental project carried out by researchers from the Cornell University College of Architecture, Art, and Planning. They saw an opportunity with the construction of new dormitories that were to stand a fragment of a typical American suburb of single-family homes.

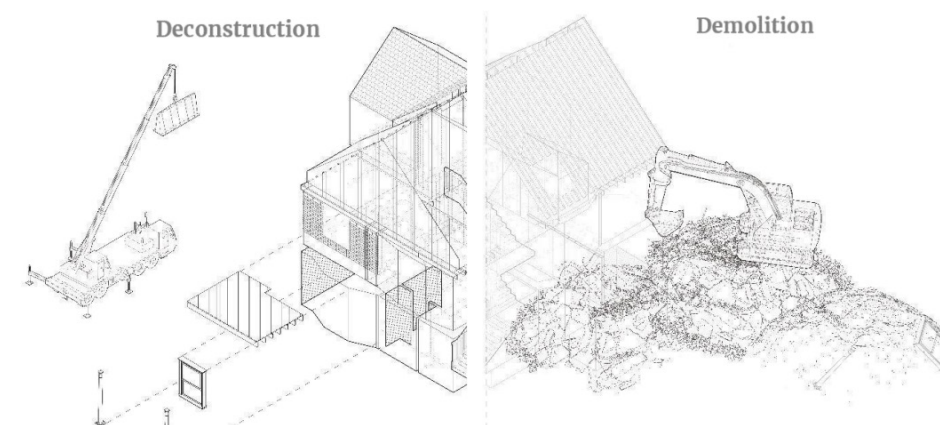


fig. 22 Panelled deconstruction vs demolition (source: Illustration by Allexus Farley-Thomas, Circular Construction Lab)

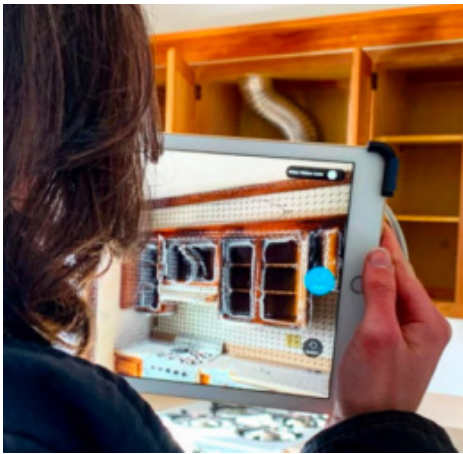
Part of the neighborhood was to be demolished by conventional methods without recuperation of materials. However, it was agreed with the developer that, as part of the Catherine Commons Deconstruction Project³⁰, one of the 3-story houses of about 400 square meters would be demolished by the Circular Construction Lab team from Cornell University and the materials reclaimed and reused. The only condition was the lead time; in a row of 9 houses, the last one was to be demolished by the team before the other 8 were demolished by the excavator. Time pressures thus demanded quick and planned action.³¹

³⁰ Heisel, Felix, "2022/23 SoA Lecture Series: Felix Heisel," Lecture Series, Charlotte College of Arts and Architecture, November 7, 2022.

²⁹ Heisel, Felix and Allexus Farley-Thomas. 2022. "Building Capacity and Knowledge in the Local Economy: The Catherine Commons Deconstruction Project" in Circular Construction and Circular Economy: Better Less Different Building by Felix Heisel and Dirk E. Hebel (Basel: Birkhäuser).

1.1 Preparation of the digital inventory

To meet the demands of time, the proprietary ScanR method developed by Circular Construction Lab was used for the inventory. Information gathering began with an on-site survey. It consisted of completing a pre-prepared excel sheet divided into 4 categories: “General building information,” “Preliminary site observations,” “Damage and Deterioration,” and “Material inventory” - the last category is also the most extensive. This is because it contains the most important information from a reuse perspective such as raw building materials, structural and architectural elements.³² In addition, they are described with quantitative and qualitative data - the type of materials, their dimensions (width, thickness, length), technical condition and installation methods. This process is illustrated in an example, where the introduction of two types of sheathing materials into the survey system is shown. The site visit procedure continues until a complete analysis of the building is completed. This is key data that will later complete the 3D LiDAR scan model, as we are not able to obtain the information needed to evaluate and classify assets with digital automated methods alone. It also reduces the risk of errors, thanks to the detailed questionnaire it is hard to “forget” to enter all the necessary information.



1.2 LiDAR scanning

When conducting an inventory of an existing building as well as when managing projects, there is always a certain amount of uncertainty and incomplete data. Providing a full set of information reduces uncertainty but at the same time significantly increases the cost and amount of time required to prepare the documentation. Thus, there is a point where additional information ceases to be cost-effective because its cost outweighs the benefits.³³

fig. 23 using iPad pro to 3D scanning (source: Felix Heisel)

fig. 24 data collection in ScanR formular (source: Joseph McGranahan)

³¹ Heisel, F, J McGranahan, and A Boghossian. 2022. “ScanR: A Composite Building Scanning and Survey Method for the Evaluation of Materials and Reuse Potentials prior to Demolition and Deconstruction.” IOP Conference Series: Earth and Environmental Science 1078

³² Mansour Esnaashary Esfahani et al, “Using Scan-to-BIM Techniques to Find Optimal Modeling Effort; a Methodology for Adaptive Reuse Projects,” Proceedings of the ... ISARC, May 24, 2019

This is exactly what was done, the researchers decided that scanning the building with sophisticated device technology such as Faro scanners was unnecessary in this case and would only significantly strain the budget and prolong the procedure. Thanks to an earlier site visit and manual data collection, Apple iPad Pros equipped with built-in 3D scanners and the Polycam LiDAR application proved to be the optimal option.³⁴ Any student present in the team could join the task without complicated training. It was important to maintain only a few parameters for this - there should be good lighting in the room, the device should be at a distance of at least 1.5m from the object being scanned and the movement of the scanner should be slow and steady to negate the risk of inaccuracy. The file was then exported to the server in a .obj format file containing the mesh geometry and the texture saved as a material in .mat format.³⁵



fig. 25 stages of 3D model development (source: Felix Heisel)

Once the on-site scanning was completed, the files were combined into a single building using Rhinoceros 3D software. The complete model of the building’s interior and exterior at this stage was an interesting interpretation of reality, but extracting information from it was not easy, requiring delving into the model and analyzing the element of interest each time. So they proceeded to try to automate the interpretation of the data - first to define a simple typology of the element (wall, ceiling, roof, floor stairs). Each mesh object plane in Grasshopper was analyzed based on its centroid surface normal, decomposed into XYZ components. “Mesh facets with a Z vector greater than or equal to -0.95 units are categorized as ceiling surfaces, facets with a Z vector greater than -0.95 units but less than or equal to -0.5 units are classified as gable-roof surfaces, given their downward slope. Facets between -0.5 units and 0.5 units are classified as wall surfaces, those greater than or equal to 0.5 units and less than 0.95 units are considered stair surfaces and those greater than .95 units are binned as floor surfaces.”³⁶ (These values were determined specifically for that particular building). Each category is then summed which allows quantification of building parameters and the data can be exported to a spreadsheet-compatible CSV file.

³³ “Polycam - LiDAR 3D Scanner.” Accessed February 14, 2022. <https://poly.cam/>

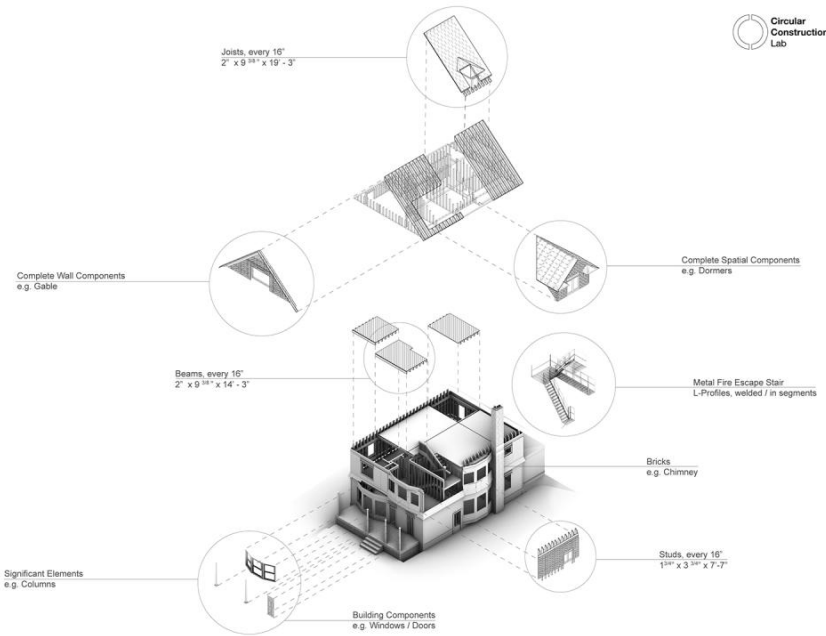
³⁴ Heisel, F, J McGranahan, and A Boghossian. 2022. “ScanR: A Composite Building Scanning and Survey Method for the Evaluation of Materials and Reuse Potentials prior to Demolition and Deconstruction.” IOP Conference Series: Earth and Environmental Science 1078

³⁵ Heisel, F, J McGranahan, and A Boghossian. 2022. “ScanR: A Composite Building Scanning and Survey Method for the Evaluation of Materials and Reuse Potentials prior to Demolition and Deconstruction.” IOP Conference Series: Earth and Environmental Science 1078

1.3 Compilation of survey data with 3D Model

The final step was to create a script to combine the two types of data and visualize them. A script written in Python to assign data from one file to categories from the other was implemented into a spreadsheet. This allowed Dimensional Information, Material Information and Disassembly Information³⁷ to be combined and visualized in a table. This thus allows the final determination of the amount of available building materials. This methodology makes it possible to adapt to different types of buildings and to modify archetype patterns³⁸ - this is how the data set for an element is determined (for example, the amount of wood and insulation for a typical ceiling per square meter and then multiplied by the areas of that type of ceiling from the CSV file).

fig. 26 combined data (source: Circular Construction Lab labs.aap.cornell.edu)



The information obtained can serve us for many purposes, the basic assumption being, of course, the potential amount of raw material for the construction of new buildings after demolition. Based on the quantitative data, the financial cost indicators for logistics and waste disposal are also calculated and compared with the potential profit from the sale or reuse of materials. In the case of a larger-scale operation, we also have other interesting parameters (as here where the number of houses in one settlement is large and the typology is repetitive). For example, we can easily calculate the overall carbon footprint that will occur as a consequence of demolition and landfill, or how much embodied carbon we can get as a negative value for new construction.

³⁶ Mansour Esnaashary Esfahani et al, "Using Scan-to-BIM Techniques to Find Optimal Modeling Effort; a Methodology for Adaptive Reuse Projects," Proceedings of the ... ISARC, May 24, 2019

³⁷ Heisel, Felix, Joseph Mc-Granahan, Joseph Ferdinando, and Timur Dogan. "High-Resolution Combined Building Stock and Building Energy Modeling to Evaluate Whole-Life Carbon Emissions and Saving Potentials at the Building and Urban Scale." Resources, Conservation and Recycling 177 (February 1, 2022): 106000.

To reinforce the message and appeal to those unfamiliar, the spreadsheet predicts two other parameters - the area of forest needed to absorb a given amount of CO2, and the equivalent of the number of trips around the world by car to achieve similar CO2 emissions.

1.4 Conclusion

In conclusion, the plus side is certainly that the process is greatly simplified as evidenced by the analysis conducted by the students (who are not experts in building diagnostics). Operating the scanner is possible for a person with only basic IT skills and basic building knowledge is sufficient to complete the survey. In this case, however, the problems begin when the inability to verify accurately occurs and observation turns into guesswork. The lack of thorough examination, sometimes with the need to open a wall or element to check its condition or test for moisture and mold, can sometimes lead to misleading conclusions. Also problematic is the difficulty of detecting potentially toxic substances, after all, often present in old buildings. This therefore forces testing only after deconstruction.



fig. 27 materials from deconstruction at local Reclaimed materials Centre (source: Circular Construction Lab labs.aap.cornell.edu)

As for the digitization of resources itself, we can say that a retrofitting of Material Passport has been done here. A set of data in the form of a spreadsheet and tables describes in a rough way the amount of materials, their reuse potential and how they are disassembled. However, it's not hard to conclude that despite many attempts to automate and speed up the process, this is still tedious work, and only applies to one single-family home, so is it cost-effective and has a chance of being a common practice? The amount of work required to obtain all this data leaves one questioning the cost-effectiveness and scalability of such an approach. Challenges identified in the project, such as the need to balance data detail with usability, and the need to adapt the process to different building contexts, point to the need for further research and refinement.



fig. 28

2. Urban scale Material Bank

The answer to the problem of complex and time-consuming inventories may lie in economies of scale. Felix Heisel with the Environmental Systems Lab and the Circular Construction Lab at Cornell University have developed a method for creating Urban Material Banks at the scale of entire neighborhoods and even smaller cities. Working in a collaboration called CROWD³⁹ they are currently developing a Sustainable Deconstruction plan for the city of Ithaca (among others). By combining urban-scale 3D scanning with a methodology for assigning material compositions to individual “archetypes” of building parts found in American suburbs, they have been able to create digital databases of materials. Quantities can thus be determined quite accurately and the process itself, despite requiring initial database preparation, allows for rapid estimation of large-scale material quantities.⁴⁰

2.1 Context

The project applies only to residential buildings in the borough and city of Ithaca, NY and coordinates its goals with local circular policy objectives. Its implementation is possible because of the very typical nature of development. American suburbs of the first half of the 20th century were built en masse as a result of population spikes and urbanization and prefabricated building elements such as wood framing (balloon framing), which were quick and cheap to install, were popular.⁴¹ The predominant architectural “style” was so-called “catalog homes” (kit homes), offered by companies such as Sears, which provided ready-to-build materials in kits, making it much easier to standardize buildings.⁴²

2.2 Methodology

As in the case of a single house, a set of most frequently repeated and typical archetypal layer sets are identified for the neighborhood and assigned a typical amount of materials per square meter. However, in order to obtain a high-resolution BSM (Building Stock Model) model, it was necessary to extend some of the methods described for the Ithaca house digital inventory process. First of all, it was important to operate on modifiable databases that constituted the “modules” of the system. This would ensure that as the city grows or wants to enrich the model with new materials (e.g., plumbing infrastructure in homes not yet included), it will be possible and ensure that the system does not become obsolete after a few years.

³⁸ Heisel, Felix, “2022/23 SoA Lecture Series: Felix Heisel,” Lecture Series, Charlotte College of Arts and Architecture, November 7, 2022.

³⁹ Minner, Jennifer, Susan Holland, Christine O’Malley, Felix Heisel, Diane Cohen, Wyeth Augustine-Marceil, Jason Rearick, and Courtney Bower. “Toward Building Sustainable Communities and Circular Economies: A Local Government Policy Guide to Alternatives to Demolition through Deconstruction and Building Material Reuse.” Unpublished, 2023.

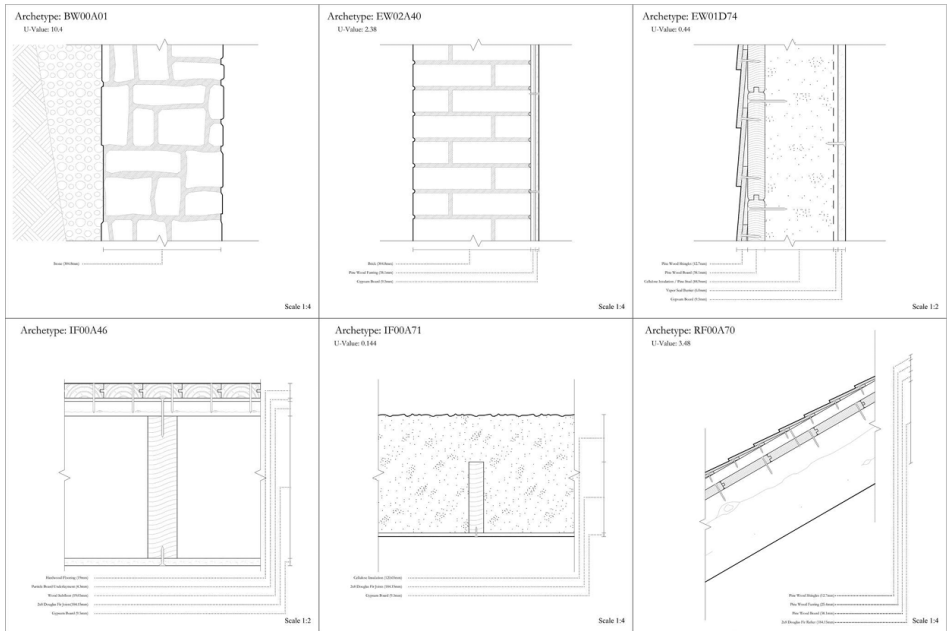
⁴⁰ Jakle, John A., Robert W. Bastian, and Douglas K. Meyer. *Common Houses in America’s Small Towns: The Atlantic Seaboard to the Mississippi Valley*. Athens: University of Georgia Press, 1989.

⁴¹ Stevenson, Katherine Cole. *Houses by Mail: A Guide to Houses from Sears, Roebuck and Company*. New York: John Wiley & Sons, 1986.

The primary database is BuildingRepo, an open and free database available online to anyone. It contains an ever-growing catalog of materials with assigned categories such as environmental, thermal, life cycle, circularity, toxicity, durability and cost data. It was also important to divide them into historical and contemporary and the possibility of comparing them. The database is then linked to the Grasshopper plug-in, which allows easy and clear visualization of the data. It allows aggregation and comparison of density, thermal conductivity, energy and embedded carbon parameters, as well as the circularity index. Such statistics are helpful when planning demolition and planning the use of materials for new construction without unnecessary storage and hoarding, it also allows estimating and optimizing costs.

The next step was to create a catalog of structural elements such as walls or roofs and to determine the typical quantities of materials in them. Obtaining these data and cataloging them was manual work. They were collected during site visits of designated representative buildings. More accurate historical information was also obtained from sources such as the “Building Technology Heritage Library” and materials from the local Tompkins County Department of Assessment’s Office of Urbanism.⁴³

fig. 29 6 examples of construction archetypes
(source: Felix Heisel, Joseph McGranahan)



Once the databases were completed, they proceeded to create an urban model covering 11,049 buildings throughout the municipality. The basic tools were Rhinoceros3D + Grasshopper, Urbano.io and proprietary software written in python in the form of code and plug-ins for Grasshopper.

⁴² Heisel, Felix, Joseph McGranahan, Joseph Ferdinando, and Timur Dogan. “High-Resolution Combined Building Stock and Building Energy Modeling to Evaluate Whole-Life Carbon Emissions and Saving Potentials at the Building and Urban Scale.” Resources, Conservation and Recycling. Elsevier BV, February 2022.

The building geometry model itself was created using data from the city’s GIS portal. The resulting vector models were then combined with administrative attributes and urban planning data, resulting in a 3D model of the city. The shape of building masses was generated from LiDAR data using the simple skeleton algorithm, which made it possible to map their shape taking into account the highest and lowest points, although the lack of precision in data classification made it difficult to separate building objects from vegetation and terrain. The 3D modeling process was carried out in Rhinoceros3D and Grasshopper, using Urbano.io tools and custom scripts, which made it possible to create BEM (Building Energy Model) models taking into account floors, basement types and segmentation of thermal zones according to ASHRAE 90.1 guidelines.⁴⁴ Then, thanks to a procedural script that was prepared for the model, roof angles were adjusted and windows and openings were added to the blocks.

The special characteristic of this model is that, compared to typical GIS models, the component unit is not a building, but a building element. As in the case of the house demolition in the previous example, the elements are identified based on vector data that assigns them the parameters of the roof, ceiling, wall, etc. and then their quantity is assigned to the BuildingRepo database.⁴⁵

2.3 Panelled deconstruction

Identified materials from Urban Mine still need to be “dug up”. According to experience from the demolition of the house at 206 College Avenue, it can be estimated that at least 6 skilled workers are needed to demolish one house in a week. There, the process took correspondingly longer because the demolition was carried out partly by professionals and partly by local residents in an act of social deed.⁴⁶ This is an interesting form of community building and environmental awareness in the community, but not an effective way of demolition. In the end, the “panelled deconstruction” method was decided upon. Similar to the digital base, the individual elements of the building were assembled. Walls, ceilings and roofs were cut into “panels” and dismantled by crane to be transported by truck to a local recycling center. There, a thorough deconstruction took place, along with a process of testing the elements for toxic substances like lead and asbestos.



fig. 30 lead pollution tester
(photo credit: Felix Heisel)

⁴³ ASHRAE. Standard 90.1-2013 Appendix G: Performance Rating Method. Atlanta: ASHRAE, 2013.

⁴⁴ Ibid

⁴⁵ Heisel, Felix, “2022/23 SoA Lecture Series: Felix Heisel,” Lecture Series, Charlotte College of Arts and Architecture, November 7, 2022.

fig. 31 panelled
deconstruction
(source: photo credit: Felix
Heisel)



2.4 Results

The final result of the experiment is a digital Material Bank of 11,049 buildings. The total weight of building materials in Ithaca’s residential buildings is 1,044,535 tons. Concrete (342,452 tons) and wood and wood-based products (253,340 tons) account for the largest portion, while smaller amounts are accounted for by brick (19,241 tons), metal (2,352 tons), glass (492 tons) and other materials. The average weight of materials for a single building is 106,891 kg, which consists of: 25,925 kg of wood, 35,044 kg of concrete and 8315 kg of insulation. Naturally, the largest mass of materials is in the foundation and basement (concrete, stone, brick) while the upper structure is wood. The calculations also showed the effect of a building’s age on material composition and carbon emissions. Modern structures, containing higher amounts of inorganic materials such as concrete, generate higher CO2 emissions, while older buildings dominated by wood can retain significant amounts of carbon dioxide. It’s worth noting that in light of regional carbon neutrality targets, the study indicates that renovation and material reuse measures in older structures can be key to reducing emissions.

The experiment showed an attempt to implement Material Passport for historic building “archetypes” and Material Bank for urban scale. The authors themselves evaluate it as successful. Despite the need to put a lot of effort into the inventory, in the end the relation of the amount of data obtained to the amount of work is very favorable. What’s more, the resulting repository can be a viable base for managing resources, calculating costs and profits, and planning future investments based on sustainable

ways of building with recycled materials. This fits well into the context of the work and shows the little-known side of the Material Bank - for existing buildings.

However, this is not a venture without drawbacks. First, as I mentioned earlier, it would only work in specific conditions. A similar model would not work in the complex street grid of European cities. It would also be futile to assume such uniformity and repetition of architecture and materials in conditions other than American suburbs. This is an interesting initiative that responds well to local problems.

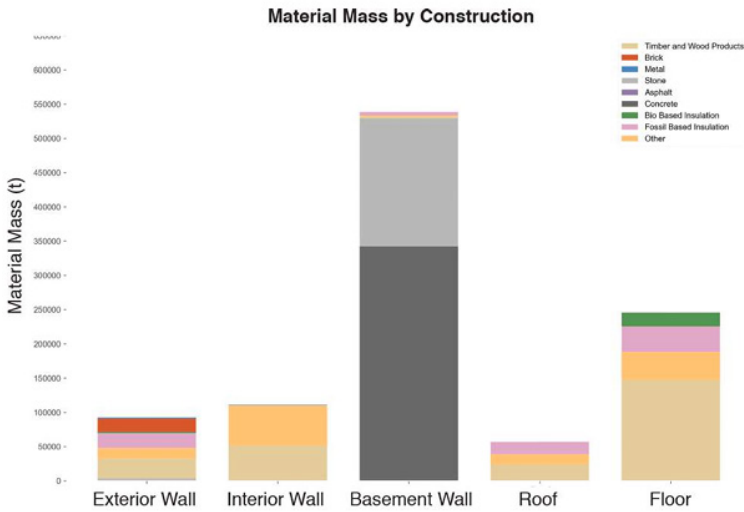


fig. 32 amount of potential materials to mine from the analysed urban area (source: Felix Heisel, Joseph McGranahan)

It would also be hard to assume that these data are extremely accurate. The authors themselves emphasize that the values obtained should be considered estimates on an urban scale. So it gives a rough picture, devoid also of quantitative data for individual components - focusing on data en masse. Another problem is human error and mistakes during site visits. Missing building data also influenced this. Lack of information on façade materials or year of construction led to imputation of default archetypes in the surveys. Also, the model did not include many interior elements or plumbing and electrical systems, where, as a rule, resource deposits like copper pipes could have a significant impact on the financial calculation.

So we can see that Reuse strategies for existing and historic buildings are a case-by-case issue and each case is really a separate project. It’s hard to count here on a catalog of materials in the form of BIM objects immediately available for use in a project. In fact, even a simple table of information may not be accurate and mistakes should always be expected.



fig. 33

3. Demolition and what comes next - Physical Material Banks

The idea of the Material Bank in the case of the City of Ithaca is to manage materials for reuse in situ, but in the case of the deconstruction of the first house at 206 College Avenue, the materials were taken from storage and should wait there for reuse. Demolition will never be perfectly synchronized with the construction of a new building, sometimes materials will wait for months until they are finally used. So a new space in the market is emerging here - storage and distribution.

3.1 Swiss context

In recent years, the Swiss AEC market has seen a number of new initiatives related to the reuse of building materials. In 2019, a proposal was submitted to parliament to intervene in the consumer and construction market - extending the life of products and making repair information available.⁴⁷ A report “Réemploi, Riutilizzo, Wiederverwenden” (ReRiWi)⁴⁸ was also released, which was one of the first to address the issue. However, these are not strictly digital initiatives; like other European markets, this one too is quite traditional in the AEC sector. The main initiatives are private ventures or research centers that more or less relate to the digital sphere. I will present here one of them which seems to be one of the more well-known in the market.

3.2 Matériuum

It is a Swiss company based in Geneva dedicated to promoting circular ways to reuse building materials. It acts as a knowledge center and intermediary. It offers expert support in identifying and how to recover materials, as well as storage and redistribution of recovered components. The company also engages in conducting workshops and events to raise public awareness of the circular economy. It also publishes numerous press articles, scientific articles and reports on materials management methods.⁴⁹

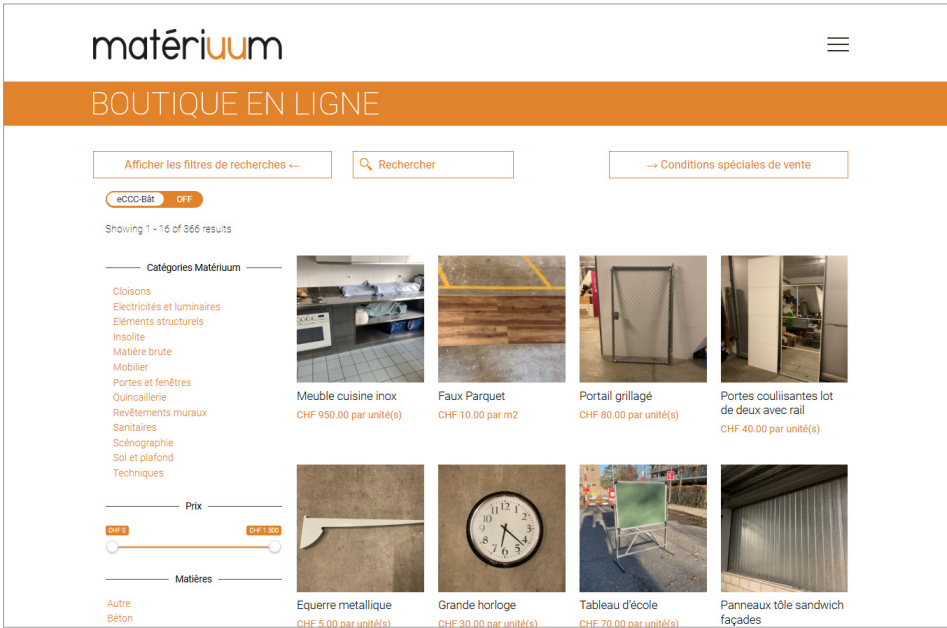
The organization's headquarters is located on Chemin des Sports in Geneva. There is a storage and sales space where reclaimed materials are on display and can be inspected and purchased. This segment of the company operates as a non-profit association, with its members contacting the owners of the buildings to be demolished to agree on the details of donating the materials and the potential for reuse. They then travel to the site to pick up the dismantled items or do it themselves. Some of the materials go directly to Matériuum's warehouse and some are entered into an online catalog and are only dismantled and shipped once a buyer

⁴⁶ P. Birrer-Heimo, 'Économie circulaire. Amélioration et étiquetage de la réparabilité des produits,' Motion 19.4597 to Swiss Parliament, 2019, <https://www.parlament.ch/fr/ratsbetrieb/dry-curia-vista/geschaefft?AffairId=20194597>.

⁴⁷ Salza with Matériuum, 'Aktuelle Situation und Perspektiven: Der Fahrplan', Wiederverwendung Bauen, 2020, <https://rerwi.ch/wp-content/uploads/2021/02/>

⁴⁸ Matériuum. Circular Economy in Construction: Local Solutions for Global Impact. Geneva: Matériuum, 2022.

is found. This reduces storage space, but it only works if the demolition of the building is scheduled far enough in advance to find potential buyers in time. Otherwise, the materials end up as usual in a landfill and are destroyed along with the building during demolition. This procedure is called opportunistic intervention, which depends on demand (which unfortunately often remains low).⁵⁰



The low demand is mainly due to the characteristics of the business, used items do not have a warranty and it is this warranty that guarantees contractors and professionals safety when giving orders to the customer for use. So they avoid used items and the main customers are individuals or small companies looking for alternative methods and savings.⁵¹ This therefore somewhat limits Matériuum’s ability to compete with new products. Also, the price is not always that attractive. Labor costs associated with disassembly and the not uncommon need to repair components add significantly to costs, and it is on the basis of these costs that the selling price is determined. Also key to the attractiveness of many components on the professional market is the lack of information on sanitary or fire standards. This makes it virtually impossible to use them in commercial projects. Combined with a short lead time (time remaining before the building is demolished) and an inconvenient way of viewing and selecting materials (a simplified online catalog or a visit to the warehouse), this business model is running out of steam and its activity is limited to a very marginal market.

fig. 35 view on Materium website - online store with reclaimed materials



fig. 34 ReRiWi Swiss report cover (source: reriwi.ch)

⁵⁰ “Reuse Dynamics in Swiss Construction.” Building Innovation Journal, 2022.

⁴⁹ M. Jammers, “BIM as a tool for reuse,” Enoncé Théorique, Ecole Polytechnique Fédéral de Lausanne Architecture section, 2023

3.3 Swiss market - macro picture

Of course, there are many more players throughout Switzerland interested in sustainable action toward reuse of building materials. According to the ReRiWi report, characteristics of the market are as follows: 35.4% of the activity is the initiative of private individuals while institutions are responsible for the remaining 66.7%. The main activities are collecting and storing materials (22.9%), applying them into new constructions (53.5%) and promoting the reuse concept (16%). Nearly a third are local initiatives (30.6%), at the canton level 21.5% and at the national level 22.3%. These organizations are funded overwhelmingly by private funds and profits (76.4%), with the remaining 23.6% provided by subsidies.⁵² The main representatives of the reuse market in Switzerland are:

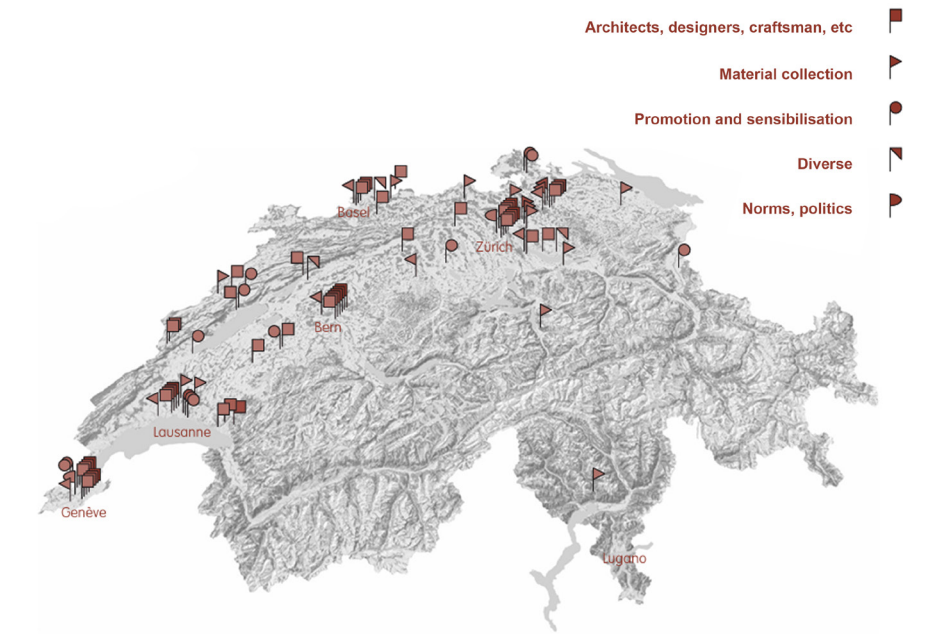


fig. 36 repartition of actors in reuse in Switzerland (source: ReRiWi report)

3.3.1 Disassembly, evaluation, storage, distribution⁵³

- BauTeilLaden Winterthur Genossenschaft: A cooperative selling construction parts, operating since 2000.
- Bauteilvermittlung Zürichsee-Oberland (BTVZ): A pilot brokerage project offering weekly supply and demand lists for construction components since 2001.
- ReWinner: An organization supporting the circular economy, managing the sale of materials from inventory to delivery (since 2014).
- Bauteilverwertung: Recovers materials from buildings scheduled for demolition and sells them online.

⁵¹ Salza with Matériuum, ‘Aktuelle Situation und Perspektiven: Der Fahrplan’, Wiederverwendung Bauen, 2020, <https://reriwi.ch/wp-content/uploads/2021/02/>

⁵² Catherine De Wolf, Deepika Raghu, Anton Sentic, and Corentin Fivet, “Innovations Practitioners Need for Circularity in the Swiss Architecture, Engineering, and Construction Sector,” EPFL, ETH, Cirkla, 2023

- Wiederverwendung: Maintains collection points and sells products suitable for reuse.
- Salza GmbH: A marketplace for selling construction materials with detailed descriptions and photographs (established in 2015).
- Matériuum: Specializes in recovered construction materials, circular design, and implementing reuse policies.
- Syphon: Engages in storage, processing, and transportation of recovered construction materials.
- Bauteilbörse Basel: Mediates between construction and demolition projects, promoting the reuse of building components.
- GGZ@Work-Bauteilladen: A store offering recovered construction parts.
- La Ressourcerie: Stores, processes, and sells recovered construction components.
- Bauteile Zürich: A platform for selling reused construction materials.

3.3.2 Knowledge and IT solution providers⁵⁴

- Useagain: A construction materials exchange platform currently being redeveloped by Sumami.
- Sumami: A company enhancing the Bauteilclick material exchange platform.
- Madaster: Documents the life cycles of buildings and materials, supporting circularity in construction.
- Nomoko: Creates digital twins of buildings, offering spatial analysis and location intelligence.
- Cirkla: An umbrella organization connecting stakeholders in material reuse within the
- EMPA - Urban Mining and Recycling unit: Develops technologies for building with recyclable and compostable materials.
- EMPA - Sprint unit: Designs for disassembly and reuse, finding solutions for circular construction.

3.3.3 Research and university centers⁵⁵

- EPFL - Structural Xploration Lab: Explores reuse of load-bearing components, such as concrete blocks and steel structures.
- EPFL - Laboratory of Elementary Architecture and Studies of Types: Documents experiences and visions of material reuse in education.
- ETH Zurich - Reuse Studio of Barbara Buser: An architecture studio focused on designing with reused materials.
- ETH Zurich - Center for Advanced Studies in Architecture: Explores circular design and innovative building techniques.
- ETH Zurich - Studio Tom Emerson: A design studio utilizing reused ma-

⁵³ Catherine De Wolf, Deepika Raghu, Anton Sentic, and Corentin Fivet, "Innovations Practitioners Need for Circularity in the Swiss Architecture, Engineering, and Construction Sector," EPFL, ETH, Cirkla, 2023

⁵⁴ Ibid

terials in architecture.

- ETH Zurich - Studio Jan De Vylder: Explores circular approaches to construction and design.
- ETH Zurich - Circular EconomyA lab: Conducts research on digitizing the built environment, enabling reuse through material passports.

3.3.4 Architectural and construction offices involved in Reuse⁵⁶

- Zirkular: Experts in circular design and using recovered materials in architecture.
- Baubüro in situ: Implements architectural projects using recovered materials, such as the K.118 project in Winterthur.
- Halle 58: An organization engaged in reusing components in construction projects.
- Leserf Architekten: An architectural office promoting the reuse of materials in building designs.
- Co. Architekten AG: Focused on incorporating recovered materials into construction.
- Umbra Architekten: Executes projects based on circular design principles in Bern.
- Meier Haushaltsapparate: Specializes in construction with recovered materials.
- Neue Holzforum AG: Experts in utilizing recovered wood in construction.
- Tischhauser AG: A construction company focusing on reclaimed materials and recycling.

3.4 Realistic use of materials from Reuse

Another interesting piece of information we can find in the ReRiWi report is the amounts of reuse materials used in real terms, divided by category. Structural materials account for the largest share, with 25.4% for wood and 14.6% for metals, respectively. This is not surprising because structural and technical building components are the easiest to reuse. Their aesthetics are not crucial and size can possibly be adjusted. This is followed by kitchen and sanitary elements (13.5%), interior finishes such as doors or stairs (10.9%) and windows (10.5%). Also obvious seems to be the large share of mineral waste (11.9%) which can be easily processed into raw materials. Other material elements account for a marginal share of the market.

⁵⁵ Catherine De Wolf, Deepika Raghu, Anton Sentic, and Corentin Fivet, "Innovations Practitioners Need for Circularity in the Swiss Architecture, Engineering, and Construction Sector," EPFL, ETH, Cirkla, 2023

3.5 Brakes of reuse

These are unfortunately common problems in the reuse market. The lack of detailed information on sanitary and fire standards and inconvenient access to material databases discourages use by architects and professionals. Given a choice of ready-made catalogs, the typical designer will use new materials by default. Undoubtedly, one of the main inhibitors to the development of reuse of building materials is the lack of digitization of available resources. According to data collected in the ReRiWi report⁵⁷, the main issues discouraging Reuse are the cost of disassembly (17.3%), inexperience and inability to apply (15%), habit (12.8%), lack of motivation (12%), storage costs (9.8%) and little choice. Least significant are lack of standards, availability and waiting time. It should be remembered, however, that the survey was conducted among people in the reuse community familiar with the subject, my guess is that if similar questions were asked of conventional architectural and design offices we might get significantly different results.

4. What can be done to improve the current state of Reuse?

So what can be done to streamline the process? Assuming that the unavailability of information and the complicated process of adopting components from reuse could be a significant factor, researchers from TU Graz have come up with an interesting concept - Digital Salvage Centers (DSC). This is a concept that could greatly facilitate the flow and implementation of materials in the reuse cycle. They would allow direct transfer from vendor to recipient, eliminating the need for storage.

We can find DSCs on the market today in the form of online reuse material portals from companies such as Materium and Salza. However, they are quite reminiscent of typical online portals for selling used items whose browsing to find a particular material is difficult and information on a particular object is often fuzzy.

4.1 Technical details - web scrapping

Researchers at TU Graz are proposing a much more elaborate system that would be quick to use for architects. It would be based on a BIM object catalog in which all elements would be easily accessible, searchable, and have the necessary set of information. So how to create such a database? It seems to be extremely time-consuming and requires manual work. So researchers propose the concept of Web Scraping - the process of automatically extracting data from websites using special tools

	Concular	Baukarussell	restore	use again	Juch Areal
fire	○	—	—	—	○
thermal	○	—	—	—	○
soundpr.	○	—	—	—	○
sp. parts	—	—	—	—	—
weight	○	○	○	○	○
lb-capa	—	—	—	—	○
2D/3D drawings	○	—	—	—	○
✓ Information is available — Information is not available ○ Information is available for some RUCs					

fig. 37 Summary of available material properties in DSCs (source: L. Gschweidl, M. Lang-Raudaschl, D. Daleyev, M. Stavric)

⁵⁶ Salza with Matériuum, 'Aktuelle Situation und Perspektiven: Der Fahrplan', Wiederverwendung Bauen, 2020, <https://reiriwi.ch/wp-content/uploads/2021/02/>

and scripts (in this case open source - Beautiful Soup) . They search for the desired information and save in a structured form of a database, in this case SQL.⁵⁸ This would ensure that data from reuse portals such as Concular, Salza or Materium would be structured and the script would verify the data for compliance with local building requirements and regulations before placing it in the database.⁵⁹ The verified data is converted into IFC models for seamless use in BIM environments.

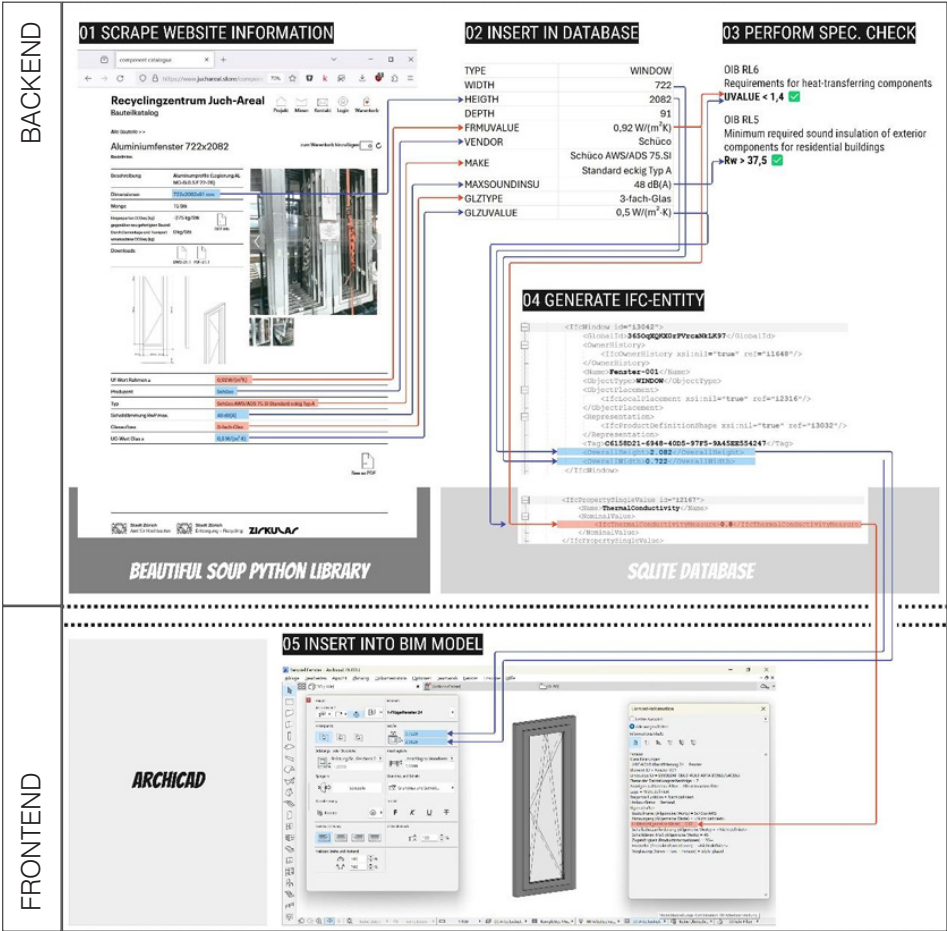


fig. 38 dataflow diagram and the whole idea diagram (source: L. Gschweidl, M. Lang-Raudaschl, D. Daleyev, M. Stavric)

⁵⁸ L. Gschweidl, M. Lang-Raudaschl, D. Daleyev, M. Stavric4, "ReUse with BIM Connecting architectural salvage centers to your BIM software" TU Graz, Institute of Architecture Technology, TU Wien, Department for integrated Planning and Industrial Building, TU Graz, Institute of Architecture and Media, eCAADe, Volume 2 - Data-Driven Intelligence, 2022

⁵⁷ Gundavaram, Raghav. Web Scraping with Python: Collecting Data from the Modern Web. 1st ed. Birmingham: Packt Publishing, 2007.

⁵⁹ Ibid

The data from the SQL database is then linked to a plug-in for ArchiCad where architects and designers can easily browse it for components that meet specific criteria, such as dimensions or technical parameters. The system also offers a visual comparison by converting the dimensional information into a simplified 3D model. By parameterizing the entire process and operating on the database, "backend" processes such as scraping and updating the database run asynchronously on the server, ensuring that users have access to the most up-to-date information without disrupting their work.⁶⁰

4.2 BIM Interface

The target audience for this solution is architects and engineers, so the authors customized the interface after consulting with the industry. The unequivocal requirement was the implementation of BIM so that many of the architects’ needs could be told. They required quantity statements, the ability to compare with non-reusable materials, the ability to perform balance sheets but, above all, the availability of a “one-click” database. The interface was able to be designed according to these requirements and the window was an example of its use.

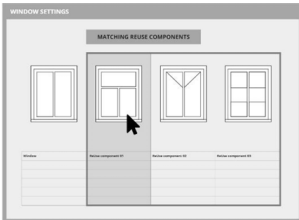


fig. 39 prototype BIM interface (source: L. Gschweidl, M. Lang-Raudaschl, D. Daleyev, M. Stavric)

4.3 Conclusions

Implementing such a program for widespread use could go a long way toward spreading the use of reused materials and components. However, the authors note that web scraping technology is more of a temporary solution. Rather, a native plug-in with a unified database shared among all actors distributing reused materials would be needed to make it widespread. This would then avoid system confusion and the omission of many items not qualified for use due to lack of data. Also, structuring material examination parameters could speed up the process at the demolition site and eliminate the subjective error of human evaluation. However, this could be difficult due to complex and differing regulations between countries regarding the use of materials used.

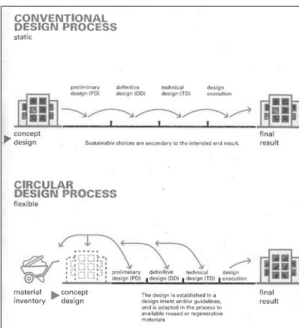


fig. 40 differences in conventional and circular economy transition (source: © Archis / VOLUME)

Subjectively, it should be assessed that this whole process is a transitional technology. Assuming that in the future every building would have a material passport this type of invention would no longer be necessary. As we have seen from the examples mentioned above, the reuse of materials from existing buildings is a very individual matter and each is practically a separate project. The greatest hope, therefore, can be placed in new investments carried out with sustainability in mind, which will gradually replace the old ones in the long term.

1. New Buildings - case study

Thus, as is not difficult to see, the greatest hope for transformation of the entire industry is located in new buildings and in thorough redevelopment based on the collection and cataloging of building information. Assuming a fundamental change now, in the long run old buildings (hopefully using circular economy methods) will be replaced by new ones and the entire urban structure will become a Material Bank. However, the database itself is not everything, the potential demountability of the building in the future also depends very much on the architectural concept itself. The use of reversible connections which are not usually an obvious choice and the avoidance of hybrid materials that make segregation and recycling difficult will enable future recoverability.

Then, with integration with Material Passport, cities could be seen as truly dynamic material warehouses, in line with the idea of Urban Mining.⁶¹ This would greatly support real-time resource monitoring, logistics processes, and long-term urban planning.

1.1 A model example of the new approach - Urban Mining and Recycling unit (UMAR)

UMAR unit is located in the NEST complex - Next Evolution in Sustainable building Technologies). It is a modular research and demonstration platform at the research center for Empa Swiss Federal Laboratories for Materials Science and Technology in Dübendorf, Switzerland.⁶² The building is designed to be a living and research unit; however, its modular structure allows functions to be adapted as needed. UMAR is intended to serve as a living and demonstration laboratory that shows how feasible it is to construct a building according to the principles of a closed-loop economy. It is built from seven prefabricated modules housed in a concrete structure. Two bedrooms, three communal modules, a bathroom module with a technical room and an entrance module were built in the factory and took only one day to assemble after being brought to the site. The entire unit occupies 126m² - the bedrooms are located on the periphery for greater privacy, and the common space, thanks to a movable wall, connects the kitchen, dining room, living room and work area. The entrance hall, on the other hand, serves as a materials library where visitors can see samples of the raw materials used in construction. The entire architectural concept is based on 5 key points for the designers:⁶³

⁶⁰ Heisel, F., Hebel, D. E., & Sobek, W. (2019). Resource-responsive construction - the case of the Urban Mining and Recycling unit (UMAR). IOP Conference Series: Earth and Environmental Science, 225, 012049.

⁶¹ Empa 2015 Introducing NEST <https://www.empa.ch/web/next/aboutnext>

⁶² Heisel, F., Hebel, D. E., & Sobek, W. (2019). Resource-responsive construction - the case of the Urban Mining and Recycling unit (UMAR). IOP Conference Series: Earth and Environmental Science, 225, 012049.



fig. 41

1.2 Design for disassembly on all scales⁶⁴

The first most basic principle was the introduction of reversible connections in all elements. Structural elements and finishes are joined using screws, clamps and designed snap systems. The design also excludes the use of chemical adhesives, binders and tapes (with the exception of biodegradable wood joints). A special challenge were the so-called “wet” rooms like the bathroom and kitchen where it’s hard to ensure tightness without silicones and grouts. The solution turned out to be all-wall panels fixed rigidly to avoid water leaks.⁶⁵ In addition, the installation process was carefully documented, which will certainly facilitate the later recovery of materials.



fig. 42 brick wall constructed without mortar (source: EMPA)

fig. 42.1 whole modules are designed to dissassembly - on rails (source: Wojciech Zawarski)

⁶⁴ Heisel, Felix, “2022/23 SoA Lecture Series: Felix Heisel,” Lecture Series, Charlotte College of Arts and Architecture, November 7, 2022.

⁶⁵ Ibid

⁶⁶ McDonough W and Braungart M 2002 Cradle to cradle: re-making the way we make things (New York: North Point Press)

⁶⁷ Heisel, F., Hebel, D. E., & Sobek, W. (2019). Resource-responsive construction - the case of the Urban Mining and Recycling unit (UMAR). IOP Conference Series: Earth and Environmental Science, 225, 012049.

⁶³ Heisel, F., Hebel, D. E., & Sobek, W. (2019). Resource-responsive construction - the case of the Urban Mining and Recycling unit (UMAR). IOP Conference Series: Earth and Environmental Science, 225, 012049.

1.3 Separation of biological and technical materials⁶⁶

A common problem in recycling, not only of building materials but in general, are various types of material conglomerates.⁶⁷ In this project, one of the demands was also a clear separation between technical materials (e.g. metals, glass, plastics) and biological materials (e.g. wood, mycelium). This is a much more difficult task than it seems because most commercially available building materials, even something as simple as OSB, are actually conglomerates made up of many chemicals and adhesives, not suitable for biological recycling. Often it is necessary to go back to basics and old solutions, for example, the wall cladding at UMAR was made of boards milled so that their installation is based on the tongue and groove technique,⁶⁸ that is, solving the problem of adhesives with simple geometry.



1.4 Reuse, recycling, composting⁶⁹

The materials philosophy is based on 3 methods of closing the circulation of materials: reuse, recycling and composting. UMAR’s reuse is, for example, the use of doorknobs dismantled from the Generale de Banque building in Brussels designed in 1974 by Jules Wabbes⁷⁰ (and therefore being a quality product in truth). This was made possible by the Belgian form of Rotor Deconstruction. The handles were installed at UMAR on a rental basis; after the building’s life cycle is over, they will be returned to Rotor and they will use them again.⁷¹ This is an interesting example of forward-thinking reuse right from the design stage.

Examples of the use of recycling include kitchen countertops and waterproof wall cladding in bathrooms. The glass panels, from Magna Glas-keramik, are made entirely of recycled and bottle glass. This gives them a distinctive look and low embodied energy thanks to energy-efficient production processes.⁷² Of course, many other recycled materials were used in the design.

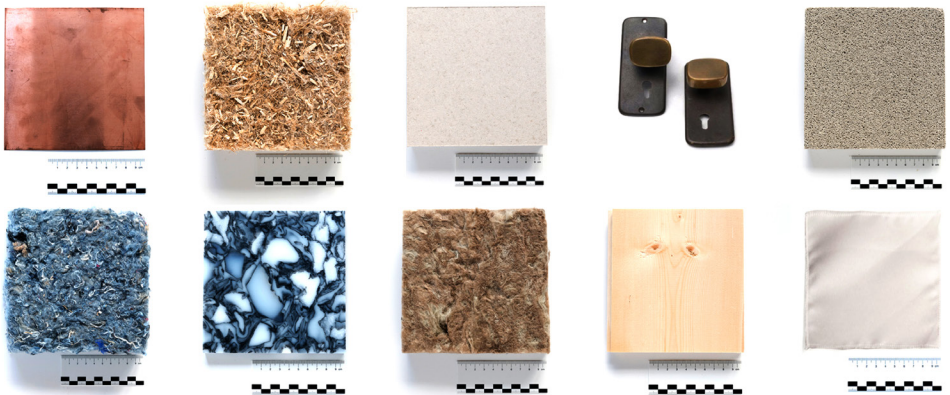


fig. 43 Selected material samples from UMAR (source: Rene Mulleri)

⁶⁸ Ibid

⁶⁹ BNP Paribas Fortis 2017 Heritage <https://www.mon-tagneduparc-warandeborg.be/en/news/2015/09/03/heritage>

⁷⁰ Heisel, F., Hebel, D. E., & Sobek, W. (2019). Resource-responsive construction - the case of the Urban Mining and Recycling unit (UMAR). IOP Conference Series: Earth and Environmental Science, 225, 012049.

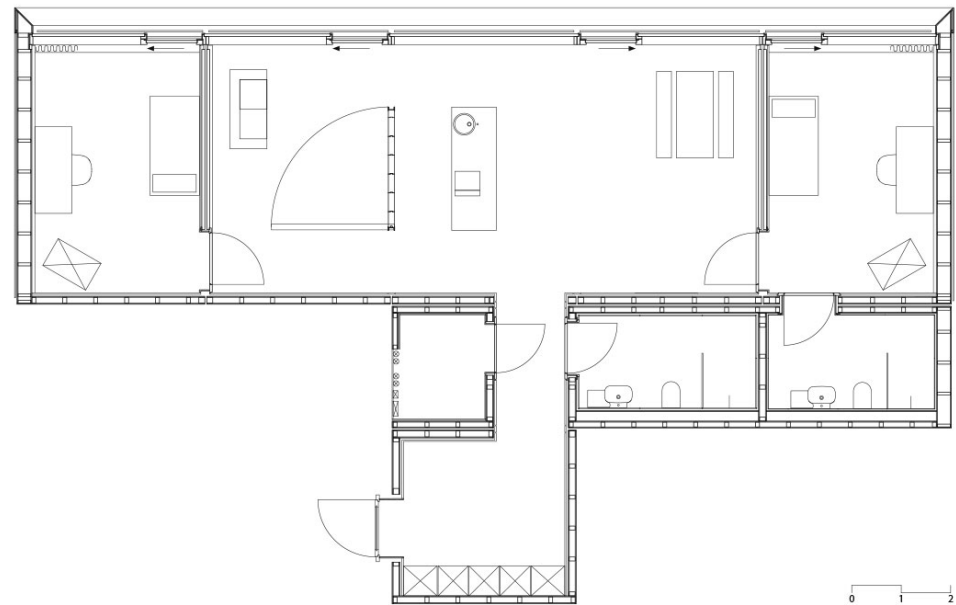
⁷¹ Ibid

⁷² Ibid

Compostability is ensured by leaving all materials of biological origin unprotected. This will prevent their contamination and they can be given back to the environment without risk. The largest compostable material by volume is insulation. An unusual material was used - mycelium. It is a fast-growing fungus which, when treated with high temperature, dies, however, its strong joints are preserved. Combined with natural materials like straw or sawdust, it is rigid, safe and has good insulating properties. At UMAR, mycelium insulation boards were made by the American company Ecoactive.⁷³ It is an interesting building material with relatively high strength and 100% biodegradable.

1.5 Self-sufficiency in materials⁷⁴

What the designers have in mind here is frugality and sober management of resources and space. Here they refer to the general social discussion about how many square meters we really need per person. They stress, however, that the most important thing is not always to minimize space, but to use materials sparingly. In their design, for example, they suggested using wireless light switches to avoid using a lot of electrical cables.⁷⁵



1.6 Product as a service⁷⁶

In my opinion, by far the most interesting point. The authors here bring a new idea to the Reuse industry. The long view, mentioned earlier with the handles, seems to be very important. What is the result of designing reusable building components if we don't find takers for them later? The option of long-term "rental" of these handles seems very interesting here. The Product as service business model can provide continuity here.⁷⁷ In addition to doorknobs, the authors also cite the example of "renting" carpets which seemingly do not represent great reuse value. This is the perspective of the user or architect. However, the case is different for the company dealing with it, which can recover the raw materials or really reuse it.⁷⁸

fig. 44 UMAR's floor plan
(source: Werner Sobek, Dirk E. Hebel, Felix Heisel)

⁷³ Heisel, F., Hebel, D. E., & Sobek, W. (2019). Resource-responsive construction - the case of the Urban Mining and Recycling unit (UMAR). IOP Conference Series: Earth and Environmental Science, 225, 012049.

⁷⁴ Ibid

⁷⁵ Ibid

⁷⁶ Ibid

⁷⁷ Heisel, Felix, "2022/23 SoA Lecture Series: Felix Heisel," Lecture Series, Charlotte College of Arts and Architecture, November 7, 2022.

1.7. Conclusions

In conclusion, UMAR is a unique building, an example of designing in accordance with the principles of circular economy. It is a prototype and demonstrator which proves that designing and building on the basis of a 100% closed loop is possible. It also demonstrates the necessity as well as the fruitfulness of interdisciplinary cooperation at all stages of building construction.



fig. 45 interior view with visible modular character of the finishing
(source: Zooey Braun)

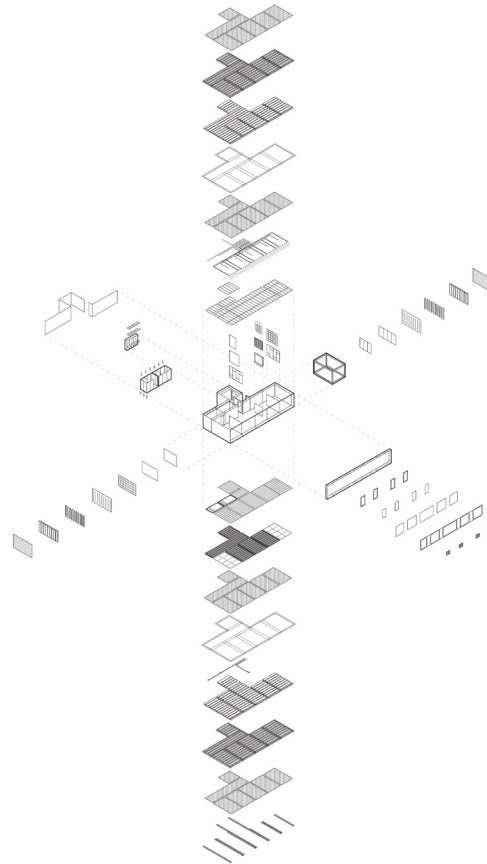
The authors emphasize, however, that the project also reveals many administrative and political challenges that may continue to inhibit such initiatives. UMAR is an important case study, but much more work is needed for the circularity concept to move to the level of widespread use. Changes are needed in the standardization and information management of materials as well as legislation.⁷⁹

Besides, there are still many future activities to come in the cycle of this building's existence. In the years to come, in addition to conducting scientific activities in the new premises, the building itself will also be a research object. It is planned to monitor the behavior of materials such as insulation as or observe the tightness of coatings where standard adhesives and synthetic joints were not used. The process of disassembly

⁷⁸ Heisel, F., Hebel, D. E., & Sobek, W. (2019). Resource-responsive construction - the case of the Urban Mining and Recycling unit (UMAR). IOP Conference Series: Earth and Environmental Science, 225, 012049.

itself will also be interesting. Today, reuse of materials or their composting is assumed. Perhaps when they are disassembled (in a few years) the materials will prove unusable or another problem will be encountered. This will be a valuable base of information about the behavior of these materials over the years and the real possibilities for their reuse.

fig. 46 UMAR's disassembly axonometry (source: Werner Sobek, Dirk E. Hebel, Felix



Finally, for such an approach to actually emerge from the experimental, niche project phases, thorough development of city-scale asset management systems and systems for aggregating data from individual buildings will be needed. UMAR is a relatively small building, but nevertheless designers admit that coordinating and later cataloging and documenting materials or construction processes has been very difficult. Without a structured and standardized system, planning for deconstruction and reacquiring resources in the future will be very difficult. One could venture to say that except for the possibility of biodegradation of a few materials, this will not be much different from the demolition of a conventional building....

2. Information management systems

This paper comes full circle here. After outlining the advantages and possibilities of Material Passport and Material Banks, and tracing the current ways in which these concepts are interpreted in the existing built environment, we return to them. This is, in fact, a big part of the answer to how to bring a UMAR-like building standard into widespread use. As the examples cited earlier have shown, the success of Reuse projects depends on a number of factors, but probably the key one is the standardization of procedures and the organization of information. Thus, this is a new place in the market for those interested in aggregating and managing building information. They may in the future play a key role as distributors of digital information about available material resources and de facto shape the market.

2.1 Madaster

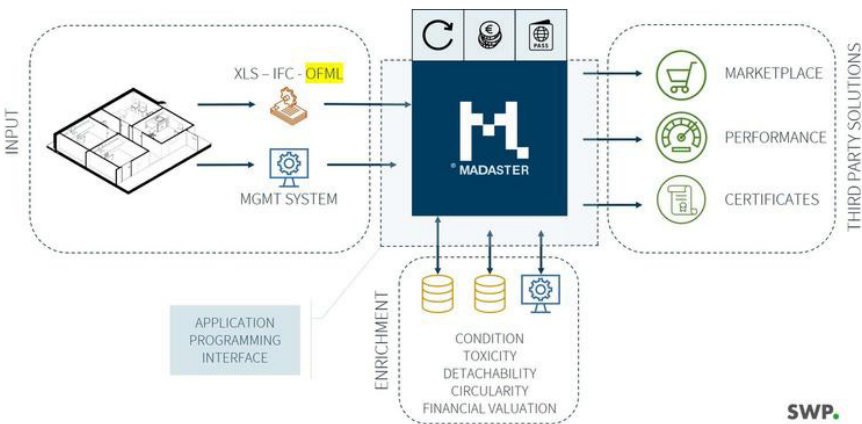


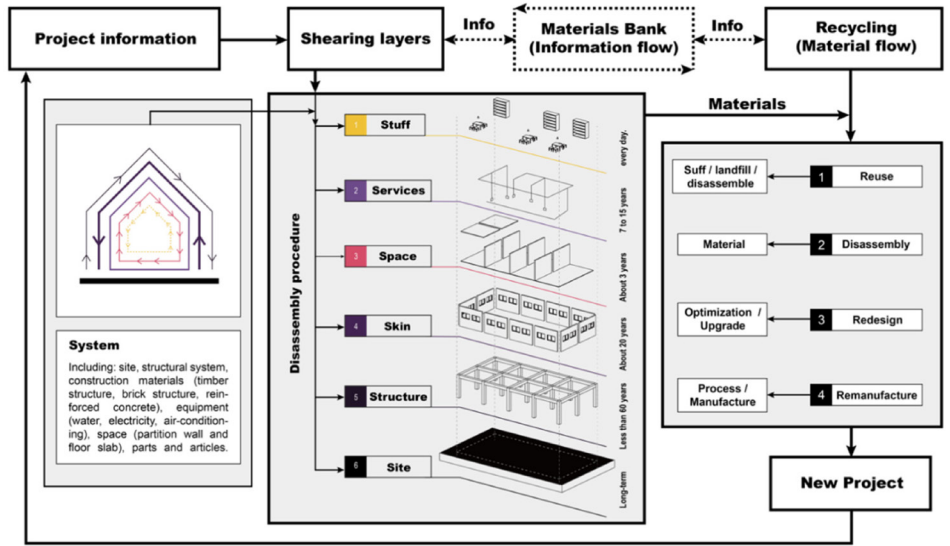
fig. 48 dataflow in Madaster (source: smartwp.nl)

One of the entities that are already addressing the topic and developing comprehensive solutions is the Dutch company Madaster. Its goal is to record and manage the materials used in construction in such a way as to bring about their maximum availability and across all building life cycles. Madaster brings its standards to the creation of Material Passport and thus can claim to be a kind of building cadastre, which stores a complete set of information about materials, building construction and instructions for its dismantling.⁷⁹ In addition to storing information, the platform also offers a number of proprietary tools for visualizing and interpreting data such as economic analysis and material circularity index. Unlike the aforementioned plug-ins for Grasshopper developed by Felix Heisel's team, this solution does not require block programming skills, making analysis of the recycling potential of the raw materials used quite easy to perform.⁸¹

⁷⁹ Madaster Platform. 2018b. "Building Circularity: Material Passports for a Circular Economy".

⁸⁰ Waal, Rianne de. 2018. "Economic and Circular Indicators for Sustainable Architecture."

Madaster adopts two data organization schemes. The first is based on the “Shearing Layers” concept developed by Stephen Brand in 1994, so it is divided into terrain, structure, outer shell, installation, spatial plan and equipment. Each of these layers has a different lifespan and are arranged from the most durable (terrain, structure) to the least durable (equipment).⁸² This model helps to better understand how the various layers of a building evolve over time and allows planning for upgrades. For example, considering the façade as one separate building element with a specific usefulness and designing it so that over the life of the structure (e.g. 100 years) the façade can be replaced, say, 2 or 3 times without complications. Thus, for Madaster, such classification can be a convenient method of data segregation - it allows precise tracking and management of materials in each layer of the building. For example, with such data it would be possible to estimate which layers of a building actually need work, and which can be left untouched during renovation. From this point of view, the building can be simplified: the worn-out elements of the layers are replaced, while the durable ones will remain and be cared for anew. Keeping records of layer-specific information makes them more predictable for future renovation and planning needs.



The second method of classification involves segregating items into material families so that materials can be managed effectively at a detailed level. Madaster lists 6 basic groups and an additional division for atypical materials that are difficult to assign in any category.⁸³ The groups are described according to their chemical and physical properties, thanks to which indicators of recycling potential and economic value are calculated, as well as the corresponding reports for them. The standard that Ma-

fig. 49 Flowchart of building disassembly and circular reuse (source: Hui Zhu, Shuenn-Ren Liou, Pi-Cheng Chen)

⁸¹ Brand, Stewart. How Buildings Learn: What Happens After They're Built. New York: Viking Penguin, 1994.

⁸² Madaster Platform. 2018b. "Classification of Materials and Building Layers."

daster adopts to describe materials is SfB coding - Samverkande Bygg (the standard used in BIM, behind the material code are technical properties, origin, carbon footprint, recyclability, function and life cycle).⁸⁴ So here we see some similarity to the data structure of a typical LCA report. The availability of such detailed environmental data summaries at the level of material families can be particularly useful at the design level - to support more informed design decisions.

These two ways of organizing data are further supported by the option to add custom documents such as disassembly guides, safety information or uses to individual building elements.⁸⁵ This flexibility makes it possible to meet the needs of different stakeholders in the construction industry. After all, Material Passport's technology is not yet standardized so data structure and report content may vary. ⁸⁶ The presented data structure, especially for large objects, is a complex set of information. The Madaster platform allows them to be visualized using 4 different filters.⁸⁷

2.2 Building explorer view

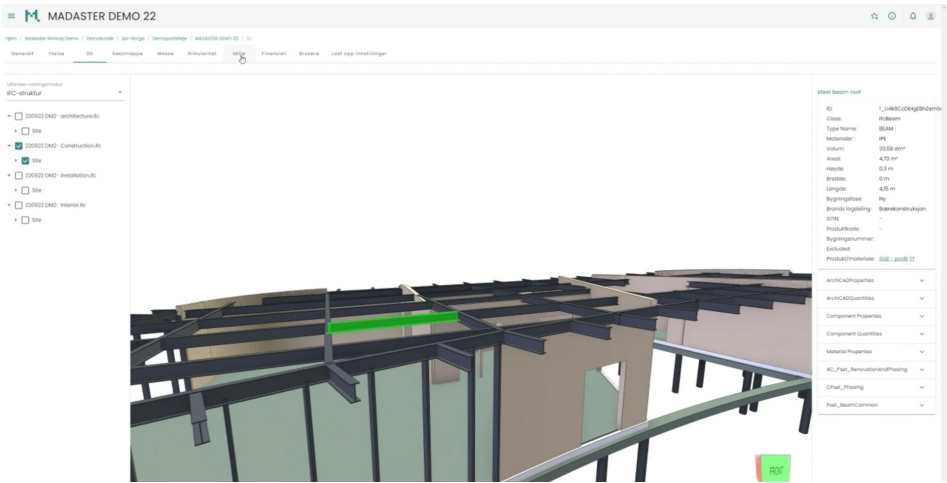


fig. 50 Madaster platform window with 3D explorer view (source: madaster webinar)

This is a basic view of the 3D model of the building and a listing of all materials in categories. Quantitative summaries are expressed in weight and absolute volume and in relation to the whole building. They are organized in a table where vertical values are ordered by layer and horizontal values by material category. Switching between different layers and material categories resembles the layer settings in other popular graphics and engineering programs so it is quite intuitive for those in the environment. It also allows for more accurate filtering and searching for elements by specific properties or name.⁸⁸

⁸³ International Organization for Standardization (ISO). ISO 12006-2:2015: Building construction - Organization of information about construction works - Part 2: Framework for classification.

⁸⁴ Madaster Platform. 2018b. "Integration of Building Data for a Sustainable Future."

⁸⁵ Munaro, Melissa. 2019. "Towards a Comprehensive Material Passport: Security, Usage, and Disassembly."

⁸⁶ Druj, Bertus. "BIM-Based Material Passport in Madaster during the Operational and Maintenance Phase of a Building," 2019.

⁸⁷ Ibid

2.3 Building process tab

This view relates to changes over time in specific areas of a building. It is used to plan renovation work and remodeling of existing buildings. It defines 5 phases of the evolution of the transformation of an existing building. The first is the current situation, it analyzes the available materials and the potential for recycling all elements outside the structure. The second is the deconstruction phase and the third is the so-called “casco.” These involve removing all elements and then leaving the raw structure ready for new interventions. The next phase (4) is “primary materials” where new or recycled materials are used to build a new structure. The last phase is the “final situation,” which is the finished model of the building. Each phase has its own separate statistics where data is organized by phase (vertical columns) and types of materials and elements (horizontal rows).⁸⁹ This allows you to accurately track the flow of raw materials at different stages of renovation - for example, to determine the real amount of recycled components, or to schedule demolition and reuse.

2.4 Circularity indicators



Madaster also has a Circularity Indicator (CI) tool. It is used to assess the potential of buildings, the extent to which the materials and products used in their construction contribute to the circular economy. It reports the result in the form of indicators (CI) for different categories - the idea is based on the Ellen MacArthur Foundation’s methodology, providing results on a scale from 0 to 100 percent.⁹⁰ A full one hundred percent means the building is made of renewable and recyclable materials, and the building itself has a long life and high potential for dismantling at the end of its life.⁹¹ The Madaster platform provides the most detailed closed-loop information on the entire building, each specific layer and phase of the life cycle: its construction, operation and end-of-life.

At the construction stage, the CI refers to the ratio of virgin to recycled or used materials. In the operation stage, on the other hand, the estimated durability of materials is compared to the average life of typical com-

fig. 51 set of example’s indicators (source: madaster webinar)

⁸⁸ Druj, Bertus. “BIM-Based Material Passport in Madaster during the Operational and Maintenance Phase of a Building,” 2019.

⁸⁹ Ellen MacArthur Foundation. Circularity Indicators: An Approach to Measuring Circularity. Ellen MacArthur Foundation, 2015.

⁹⁰ Madaster Platform. Circular Indicator. Madaster, 2018.

ponents. Finally, the CI indicator is examined for the decommissioning stage - the amount of demolition waste relative to reused or recycled resources.

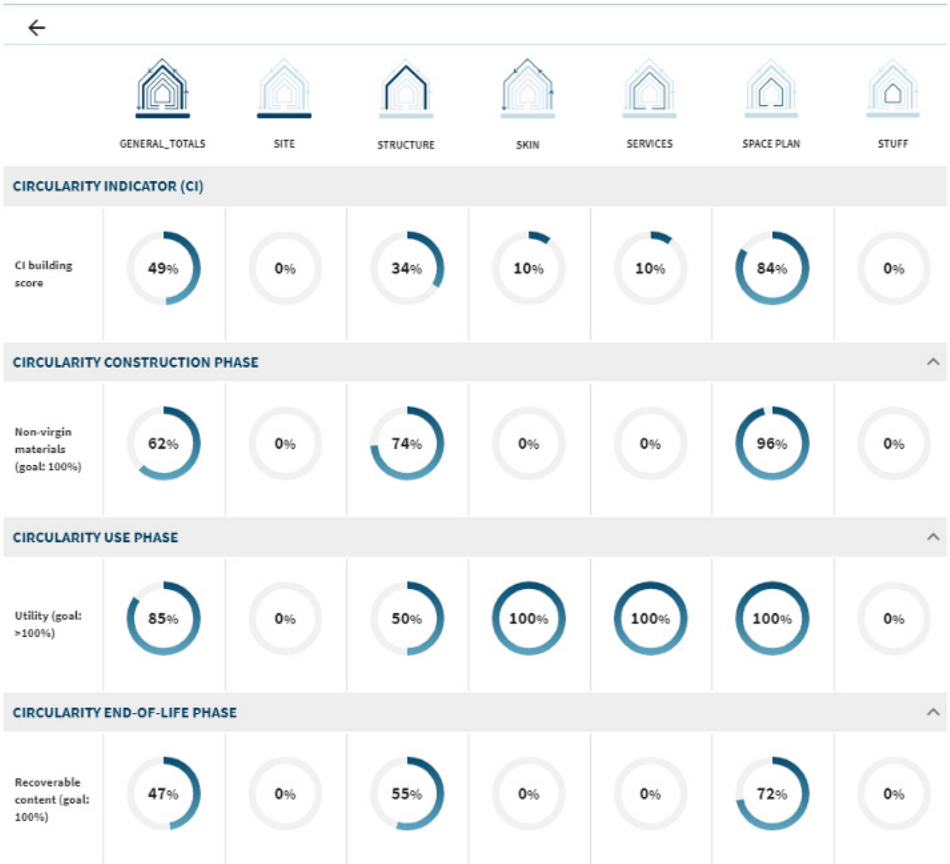


fig. 52 Madaster circularity indicators in generated report (source: madaster manual)

Another important factor affecting the CI score is the completeness correction applied to the system. In this case, the BIM model is evaluated against Madaster’s criteria, taking into account the amount of materials whose composition is unknown or not coded with the SfB standard. This provides information on how complete the result of the CI analysis is.⁹² With a BIM model with fussy material properties, these results are not meaningful.

2.5 Financial indicators and potential benefits

A key tool in the economic category is to estimate the residual value of a building and provide tools for financial analysis to enable effective planning and management of materials. Residual value is the anticipated value of an asset at the end of its useful life or anticipated useful life. In the case of architecture and construction, we’re talking about materials,

⁹¹ Madaster Platform. Madaster User Guide, 2018.

components or building objects at the end of their useful life, along with the inclusion of all costs resulting from their recovery such as dismantling, transporting and handling the processing.⁹³ The Madaster platform also takes into account the different life scenarios of individual materials, regulations and takes into account changing market trends.⁹⁴ This methodology provides insight into an essentially realistic estimate of how much economic potential is actually achievable in the long term from buildings.



The first group of forecasts - based on a set of data for each layer of the building and the materials within it - functions over their lifetime. This means that the useful life depends on the functions performed in each layer, which is the rationale for calculating the net present value, including the amount of residual value projected for the present value. This is what justifies explaining to the owner, as well as to investors and banks, the projected amount possible at the time of demolition (including all costs).⁹⁵ Thus, the tool calculates how much the materials in different parts of the building will be worth in the future, when their useful life is over. To do this, it “brings” their future value to the present moment using a financial method called Net Present Value (NPV). This takes into account that different parts of a building (e.g., roof, walls, foundations) have different useful lives - some last longer, others shorter.⁹⁶ For example, the structure will stay for the rest of the building’s life while it is possible that the facade will have to be changed.

fig. 53 financial indicators set, price of material mass vary over time (source: madaster manual)

⁹² Fabozzi, F. J. (2014). Foundations of Financial Markets and Institutions. Pearson Education.

⁹³ Madaster Foundation. “Material Passport: Enabling Circular Construction.” Accessed December 17, 2024.

⁹⁴ Madaster Platform. Residual Value Methodology. Madaster, 2018

⁹⁵ Druij, Bertus. “BIM-Based Material Passport in Madaster during the Operational and Maintenance Phase of a Building,” 2019.

In addition to calculating residual value, Madaster also offers other financial analysis tools. One of them is the assessment of the capital value of a building, i.e. the value of “frozen” assets in a construction facility. Although this sounds similar to the residual value assessment, this analysis is broader in scope, not just limited to the end of the life cycle of the materials, but takes into account their value over their lifetime.⁹⁷ It also refers to real market values today, not projections and forecasts (Financial and investment indicators such as Gross Asset Value (GAV) or replacement value of a building are often used here)⁹⁸ While residual analysis can be an indicator used for, say, demolition planning, capital value allows for a realistic assessment of the value of a building’s assets from the perspective of real estate portfolio management and less from the circularity side.

Another indicator is LCC - Life Cycle Cost analysis. It is a tool for calculating the cost of operating a building at different stages of life. It refers strictly to the costs resulting from the use and forecasting of repairs and renovations based on the data described in the life cycle analysis. This tool also allows calculating CO₂ emissions. Thus, the platform includes a comprehensive set of financial indicators and determining the environmental costs of greenhouse gas emissions⁹⁹ and energy costs of individual repair and operation works.

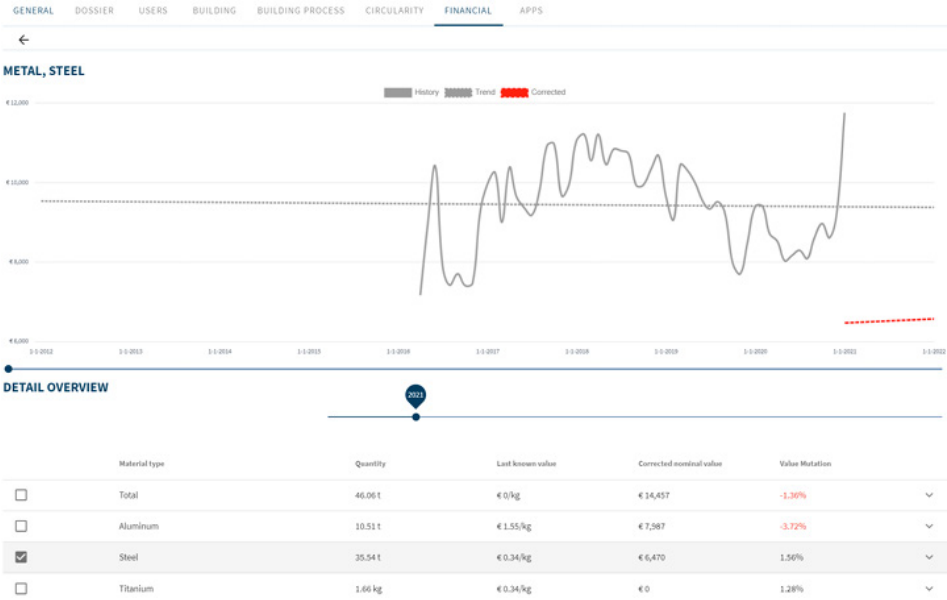


fig. 54 steel embodied in project price over time (source: madaster manual)

⁹⁶ Ellen MacArthur Foundation. “Circular Economy in Construction.” Accessed December 17, 2024.

⁹⁷ “Investment Portfolio Management in Construction,” European Commission. Accessed December 17, 2024.

⁹⁸ “CO₂ Impact Assessment in Construction,” European Commission, Accessed December 17, 2024.

It is also interesting to apply the previously mentioned CI - Circularity Indicator in an economic context. The higher its value, the greater the potential for reuse, or resale, of materials in the future. Juxtaposed with other indicators, investors can get a more realistic picture of the actual

projected return on materials in the long term.¹⁰⁰ The use of Madaster tools also helps meet the requirements of BREEAM or LEED certifications.¹⁰¹ Both BREEAM and LEED take into account the potential for reuse of materials in buildings, promoting recycling, reuse of structural elements, and design that facilitates disassembly and adaptation (however, the assessment often focuses on the amount of recycled materials rather than the practicalities of actually reusing them). This is especially useful for complex buildings where volumes of data are very difficult to organize and process in the conventional way on spreadsheets.

Generally speaking, the financial tools offered by companies such as Madaster have great potential for a paradigm shift in thinking about construction investments. Currently, the main value is the highest possible rate of return in the shortest possible time. If a compelling case could be made for getting investors to put their money into environmentally friendly solutions using data analysis indices from Material Passport. This could be a turning point in the entire history of efforts to introduce a circular economy. One key factor is the residual value of buildings.

The positive factor of a significant increase in residual value could significantly affect the creditworthiness of investors - an important argument. Banks in their analysis evaluate creditworthiness by assessing the value of assets as collateral. Currently, the value of the building itself (without the land) has little residual value. As the residual value increases (with predicted price of materials to be reused), their sum increases which translates into greater creditworthiness.¹⁰² This could convince the investor, even though he has to invest more money and the return on investment will come later (which is the main problem of green buildings), he has more creditworthiness for new investments due to the larger assets. Greater asset value could be a key financial argument. However, banks base their calculations on hard and documented data. But with a solid foundation of calculations and data structure, e.g., offered by Madaster tools, this could be a compelling argument. Such a financial model could be a turning point in the spread of the closed-loop economy in the construction sector, as it would in some way shift transition costs from private actors to banking institutions and lenders - by documenting the reusability and value of building components. Unlike construction investors, they often operate on longer time horizons.

⁹⁹ "Optimization of Building Investment Portfolios Using Material Data,". Journal of Sustainable Finance, 2024.

¹⁰⁰ Pomponi, Francesco, and Alice Moncaster. "Circular Economy for the Built Environment: A Research Framework." Journal of Cleaner Production 143 (2017): 710-18.

3. Proof of concept - application of Madaster tools on UMAR's case

To better understand the usefulness and application of tools such as Madaster, it is useful to show their use in practice. Thanks to researchers from the Karlsruhe Institute of Technology and Turntoo in Amsterdam who “digitized” the resources of the previously discussed UMAR building in Dübendorf, we can learn about the operation of the Madaster platform in practice. They used the tools provided by Madaster (in particular, the Building Circularity Indicator) to conduct a circularity assessment of the building. Thanks to the material passports Madaster created, it was possible to assess and prove the building’s circularity index at 96% while 95% of recycled and renewable materials were used in the UMAR construction process,.

3.1 Methodology - data collection

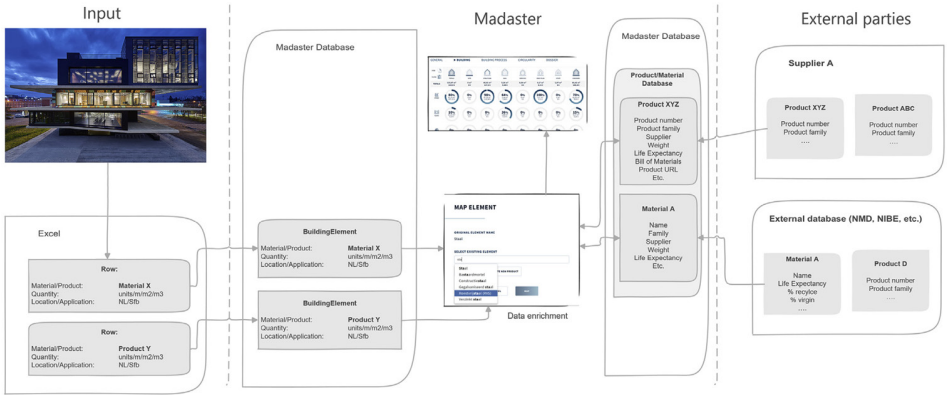


fig. 55 Scheme of data input, hierarchy, calculation, output and connection to external partners on the Madaster platform. (source: Felix Heisel, Sabine Rau-Oberhuber)

In order to thoroughly explore the full potential of circularity resulting from the CI - Circularity Index, the process of data entry and interpretation involved 4 steps. The first step was to analyze the materials proposed in the project at the concept stage. Since the data needed for material passports are not always provided by manufacturers and their structure varies, it was first necessary to analyze the available options proposed by the architects. The two main categories were technical information (including circular) on a specific material and the location of the element in a specific location and layer of the building¹⁰³ (as described in the Madaster paragraph). Next, the data had to be entered into spreadsheets. For this purpose, 32 material data sheets were created and assigned to 90 products used in the UMAR building.¹⁰⁴ The “material” category included the following parameters: name, specific gravity, supplier, useful life, raw material sources and quality, end-of-life scenario and recycling process performance. This database was then assigned to the 90 differ-

¹⁰¹ F. Heisel, S. Rau-Oberhuber, “Calculation and evaluation of circularity indicators for the built environment using the case studies of UMAR and Madaster,” Journal of Cleaner Production 243, 2019.

¹⁰² Ibid

ent items mentioned - these were characterized by the following parameters: brand, product code, supplier, functional and technical life, volume, quantity, connection details with regard to ease of disassembly and material separation, and NL/SfB standard material codes.¹⁰⁵ Since the Swiss version of the Madaster platform did not yet exist at the time, the data had to be translated into Dutch format. So the simplest thing was to enter this data into excel sheets which were then sent to Madaster and translated by them. From then on they were available and editable online in the web application where, for example, information on the criteria for dismantling a building was added.

3.2 Methodology - data processing - obtaining indicators

Then, when the database on the madaster platform was complete, the calculation of the Circularity Index (phase 3) and the interpretation of the results (phase 4) proceeded. Based on the material and product datasets, the madaster platform carried out the CI calculation according to the algorithms. The final result consists of a factor of the ratio of virgin to recycled/reusable materials, a factor of the expected lifespan of the products used compared to the average lifespan of status-quo products, and a factor of the ratio of waste materials to reusable and/or recyclable materials generated during the renovation or demolition of a building.¹⁰⁶ According to these analyses, the UMAR unit was made from 95% recycled or rapidly renewable materials and achieves a usability rate (of these materials) of 98%. Moreover, 92% of the materials used are suitable for re-integration into the end-of-life cycle - taking into account the total weight of the materials used in the construction.¹⁰⁷



However, the researchers wanted to make the rate more realistic. Even assuming a careful and properly planned dismantling process, potential unplanned and undesirable end-of-life scenarios cannot be ruled out. In order to better understand the impact of materials management at the

fig. 56 generated madaster report (source: Felix Heisel, Sabine Rau-Oberhuber)

¹⁰³ F. Heisel, S. Rau-Oberhuber, "Calculation and evaluation of circularity indicators for the built environment using the case studies of UMAR and Madaster," Journal of Cleaner Production 243, 2019.

¹⁰⁴ Ibid
¹⁰⁵ Ibid

end of a building's life, a sensitivity analysis was conducted. A 20% reduction in recyclable material content was assumed. This is therefore about the assumption that materials and components are subject to wear and tear through operation, and we can never assume recovery of 100 materials. Even with these assumptions, the results show high circularity: 87% of materials are recycled or renewable, the utility rate remains at 98%, and 86% of materials are recyclable.¹⁰⁸

The main reason for this high CI was the use of Forest Stewardship Council - FSC certified from local suppliers. Its use includes module frames, load-bearing elements, floors, ceilings and some of the finishes. The use of wood species such as spruce, silver fir and light brown ash made it possible to source them 100% from nearby sawmills. The local sourcing of materials reduced emissions from transportation to the necessary minimum, which translated directly into the CI and embodied carbon indicator. In addition, significant amounts of materials were recycled (glass panels, ceramic tiles, countertops) and reused (e.g., vintage doorknobs by Jules Wabbes).

3.3 Results

It is also worth noting the process itself and how Madaster processes the data. Some of the formulas are based on national or European legislation, for example, the one describing recycling efficiency fits the European Commission's definition - "the ratio obtained by dividing the mass of output fractions taking into account recycling by the mass of waste ... of the input fraction expressed as a percentage."¹⁰⁹ This is a good thing, because it leads to unification of standards, but on the other hand, the European Commission's directive is not entirely sufficient in this regard. This is because it omits aspects such as energy consumption during the operation of a building, the embedded energy of materials and products, or the amount of water needed to construct and operate a building. These are important components that are not available at the moment, but Madaster is working to put them in place.¹¹⁰ The mentioned definition of recycling also does not include materials that are burned - in other words, non-recyclable materials are excluded from the indicator, which can also be misleading when interpreting the results. This is because the indicator is not a global parameter for all project materials, but assesses the quality of potential recycling of only those materials fit for reuse.¹¹¹ Madaster is currently developing alternative definitions of its own (some of which are already available on the platform) which, according to Felix Heisel¹¹², are very useful tools for evaluating design decisions and effectively implementing the circular economy. However, without synchroniza-

¹⁰⁷ European Commission, 2012. Laying Down, Pursuant to Directive 2006/66/EC of the European Parliament and of the Council, Detailed Rules Regarding the Calculation of Recycling Efficiencies of the Recycling Process of Waste Batteries and Accumulators. European Commission, Brussels, Belgium. Commission Regulation No. 493/2012.

¹⁰⁸ Madaster, 2018b. Explanation Madaster Circularity Indicator. Madaster Services B.V, Utrecht, The Netherlands.

¹⁰⁹ F. Heisel, S. Rau-Oberhuber, "Calculation and evaluation of circularity indicators for the built environment using the case studies of UMAR and Madaster," Journal of Cleaner Production 243

¹¹⁰ Heisel, Felix, Hebel, Dirk E., Sobek, Werner, 2019a. 'Resource-Respectful construction e the case of the urban mining and recycling unit (UMAR)'. In: SBE19 Brussels-BAMB-CIRCPATH 'Buildings as Material Banks- A Pathway for A Circular Future', 5-7 February 2019, Brussels, Belgium.

¹¹² Ibid

tion with EU legislation, they will not go beyond the architect’s workshop as an authoritative indicator the reasons for which are described above. This is because introducing them today as, for example, legally required standards for modern buildings could lead to easy manipulation and opportunities to circumvent them.

fig. 57 Volume and mass of materials used in the UMAR unit categorized according to material families and applications/locations (source: Felix Heisel, Sabine Rau-Oberhuber)

	Totals		Site		Structure		Skin		Services		Space Plan		Stuff	
Totals	151.52	m³	0.00	m³	44.26	m³	84.22	m³	0.20	m³	20.82	m³	2.02	m³
Stone	48.40	t	0.00	t	25.13	t	9.68	t	0.95	t	11.13	t	1.51	t
	79.69	m³	0.00	m³	0.00	m³	77.79	m³	0.00	m³	1.88	m³	0.00	m³
Glass	5.02	t	0.00	t	0.00	t	2.96	t	0.00	t	2.07	t	0.00	t
	2.49	m³	0.00	m³	0.00	m³	1.58	m³	0.00	m³	0.91	m³	0.00	m³
Wood	5.92	t	0.00	t	0.00	t	4.07	t	0.00	t	1.85	t	0.00	t
	55.93	m³	0.00	m³	44.00	m³	4.66	m³	0.00	m³	5.32	m³	1.95	m³
Plastic	29.76	t	0.00	t	23.09	t	2.13	t	0.00	t	3.21	t	1.36	t
	0.84	m³	0.00	m³	0.00	m³	0.11	m³	0.04	m³	0.62	m³	0.05	m³
Organic	0.73	t	0.00	t	0.00	t	0.02	t	0.04	t	0.66	t	0.06	t
	11.27	m³	0.00	m³	0.00	m³	0.00	m³	0.00	m³	11.26	m³	0.01	m³
Metal	0.85	t	0.00	t	0.00	t	0.00	t	0.00	t	0.85	t	0.00	t
	1.32	m³	0.00	m³	0.26	m³	0.08	m³	0.16	m³	0.81	m³	0.01	m³
	6.06	t	0.00	t	2.04	t	0.54	t	0.91	t	2.49	t	0.08	t

It is also important to control the reuse and recycling process so that the indicators can be reliable. The aforementioned glass panels from Magna Glaskeramik are 100% recyclable, but this applies when they actually end up back in that company’s hands rather than ending up in the trash. So the Usability Index (UR) applies here. It determines the quality and reusability of a product. Since processing requires energy and to reuse you only have to disassemble the item, it is in CE’s interest to make it of the best quality and its life as long as possible. This will also reduce the risk of the aforementioned dumping of the product in a landfill.

Another aspect highlighted by the authors is scalability in terms of access to information. In the case of Madaster’s materials database, we can select different detail filters which allows us to evaluate design decisions early in the project. In this case, however, the database was built in spreadsheet format rather than a BIM Model correlated with the materials database. This, of course, did not affect the reliability of the results but is much more difficult in the case of significant design modifications and sometimes requires manual data entry.¹¹³

3.4 Conclusions

The results of Madaster analysis for UMAR are an important case study of the application of such tools in practice. As of today, this is the only known comprehensive application of Madaster for a constructed building with such a large scale of detail. It is also a demonstrator and a living laboratory - a model building, unattainable in market realities at this point. However, it demonstrates that this is an achievable level and is undoubtedly becoming a benchmark for those interested in constructing buildings that comply with the Circular Economy. It also involves the need

111 F. Heisel, S. Rau-Oberhuber, “Calculation and evaluation of circularity indicators for the built environment using the case studies of UMAR and Madaster,” Journal of Cleaner Production 243,

to work with new entities involved in the organization, management and storage of data. Although UMAR is a relatively small building, the amount of data would be difficult for architects to process with traditional tools.

The analysis also revealed a number of obstacles at the administrative and political levels. Current indicators proposed by lawmakers do not yet take into account all aspects necessary to evaluate buildings. This forces external entities to set their standards and this unfortunately leads to fragmentation and inability to make comparisons. It also makes it more difficult to introduce uniform standards and consumes more time for research and development.

4. Material Passport - application and workflow in practice (how to really use it in office environment)

I would like to devote the last chapter before moving on to the analysis of completed buildings with Material Passport applied, to a technical analysis of what Material Passport actually looks like in practice and how architects and engineers use it when working in the office. I will focus here on coordinating Madaster together with BIM programs because I believe that in such a configuration these tools become really useful for architects to make better decisions in the conceptual phase. However, in order for this to work, BIM-workflow has to follow certain rules quite strictly. The process of exporting files from Revit or Archicad itself is not complicated, but modeling discipline and high digital “hygiene” of the file are important.

4.1 BIM

BIM, or Building Information Modeling, is a concept that always appears in industry discourse when it comes to digitization or innovation. It is a concept that is understood in many ways among professionals, from a broad definition, i.e. understanding BIM as a methodology of work covering the entire life cycle of a building, as well as a narrow one, i.e. understanding BIM as a product, a tool for improving the work of a designer.¹¹⁴ In the broader sense, the digital model through which architects more efficiently create sets of building documentation is only part of the data. When taking into account the detailed material information it contains and the time dimension - the exchange and use of information at all stages of a building’s life, it becomes a powerful tool to support reuse and create material passport. According to Becker et al. (2018), BIM is a digital planning and construction method that aims to support construction processes throughout the building life cycle. This definition includes

112 Matijka, P., & Tomek, A. (2017). Ontology of BIM in a construction project life cycle. Procedia engineering, 196

the use of a model for a building that encompasses all of its properties, which in turn facilitates the exchange of data between different actors from the architectural, engineering and construction (AEC) community, and consequently improves the quality of this connection.¹¹⁵ However, this requires a rigorous approach to workflow at all project phases and in the exchange of information between trades.

4.2 Standards and models

Since it is rare for any independent specialist in the construction industry to work on the same software, BIM tools operate on the same standards for data structures. As a result, files from different applications can be translated and interoperability ensured between different tools and participants in the construction process. For example, for Revit, a common data standard is RS - Revit Standards. For different countries, there are separate standards tailored to national markets, but some are better and others worse for interoperability. For example, the Forum of Standardization organized by the BIM Locket platform recommends using the Dutch NLRs standard for Revit which translates very well into the interoperable IFC - Industry Foundation Classes format. NLRs can also be translated well into the previously mentioned Sfb data format which allows for a lot of information on life cycle, recyclability potential or emissivity of materials.¹¹⁶

The implementation and development of BIM standards in Switzerland is done through organizations such as Bauen Digital Schweiz and the buildingSMART Switzerland platform. It advocates the use of open international standards such as IFC (Industry Foundation Classes) and BCF (BIM Collaboration Format).¹¹⁷ The Swiss BIM guidelines are in line with SIA 2051 standards, which define a framework for exchanging data and structuring BIM models throughout the life of a project.¹¹⁸ Among other things, the standard defines levels of detail in the models and rules for organizing data that enable better collaboration between designers, contractors and investors. However, the standards are still being developed for circularity parameters, and some material passport and data management companies are recommending the use of Dutch formats.

4.3 IFC

Industry Foundation Classes is the most popular format and is used for collaboration between different industries in the construction sector. So it stands to reason that the primary format for importing data from BIM into the Madaster discussed earlier is IFC. Its primary purpose is to define

the geometry of an object and its location in a project and then assign a desired set of additional information such as properties, quantities and classification with building objects and maintain relationships between them. The data is structured in a “tree” format which provides a clear and hierarchical order, also allowing for layered display in various management and modeling programs.

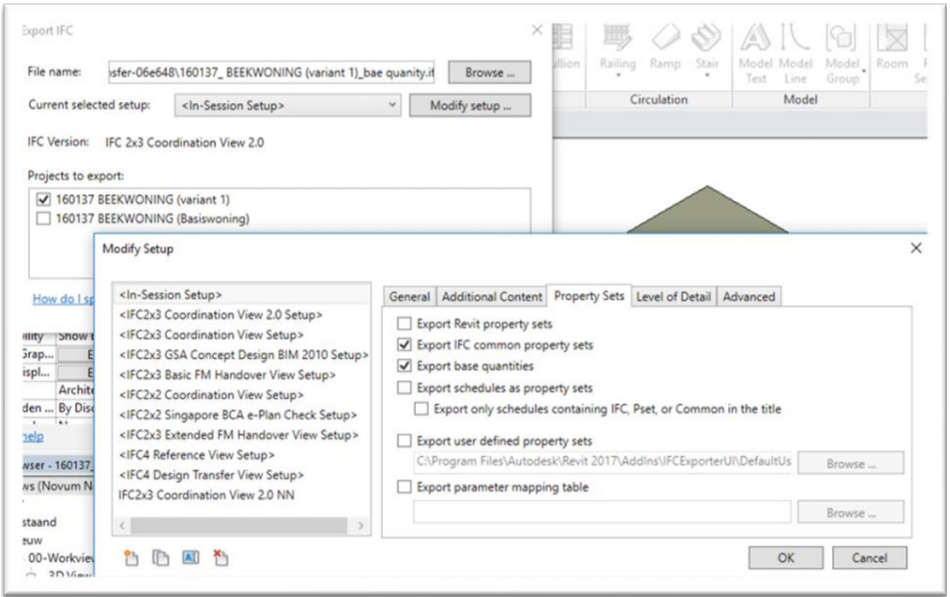


fig. 58 IFC export windows in Revit with desired settings (source: madaster manual)

In the fragmented construction industry, where each specialist uses separate software developed specifically for them, the IFC format enables collaboration. It overcomes inefficiencies by avoiding re-modeling and assigning information every time files are exchanged between specialists. This is what makes the existence of forms such as Madaster possible and increasingly simple for designers. However, IFC is a lossy format and impossible to re-edit in the parent program once exported. This is both its plus and minus. The author of the file can be sure of his copyright and ownership rights because once the file is sent, it will not be further modified, but in case of mismanagement or if some information is lost at the coordination stage, it may take a lot of effort to recover it. Therefore, not all specialists use IFC and sometimes they prefer proprietary formats native to modeling programs which eliminates the occurrence of errors at the management or export stage.¹¹⁹

4.4 Export to Madaster - requirements

The IFC format itself has many versions and is constantly evolving and just preparing it requires some basic knowledge. It is sometimes criticized

¹¹³ Becker, R., Falk, V., Hoenen, S., Loges, S., Stumm, S., Blankenbach, J., Brell-Cokcan, S., Hildebrandt, L., & Vallée, D. (2018). BIM-Towards the entire lifecycle. International Journal of Sustainable Development and Planning, 13, 84-95.

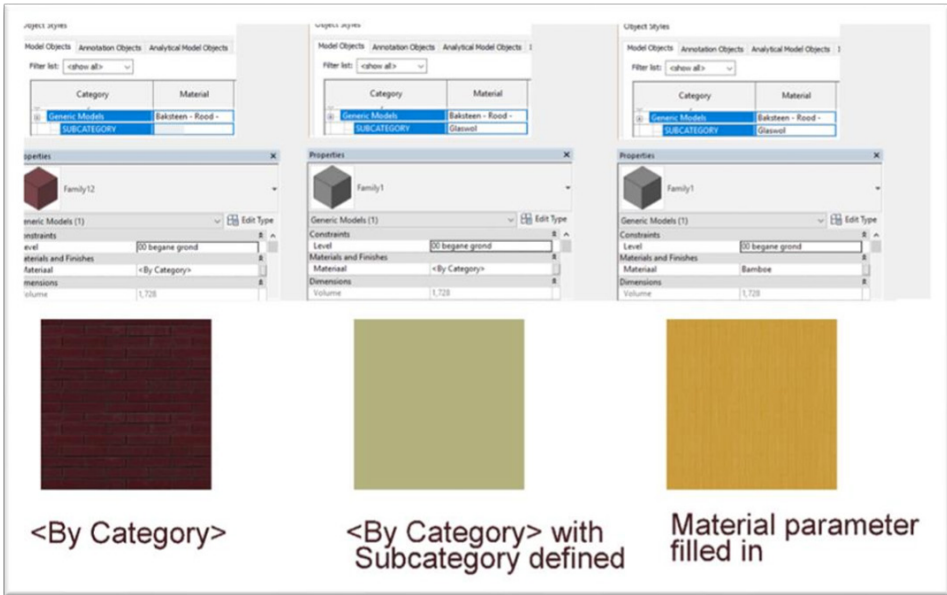
¹¹⁴ Drujij, Bertus. "BIM-Based Material Passport in Madaster during the Operational and Maintenance Phase of a Building," 2019.

¹¹⁵ buildingSMART Switzerland. IFC und offene Standards. Accessed December 30, 2024. <https://www.building-smart.ch>

¹¹⁶ SIA. SIA Standard 2051: Building Information Modelling (BIM). Zürich: Swiss Society of Engineers and Architects, 2017.

¹¹⁷ Drujij, Bertus. "BIM-Based Material Passport in Madaster during the Operational and Maintenance Phase of a Building," 2019.

because if it is exported by a person who does not know anything about it, it can simply be useless. The same is true when exporting an IFC file to the Madaster platform. In the user’s manual, Madaster specifies exactly what is necessary when preparing the file to be able to get reliable data from analytical tools on the platform. Based on this, D. Bertus¹²⁰ proposes such a scheme to streamline the process, including both automated and manual steps to address these challenges:



4.4.1 Positioning in the coordinate system

As with the export of an IFC file, the location relative to the project zero is important. Madaster requires a building to have its specific geographic location locatable in the cadastre. So the project must have its zero point linked to the appropriate geographic coordinates (depending on the country or region) and the project base point must be equal to the survey point and the zero point.¹²¹

4.4.2 IFC units

It is required to modify the default export template. Some parameters such as “Building element proxy” and “Building element part” are not readable by the Madaster platform. Their use should be avoided because they cannot be assigned to any category or linked to the database which results in a messy structure.¹²²

fig. 59 assigning the right material parameter in Revit (source: madaster manual)

¹¹⁹ Druij, Bertus. “BIM-Based Material Passport in Madaster during the Operational and Maintenance Phase of a Building,” 2019.

¹²⁰ Ibid.

¹¹⁸ Druij, Bertus. “BIM-Based Material Passport in Madaster during the Operational and Maintenance Phase of a Building,” 2019.

4.4.3 Unique GUID

GUID - Global Unique Identifier is a 128-bit number generated when a new object is created in the model. Every wall, column, window and other BIM object has its own unique number where the possibility of finding another one the same is minimal.¹²³ To import a model into Madaster, the objects in the model must have just these unique GUID numbers. Thanks to its uniqueness, it is possible to track the life cycle and suitability of an element throughout the life of the building.¹²⁴

4.4.4 Material

Objects should be assigned materials according to the standard and naming standard used (e.g., the SfB mentioned earlier).¹²⁵

4.4.5 IFC-type

The IFC-type parameter should be as detailed as possible. It defines the typologies of objects in BIM models i.e. for example, a wall and its type, a window and its type, etc. The more detailed the information, the more reliable the Madaster analysis. The type can even include parameters such as a specific proprietary name or manufacturer code.¹²⁶

4.4.6 SfB classification

Madaster requires IFC files to have an NL/SfB classification that describes material and environmental properties well. This involves assigning each material and element a code consisting of 4 elements.¹²⁷ These denote in turn: “the environment to be built and the spaces to be created,” “the functional components of the facility to be built,” “construction method and construction material to be used,” and “preparation and construction process to be organized, the characteristics and properties of a building, spaces and (building) materials and the characteristics of the activities of (future) users.”¹²⁸

4.4.6 Base quantities

The IFC model when exported from Revit, for example, should have included a quantitative summary of the basic elements included in the design. So it is important that at this stage the model is a reliable representation of the designed building.¹²⁹

¹²¹ BIMshares. “GUID - Definition and How It Works in BIM Projects.” BIMshares (blog), September 9, 2024. <https://bimshares.com/blog/guid-definition/>.

¹²² Druij, Bertus. “BIM-Based Material Passport in Madaster during the Operational and Maintenance Phase of a Building,” 2019.

¹²³ Ibid.

¹²⁴ Druij, Bertus. “BIM-Based Material Passport in Madaster during the Operational and Maintenance Phase of a Building,” 2019.

¹²⁵ Ibid.

¹²⁶ NEN. NL/SfB Classification System. 2018. accessed December 30, 2024. <https://www.nen.nl>.

¹²⁷ Druij, Bertus. “BIM-Based Material Passport in Madaster during the Operational and Maintenance Phase of a Building,” 2019.

4.4.7 Property Set

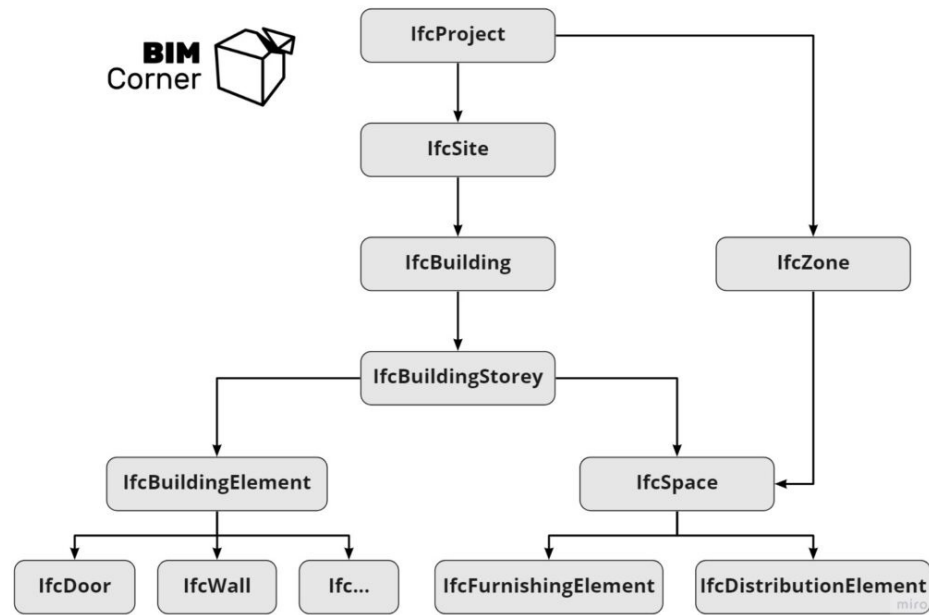
Madaster recommends using the “Renovation status” or “Phasing” parameters when working on new buildings, and requires their use for renovation or remodeling projects. This allows for better tracking of phasing and better visualization of the model.¹³⁰

4.4.8 2x3 export

This is nothing more than a version of the IFC format. Currently Madaster works best with the 2x3 version which is the 3rd generation of IFC. There are already newer standards have a more extensive parameter tree, but at the moment they are not supported by Madaster.¹³¹

4.5 Generating material passport in practice

For material passports to work effectively, high-quality data and ongoing updates are essential. Production models often have more detail compared to design models, but they may lack the key parametric data required to create material passports. To mitigate this problem, designers are advised to specify BIM requirements aligned with platforms such as Madaster in project tenders. Also important is the role of the BIM manager as the person responsible for developing and verifying the models and file during the process consistently throughout the project



128 Ibid

129 Druij, Bertus. “BIM-Based Material Passport in Madaster during the Operational and Maintenance Phase of a Building,” 2019.

Creating a material passport through the Madaster platform involves exporting an IFC file to the online platform. During this export, the requirements discussed must be met, then the process should be relatively simple. Once uploaded to Madaster, the platform automatically processes the data and links it to the internal database.

The usefulness of a material passport depends on the accuracy and completeness of the data. Achieving a balance between the data collection effort and the value of the information is crucial. Typically, the goal is to collect about 80% of the required data with minimal time investment.¹³² Incomplete data, however, can lead to errors in building-wide analyses.

4.6 Problems in exports

The main challenge in generating material passports is incomplete and inconsistent data in the BIM models that serve as their basis. Many components in these models do not meet the specifications required by platforms such as Madaster (which is due to human error or imperfections in the IFC export models). This includes adhering to NL/SfB grading standards, assigning accurate material data or using appropriate IFC type designations. This problem is particularly evident in the installation layers of buildings, where international standards such as EMCS often conflict with local classification systems. What’s more, many products and materials in BIM libraries - especially those less commonly used - lack the necessary material parameters. This data gap further complicates efforts to automate the creation of material passports. Another problem is the frequent need for manual intervention to enrich data on the Madaster platform. This is largely due to the lack of standardized naming and classification systems for materials and products in the various BIM object libraries that we download from the Internet (e.g., from the BIM Objects website). These inconsistencies lead to inaccuracies in automatic data mapping, making it necessary to manually fill in missing information.¹³³

4.7 Lessons and problems with Material Passport in practice

At the operation and maintenance stage, we encounter a significant problem - the lack of a standardized approach to updating BIM models. The fragmented nature of modeling - where different parts of the model are developed using different software by different project participants - further complicates the process. This fragmentation makes it difficult to keep the data up-to-date and use it effectively when generating material passports.¹³⁴

132 Çetin, S., et al. “Data Requirements and Availabilities for Material Passports: A Digitally Enabled Framework for Improving the Circularity of Existing Buildings.”

130 Ibid

131 Druij, Bertus. “BIM-Based Material Passport in Madaster during the Operational and Maintenance Phase of a Building,” 2019.

Also, motivating building owners to keep their material passports up to date is a major challenge. Currently, there is not enough legislative pressure or financial incentives - such as tax credits - to encourage owners to document changes and keep their data up to date.¹³⁵ Establishing a certification process for material passports could increase their credibility and encourage their use. Although Madaster is exploring the integration of material passports with condition measurement processes, such as NEN 2767-compliant assessments, practical implementations of these solutions are still lacking. Certification could also include quality checks through visual inspections combined with existing condition assessments. These measures could also unlock other incentives, such as better loan terms, further underscoring their MP importance to building owners and stakeholders.¹³⁶

In summary, generating material passports from BIM models requires rigorous data management at every stage of the project. However, further work on certification, standards development and measurement process integration is needed to ensure the practical applicability and effectiveness of material passports in promoting sustainable construction. At this point, unfortunately, they are not yet backed by any “legal force” or real added value for investors. All indications are, however, that this will change in the near future, as private entities, as well as institutions and national governments in the EU, are working on introducing their own regulations for Material Passport.

¹³³ Trubina, N., Leindecker, G., & Askar, R. "Digital Technologies and Material Passports for Circularity in Buildings: An In-Depth Analysis of Current Practices and Emerging Trends."

¹³⁴ Druij, Bertus. "BIM-Based Material Passport in Madaster during the Operational and Maintenance Phase of a Building," 2019.



fig. 61

Finally, having a full picture of the Material Passport and Material Bank concept, it is worth moving on to examples of application in real construction. Unlike the UMAR unit where financing is provided by the research unit and the building itself is the research area, conditions in the free market are quite different. Here, circular concepts must have an assured return in advance and fit into the entire financial mix of the project.

1. Temporary City Hall, Rau Architecten, 2011 Brummen, the Netherlands - a building designed as a Material Bank

The first example is Temporary City Hall in Brummen, the Netherlands. This is an example of designing buildings as Material Banks in the long term because the main design strategy was design as a service. The architects at RAU Architecten were challenged to create a sustainable extension of the 1890 villa while preserving the original foundations.¹³⁷ The main intention of the client (i.e., the city of Brummen) was to build a sustainable building so as to set an example for new developments in the area. The scope of work included the demolition of the former buildings around the villa, the preservation and restoration of the historic buildings, and the design of a new city hall in integration with the U-plan villa. The new building achieved a score of about 90% reuse potential of the materials used, assuming a building life cycle of 20 years. Such a high score was achieved thanks to a combination of factors, such as appropriate material selection, modular design, an innovative way of working with contracts and, finally, the implementation of Material Passport.¹³⁸

1.1 Design as a service

The most innovative and unusual approach is definitely the way they plan for reuse and a long-term perspective. The RAU architects even moved away from the name “building” to the name “product” when telling the story of this project. The various main elements of the building: the facade system, the main wooden structure, the interior wall system, the green roof and the glass roof are all components of the “product.” Their owners in reality are not the municipality, but subcontractors and suppliers who provide them on a “leasing” basis. The modular approach thus had to assume quick assembly and disassembly and the durability of some components was further enhanced. For example, as a result of negotiations with a wood supplier for structural beams and columns, their cross-sections were designed much larger than their static calculations would suggest. As a result, their wear and tear over the life cycle of the building will be minimal and finding them a new use after demolition will be easier.¹³⁹ The same was done with the rest of the previously mentioned

¹³⁵ Ungureanu, Viorel, François Fohl, Jie Yang, Oliver Hechler, Vlatka Rajčić, and Raluca Buzatu. “Recovery and Reuse of Salvaged Products and Building Materials From Existing Structures.” In Springer Tracts in Civil Engineering, 93-120, 2024.

¹³⁶ “A Building That Can Be Reused: Brummen Town Hall,” January 11, 2022. <https://www.ellenmacarthurfoundation.org/circular-examples/brummen-town-hall>.

¹³⁷ Marijn, Emmanuel “Material passports for the built environment”, Madaster Lecture Series, Baltimore Sister Cities, April 11, 2021

elements. Opting for above-average material quality or higher static strength will significantly affect reuse potential and translate into financial benefits. Additionally, these materials are accurately cataloged through BIM Material Passport. As a result, architects and main contractor Royal BAM Group guarantee that at the end of their useful life, building materials will retain at least 20% of their residual value.¹⁴⁰ These aspects are part of the architects' planned design methodology CS - Circular Strategy divided into 3 stages.

fig. 62 ground floor plan - temporary intervention in blue (source: plan by RAU Architekten, edited by Kewin Niewiarowski)



1.2 CS1: Maximize material and energy efficiency

Minimizing resource consumption through downsizing and cost-effective design solutions are also used as part of the strategy. The lightweight wooden structures at Brummen City Hall have reduced the amount of materials needed while reducing carbon emissions during production and transportation. This not only reduced waste in the process, but also reduced the need for new raw materials in future projects.¹⁴¹

138 "A Building That Can Be Reused: Brummen Town Hall," January 11, 2022. <https://www.ellenmacarthurfoundation.org/circular-examples/brummen-town-hall>.

139 Gerding, Ditte P., Hans W. Wamelink, and Els M. Leclercq. "Implementing Circularity in the Construction Process: A Case Study Examining the Reorganization of Multi-actor Environment and the Decision-making Process." *Construction Management and Economics* 39, no. 7 (July 3, 2021): 617-35

1.3 CS2: Extend product value - standardization

Product valorization is another aspect, regarding the design of buildings with individual components that can be easily repaired, upgraded or recycled. This philosophy is being implemented in the case of Brummen City Hall, which uses structural modules that can be dismantled, ensuring easy separation and replacement of components. The work also included standardization of components, making them more versatile and expandable to other projects. The project also includes solutions for reusing façade materials, including glass panels and wood elements.¹⁴²

1.4 CS3: Extending the value of resources

The approach to increasing the value of materials is to use resources that can be recycled or reused in an unprocessed or processed state. Brummen City Hall has used biodegradable resources such as bamboo floor finishes. What is irreversibly consumed during lifetime, in the end, return to the environment from which they came, without harm once the building has served its purpose. Following this approach, the use of concrete has been reduced to the bare minimum (foundations) while metal elements are mostly reusable.¹⁴³

1.5 Relationships and cooperation between stakeholders

In the case of Brummen City Hall, implementing an ambitious sustainable program required multifaceted cooperation between the parties involved. First, the client who spearheaded the project had ambitious goals for a circular economy and was keen to build a model building. However, the investment was financed with public funds, so idealistic assumptions with a high risk of failure could not be afforded. The client not only asked for a building with a short useful life, but really required that the building could be dismantled in such a way that its materials could be reused. Combined with treating the materials as a "rented" product, this had a high chance of success under market conditions. These high expectations set the stage for all stakeholders and strongly influenced decisions made on design and construction issues.

The leading figure in the implementation of the project was the contractor, who coordinated with designers, suppliers and other specialists. One of the biggest advantages of the majority application of the design-build contract model is that the contractor was involved from the early design stages, making it possible to ensure effective synchronization of activities, a better understanding of closed-loop objectives and the selection

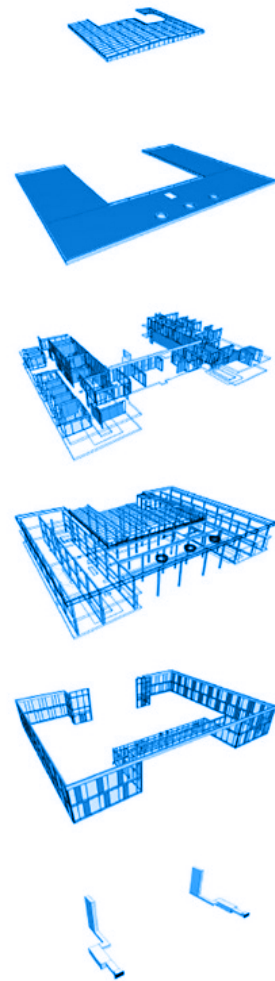
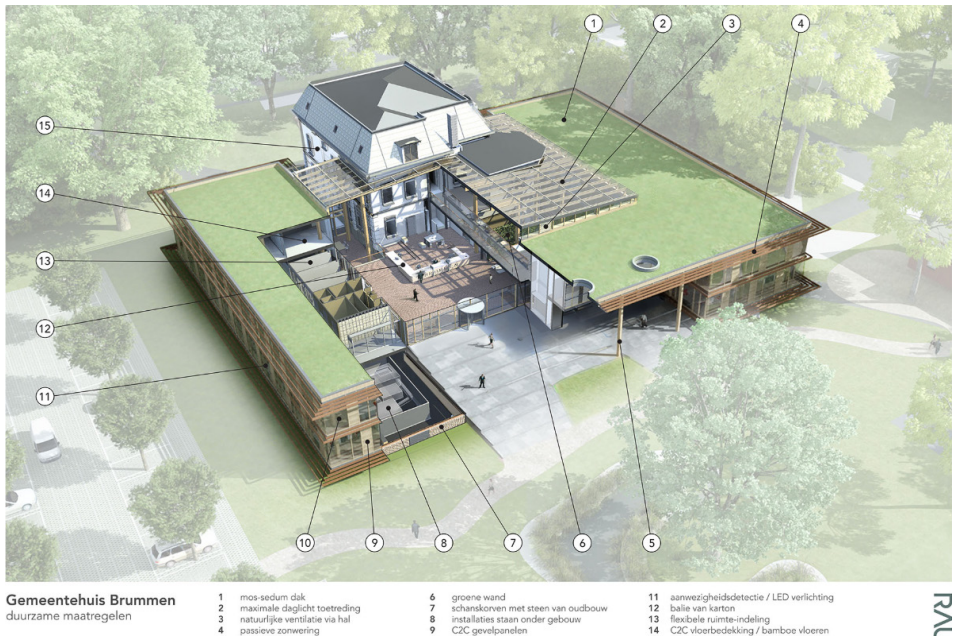


fig. 63 exploded view, divided in madaster view categories (source: RAU Architekten, edited by Kewin Niewiarowski)

140 Ibid
141 Ibid

of components that could actually be reused in the future. He was also responsible for resolving all technical issues, such as the integration of demountable structures or the use of materials with specific properties as requested by the client. Also interestingly, the main axis of the client's communication with the contractor and architect was the project manager who managed the design team. No less important was the establishment of cooperation with circularity experts. They acted as consultants and communicated mainly with the architect. The experts brought to the project their knowledge of innovative technologies and solutions to realize the circular economy. However, they did not have a direct but indirect influence on the project. (mainly at the stage of material selection).¹⁴⁴

fig. 64 schematic aerial view
(source: RAU Architecten)



1.6 Inter-industry cooperation - conclusions

The construction of Brummen City Hall reveals the difficulties involved in putting the circular approach into practice. One of the main challenges was that there was little information about circular economy principles among the traditional participants in the construction process, namely subcontractors and suppliers. Since they had no experience working with such innovative materials and technologies, this would result in resistance to change and require additional training and education. These steps were taken by the team, which then organized a series of workshops and educational sessions, not only to disseminate information, but also to build a common understanding of the closed-loop concept.¹⁴⁵

It was therefore necessary to manage such stakeholders with different

¹⁴² Gerding, Ditte P., Hans W. Wamelink, and Els M. Leclercq. "Implementing Circularity in the Construction Process: A Case Study Examining the Reorganization of Multi-actor Environment and the Decision-making Process." *Construction Management and Economics* 39, no. 7 (July 3, 2021): 617-35

¹⁴³ Ibid

expectations and levels of interest in the process. Thus, more balanced trade-offs than just open communication were needed to balance the trade-off measures presented with environmental and economic goals. This was made possible by the intensive involvement of all parties in the process design, which included circularity principles at each of its stages, from design through construction and even planning for future dismantling. Although the project in Brummen was a success and demonstrated that circularity could indeed be achieved in practice, it required a systems approach, expert support and strong client leadership. The project was not an experience of innovative construction, but a lesson in collaboration and education for change toward sustainability.

fig. 65 view on the inner courtyard and the demountable wooden structure (source: architectuur.nl)



1.7 Conclusion

As you can see, Brummen City Hall is not only about advanced Material Passport technologies and modern building materials. In practice, it turned out that the implementation of Material Passport is the easiest step and the selection of materials can remain as traditional as possible. Much more important was the conscious selection and actual anticipation of its reuse aspect at the architectural concept stage. In my opinion, the open and frank exchange of information between the architects and the contractor was the most valuable part of the process. This demonstrates emphatically that architectural ideas enriched by the knowledge and experience of those actually constructing the buildings can actually work.

Once , we also see the forging of new professions in the construction industry like circularity experts. One can speculate that in time architects will acquire the necessary knowledge and will not need these additional actors. However, it is hard to say whether this will be the case for large and complex projects or only for small, low-complexity buildings. The increasing number of actors in the construction process and the sheer compilation of projects for price and profitability could also be an interesting aspect from this. In fact, do the financial benefits of potentially increasing the residual value of buildings outweigh the design costs and increased investment in better quality materials? It's hard to know for now how the process is going, all that remains is to closely follow the life cycle of buildings like Brummen Town Hall and spin a conclusion at the end of its life cycle.

fig. 66 view on the inner courtyard and the demountable wooden structure
(source: Janice Lobo)

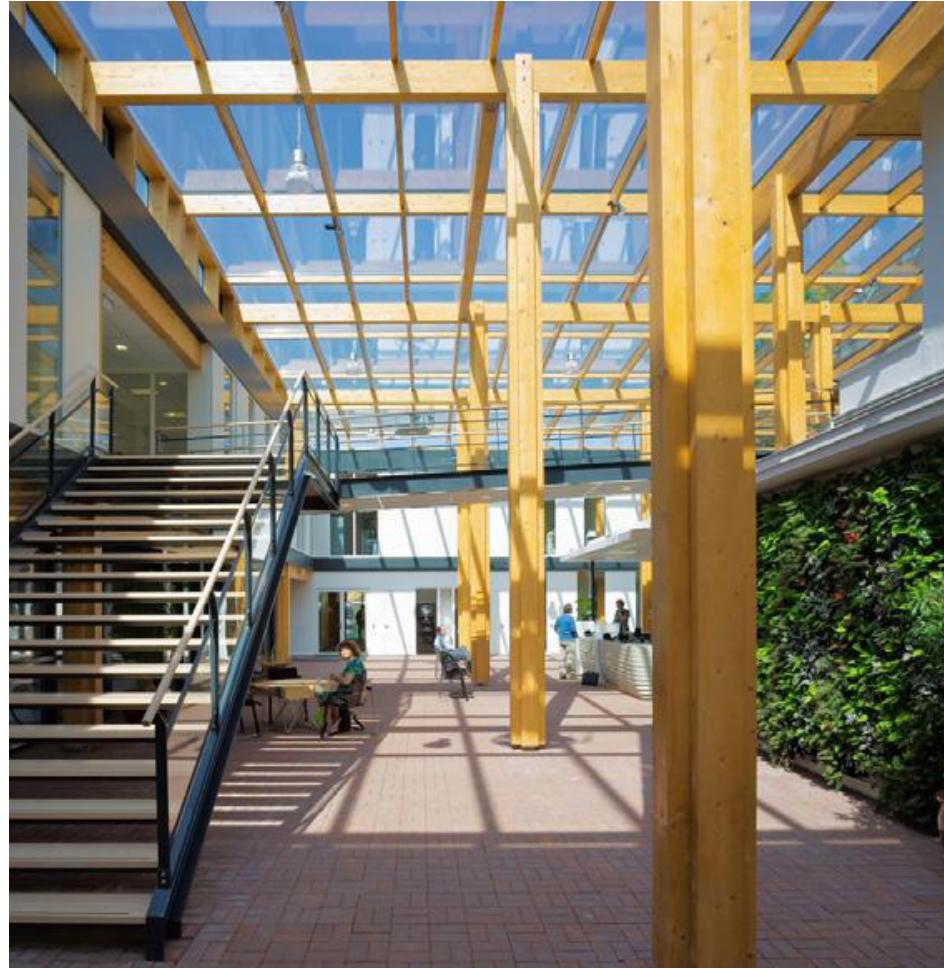




fig. 67

2. Triodos Bank Building

I find this building particularly noteworthy. It is repeatedly presented as a model for Material Passport implementation and a building that theoretically fits into all modern green building standards. It also won a BREEAM certificate at the outstanding level and the Madaster material passport made for it was judged by the architects to be extremely accurate and complete. Also, the potential for dismantling and reusing materials theoretically places this building very high on the list.¹⁴⁶ Unfortunately, what looks great on paper doesn't always work in reality, and in this case the potential for reusing elements is debatable, as I will try to prove in this case study.

Triodos Bank's new headquarters was to materialize the company's philosophy. It is a financial institution with a successful track record of investing in pro-social and environmental initiatives. It is not surprising that the main axis of RAU Architecten's narrative was to create an ecological project that was attempted in every way to legitimize with available forms of rankings and certifications. The project aims to create a modern office space that fosters collaboration and knowledge sharing. Covering 13,000 sq m, the project includes a five-story building open not only to the bank's employees and clients, but also an open first floor for visitors to the adjacent park. The architects designed three interconnected towers. The building is based on a reinforced concrete core that supports a wooden structure that is the main component matter.¹⁴⁷ The main reasoning behind this solution was to maximize daylight entering the building by eliminating columns on the fully glazed facade.

The interior layout accommodates a variety of needs: the first floor houses public amenities such as a restaurant, library, exhibition space and meeting rooms. The upper floors are dedicated to open-plan offices, while technical rooms, storage and facilities are located in the basement. The design emphasizes natural light and efficient space management.

2.1 Materials - BREEAM shadow cost vs reuse potential

Thanks to the work of Marie Chevalerias, we can learn exact numbers describing the environmental impact of the materials used in Triodos Bank. I find these figures particularly interesting because they will contrast the reusability at the end. In this analysis, the main reference is the shadow cost - an indicator used in the BREEAM rating. To understand what the figures mean, let me first explain the concept. The shadow cost is an indi-

¹⁴⁵ Marie de Klijn-Chevalerias, Saqib Javed, "The Dutch approach for assessing and reducing environmental impacts of building materials," *Building and Environment*, Volume 111, 2017, Pages 147-159,

¹⁴⁴ Madaster Global. "TRIODOS BANK: A MATERIAL BANK - Madaster Global," August 18, 2022. <https://madaster.com/inspiration/triodos-bank-a-material-bank/>.

cator that measures the environmental impact of the materials used in a project. It is the cost that could generate neutralization or compensation for the environmental impacts of these materials. In fact, the shadow cost compares to the environmental footprint of construction by reference standards. For the Triodos Bank project, the total shadow cost is 0.65 euros/m², which is 35% less than the reference cost of 1euro/m², thus offering 5 points in the BREEAM material section.¹⁴⁸

Technical installations are the main source of environmental impact, generating shadow cost. Climate ceilings account for about 64% of the shadow cost and are made of sheet steel and copper pipes. Prefabricated elements heat and cool offices, providing pleasant air conditioning. The high cost of the shade is due to the copper pipes. The cooling coil accounts for about 30% of the shadow cost, and a more powerful model was chosen because of the cooling requirements of an office with large glazed areas. We can note the first inconsistency here. The architectural idea is to have total glazing, the whole effort of the spectacular wooden structure was made for this very purpose. In the end, it turns out that this design decision forces the installation of an advanced cooling system that alone generates 15% of the entire building's shadow cost.¹⁴⁹

The shadow cost of floors is generated by concrete and anhydrite, which account for half of the cost. An important component is OSB, responsible for 39% of the cost in the flooring category and 12% for the overall facility. OSB is used to lay anhydrite on a wooden substrate (this is due to toxic emissions in the manufacturing process). The floors also have low reusability. Their traditional layered construction makes it impossible to dismantle without destroying them, besides, they would be an extremely unattractive (to reuse) element due to their non-standard dimensions and specifications. It is worth referring here, for example, to the flooring solutions in the UMAR unit, where the boards were tried to be assembled in a dismantling manner without the use of screeds, while their finishing (carpets and rugs) were provided on a "lease" basis.¹⁵⁰

98% of the facade's shadow cost comes from triple-layered glass with an aluminum coating on the outside of the wood frame, which reduces the use of aluminum. Aluminum generates a shadow cost 950 times greater than wood. Its share of the facade's shadow cost is 2.7% compared to 0.3% for wood. So this is a kind of trade-off for aluminum windows. However, it would be worth considering whether surely wood windows will remain in good shape for years to come, and wouldn't aluminum windows be much better for reuse in the future even despite higher emissions?¹⁵¹

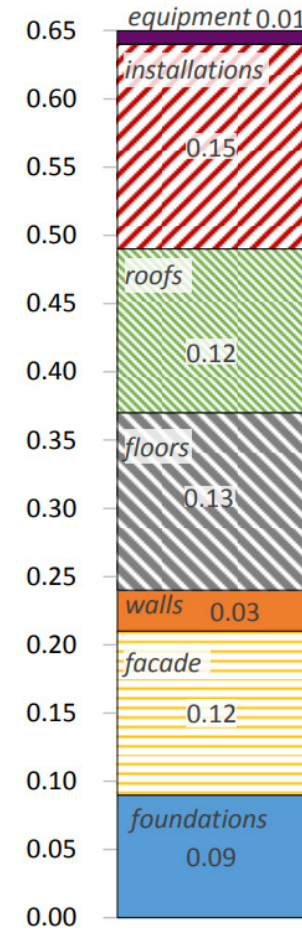


fig. 68 Total shadow cost of the building (source: M.Chevalerias)

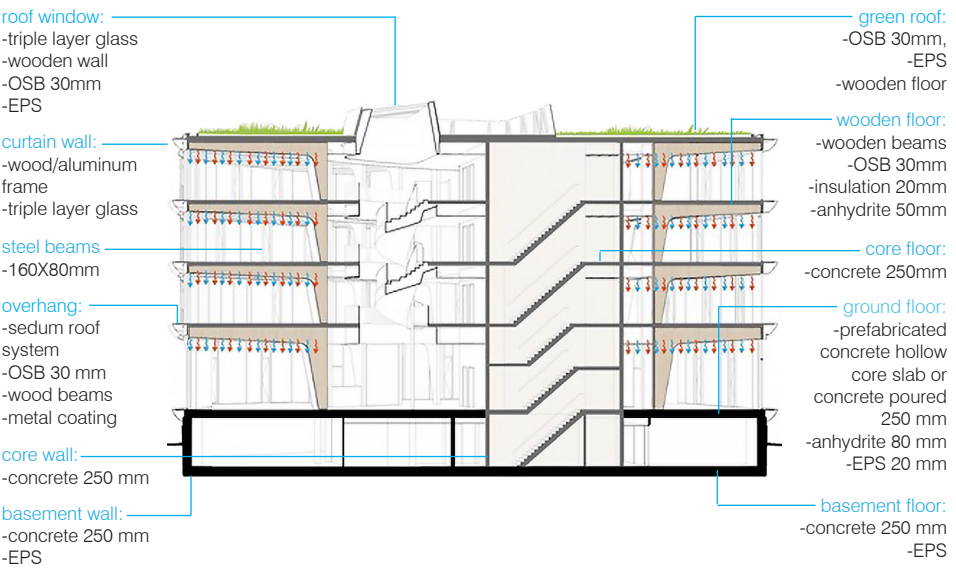
¹⁴⁷ Madaster Global. "TRIODOS BANK: A MATERIAL BANK - Madaster Global," August 18, 2022. <https://madaster.com/inspiration/triodos-bank-a-material-bank/>.

¹⁴⁸ Ibid

¹⁴⁹ Ibid

¹⁴⁶ Marie de Klijn-Chevalerias, Saqib Javed, "The Dutch approach for assessing and reducing environmental impacts of building materials," Building and Environment, Volume 111, 2017, Pages 147-159,

Like floors, roofs are characterized by a high content of OSB is responsible for 32% of the cost of shading roofs (and the roof itself is 12% of the total). EPS with high insulation value accounts for 31%. The green roof, while environmentally beneficial, accounts for 15% of the shadow cost, mainly due to the use of plastics in the drainage system.¹⁵²



Concrete and EPS in foundations and basement walls account for 67% of the shadow cost of this category. Steel-reinforced foundation piles account for 34%, with a high shadow cost per cubic meter and a large amount of materials used. EPS insulation contributes 38% to the shadow cost. Although the entire foundation accounts for only 9% of the shadow cost for the entire building, it is a separate topic. Later in the paper, I will further discuss their shape and nature, which is important for the project in this particular location.¹⁵³

As you can see, solutions that score great on the BREEAM rating in terms of demountability or reusability don't necessarily fare as well. Also questionable is the very concept involving a huge design effort to eliminate columns on the facade and ultimately forcing the use of extremely powerful cooling systems. Triodos Bank fits in with the tenets of sustainable construction and partially implements the material bank concept. However, an analysis of the materials used and the way they are combined indicates many areas for improvement. In addition, the transparency of material data and its cataloging is undoubtedly a positive aspect. This will make the recovery of potentially suitable materials in the future easier (it also makes it possible to perform valuable analyses like shadow costs).

fig. 68.1 Triodos Bank section through the tower and its core (source: section by RAU Architecten, edited by Kewin Niewiarowski)



fig. 69 fixing the wooden structure (source: RAU Architects)

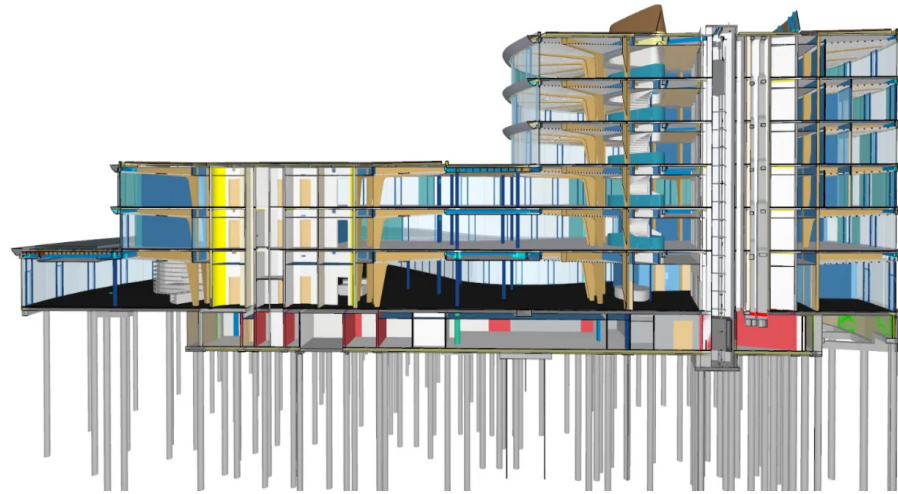
¹⁵¹ Ibid

¹⁵⁰ Marie de Klijn-Chevalerias, Saqib Javed, "The Dutch approach for assessing and reducing environmental impacts of building materials," Building and Environment, Volume 111, 2017, Pages 147-159,

2.2 Construction - Deconstruction

We can divide the construction of Triodos Bank into several stages and material groups particularly interesting from the point of view of reuse. These will definitely be the foundation and the load-bearing structure. The architects and Madaster also state that the facade and some of the interior elements such as the walls are classified in material passport and reusable. However, there is no data available on this apart from the declaration.

fig. 70 model of building with foundation poles
(source: jpvaneesteren.nl)



The foundation is a classic solution. It is founded on 200 reinforced concrete piles, each 10 meters long because of the low level of the load-bearing soil. Resting on them is the base of the building, which is one underground floor, also built entirely of reinforced concrete. It houses technical rooms and bicycle garages. Although this is a convenient solution from the point of view of installations and systems, it is surprising that it is used if the building is also branded with the Material Bank slogan. This is because it is very much at odds with this idea. Such foundations are very specific structures designed specifically for that particular building, rather unsuitable for demolition and reuse. They are filled with duct and pipe systems and channels and the amounts of concrete poured there are very large. When the building is deconstructed, they can only be demolished, but the 200 reinforced concrete piles reaching 10 meters below the basement floor level are likely to stay there forever significantly worsening the building's Marine Aquatic EcoToxicity Potential (MAETP) rating.¹⁵⁴

The author of Assessing Environmental Impact of Buildings using the Dutch Approach - Marie Chevalerias¹⁵⁵ proposes alternative solutions

¹⁵² Marie de Klijn-Chevalerias, Saqib Javed, "The Dutch approach for assessing and reducing environmental impacts of building materials," Building and Environment, Volume 111, 2017, Pages 147-159,

¹⁵³ Ibid

in her paper, also citing existing similar examples from building practice. She gives 6 combinations of solutions with alternative location of technical rooms on the roof or outside the building. Most interesting, however, is her use of wooden piles as the main foundation of the building. Since wood in BREEAM listings has "zero" emissivity the shadow cost of the foundation then drops to zero. If we wanted to actually treat the Triodos building as a material bank this could be an apt solution. Then possible deconstruction in the future would make sense. The wooden piles could simply remain in the ground without harming the environment. Unfortunately, however, as it stands, the talk of a material bank concept does not hold water. The building residue would be too significant and a very large part of the materials would be impossible to reuse.



fig. 71 view on the tree-like interior structure
(source: Marcel van der Burg)

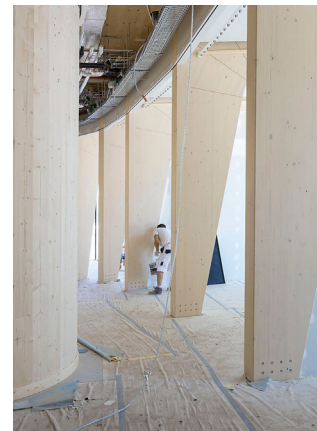


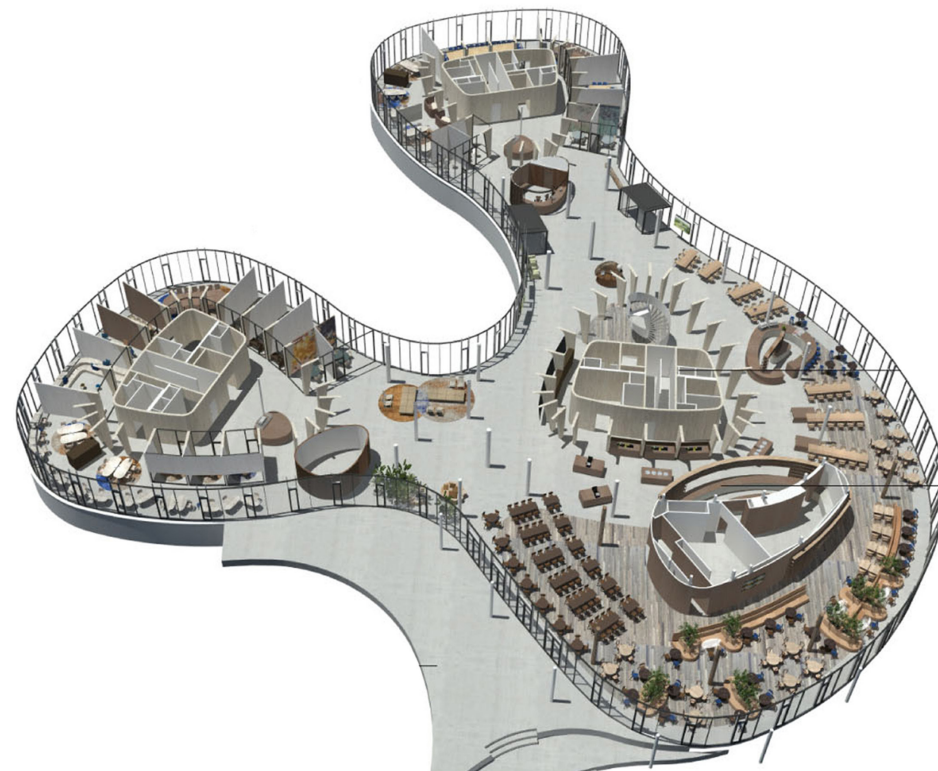
fig. 72 structure fixing details
(source: Marcel van der Burg)

However, the case is different for the main structure of the building. A 200mm-thick cross-laminated timber main core (in the case of tall towers, also a reinforced concrete core) sits on a reinforced concrete foundation. These are standard slabs with cut-outs for the entrance to elevator shafts and stairwells. From the core there are specially designed columns that flow seamlessly into the beams (integrated, L-shaped). They are fastened with 120 to 150 mm screws, which is good for their reuse potential.¹⁵⁶ The overall design is somewhat reminiscent of tree branches. The load-bearing layer of the floors is CLT glulam panels and the edge termination, where the curtain wall is mounted, is a lightweight metallic structure also bolted from standard components.

¹⁵⁴ Espazium. "Prime À L'anticipation | Espazium," June 18, 2021. <https://www.espazium.ch/fr/actualites/prime-lanticipation>.

All of these elements have great potential for reuse, especially when they are all cataloged in Madaster. In my opinion, however, the L-shaped glulam structural elements are problematic. Of course, they are fully removable and easy to recover, but an element so unusual can be difficult to use elsewhere. There is no denying that this is something designed specifically for this building. So it is a slight “bending” of the rules of the game. It would seem that when talking about a model bank of materials, the materials should be as versatile as possible and, in fact, possible for further use in another form. In addition, these pillar-beams are the basic component of the structure, so there are a lot of them.

fig. 73 axonometry of the ground floor
(source: RAU Architecten)



2.3 Conclusions

According to Madaster officials, the new Triodos Bank site is a groundbreaking example of the use of a material passport - a system that records each construction component based on its composition, origin and quantity.¹⁵⁷ In theory, this would maximize the potential for future reuse of materials, in line with the principles of a circular economy. However, there is no denying that this is not 100% true. Although the Triodos Bank building is an environmentally friendly building and has a strong design intention to do so, it is clear that sometimes other features were more

¹⁵⁵ Madaster Global. “TRIODOS BANK: A MATERIAL BANK - Madaster Global,” August 18, 2022. <https://madaster.com/inspiration/triodos-bank-a-material-bank/>.

important. For example, it was the architectural form and the architect’s strong idea that probably came first and was later filled with content in a way that met the client’s requirements for an “eco-friendly” building.

As for Material Passport itself, all materials were digitally cataloged, making information such as physical properties, source and recycling potential readily available. Achieving this level of accuracy required close collaboration between contractors, architects and suppliers, who provided precise IFC files with the building data model. The quality of these records was essential for the material passport to serve as a practical tool for the future.¹⁵⁸ Triodos Bank’s commitment to reuse stems from both the use of modular wood construction and detailed documentation, minimizing construction waste and keeping resources in circulation longer. Such thorough documentation, unfortunately, does not guarantee 100% success of recycling and reuse of these materials in the future. As I pointed out earlier, the high uniqueness of the elements and the possible impermanence of, for example, wooden windows (chosen over aluminum to meet BREEAM requirements) is a sign of less forward thinking into the future.

The final, and perhaps most important, conclusion is the relationship of the building’s footprint to its location. It is located in the picturesque scenery of the Dutch suburbs in the middle of a green park (the construction was not without incidents and protests). Keeping in mind that it was founded on very massive and “indestructible” foundations, so what is the point of even considering demolishing it in the future? It occupies valuable public space and perhaps in the future it will get a chance to be a “monument”.

¹⁵⁶ Madaster Global. “TRIODOS BANK: A MATERIAL BANK - Madaster Global,” August 18, 2022. <https://madaster.com/inspiration/triodos-bank-a-material-bank/>.

fig. 74 atypical office floor
(source: RAU Architekten, edited
by Kewin Niewiarowski)

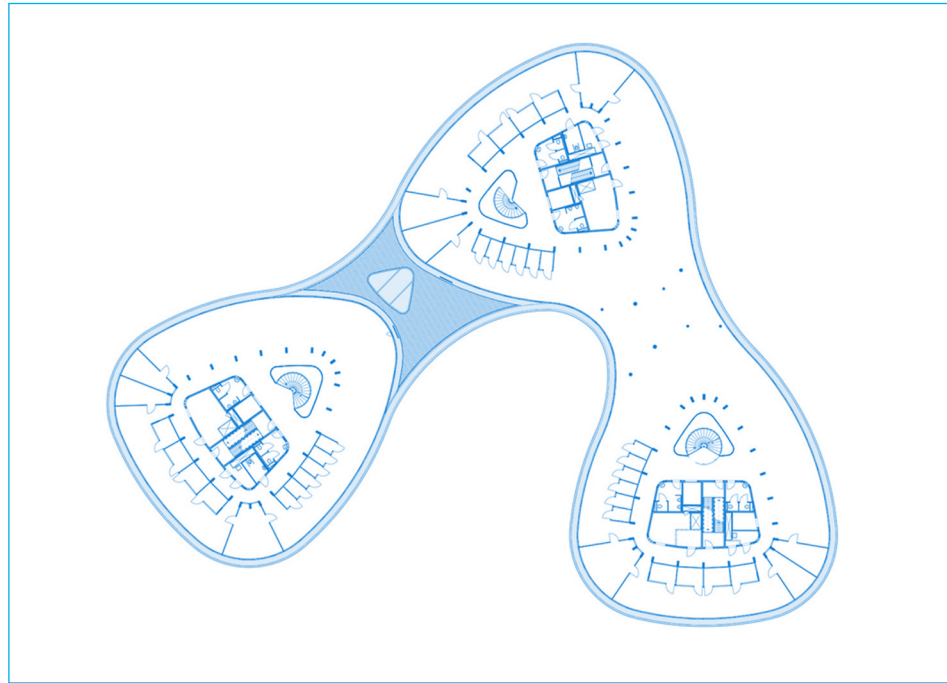


fig. 75 ground floor plan (source:
RAU Architekten, edited by
Kewin Niewiarowski)

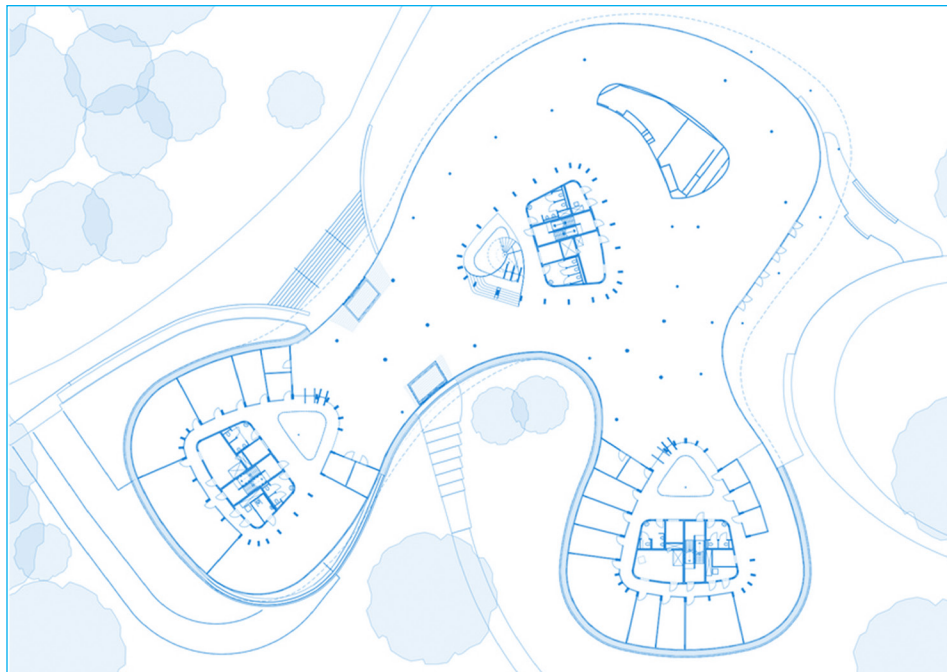


fig. 76 basement plan
(source: RAU Architekten, edited
by Kewin Niewiarowski)

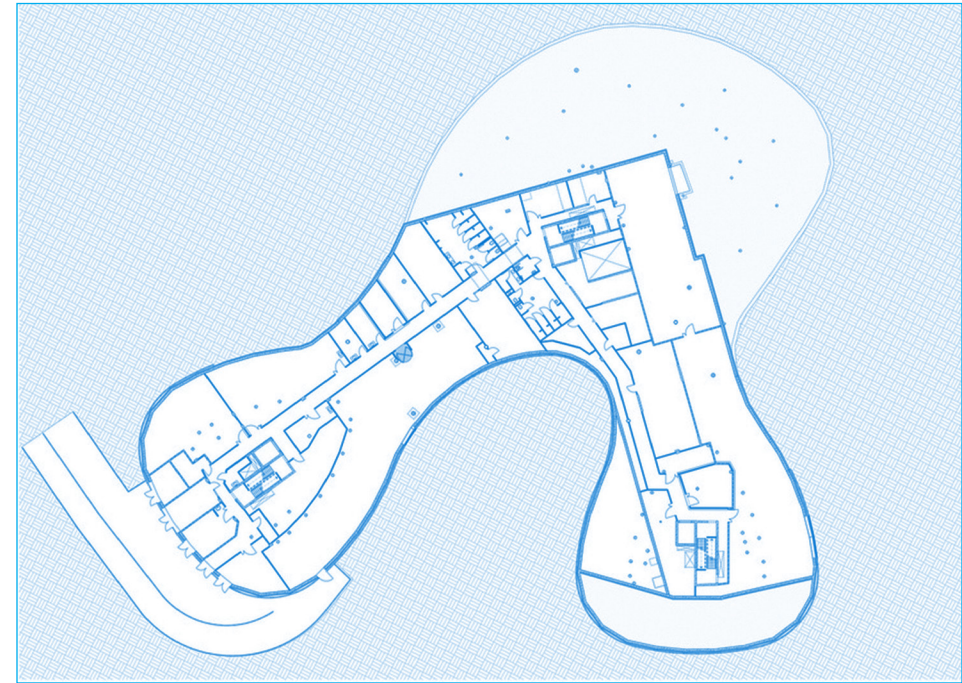


fig. 77 east elevation
(source: RAU Architekten, edited
by Kewin Niewiarowski)

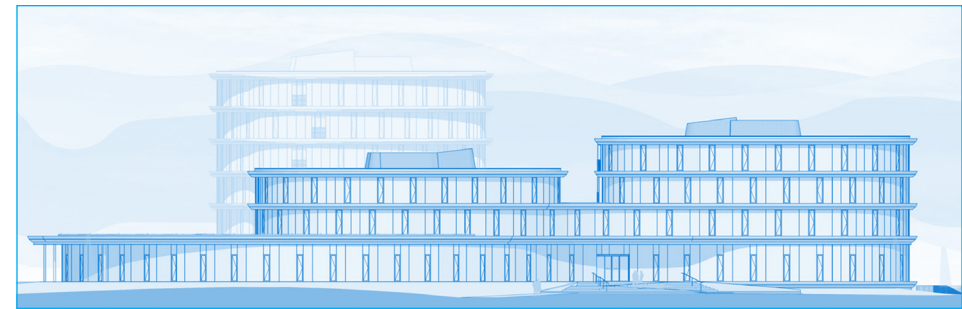
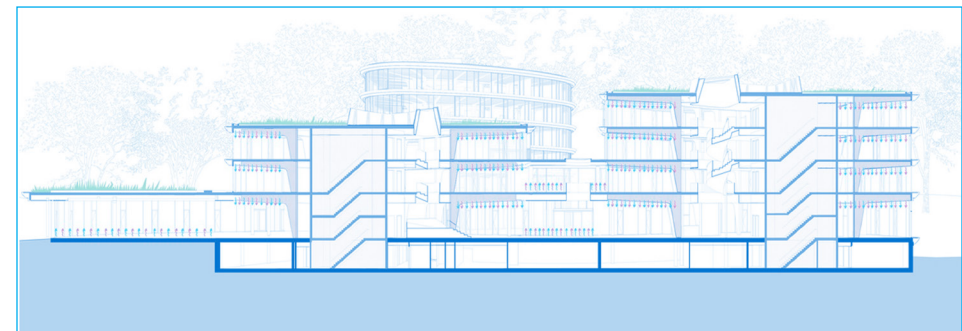


fig. 78 longitudinal section
(source: RAU Architekten, edited
by Kewin Niewiarowski)



Chapter 5

1. Can architecture really be something dynamic?

Architecture is a field that does not like quick changes. A building once erected lasts for decades and sometimes almost forever. So how does the idea of a smooth flow of materials from one building to another relate to this feature of architecture? After all, the Material Bank concept is actually the personification of the transformation of architecture from a static to a dynamic domain. Having already had a virtually complete view of Material Passport and having studied examples from its application, it might be interesting to take a new look back to the past where architects have long pondered concepts of buildings that can evolve with time and the cycle of their life.

1.1 Metabolism

This very idea of mutable, evolving architecture was central to the Metabolism movement that emerged in Japan in the 1960s. Though groundbreaking, its failure became obvious with the demolition of Tokyo's Nakagin Capsule Tower in 2022. The movement, was founded by Japanese architects such as Kisho Kurokawa, Kenzo Tange and Fumihiko Maki. It drew inspiration from biological growth. They imagined buildings as living systems - flexible, able to expand or change according to the changing needs of society. Their basic concepts included modularity, adaptability and the separation of fixed building cores from interchangeable components. This flexibility was intended to reflect the rapid urbanization of Japan after World War II, where cities had to change with the changing lives of their residents.¹⁵⁹

A standout example was the Nakagin Capsule Tower, completed in 1972. Designed by Kurokawa, the building had a concrete core with small, detachable residential capsules that could theoretically be swapped out and replaced.¹⁶⁰ Other notable projects included the Expo '70 pavilions in Osaka and Kenzo Tange's visionary Tokyo Bay Project, which reimaged entire cities built on water using modular structures.

¹⁶¹

Since Nagakin Tower is a peculiar representative of the genre it is worth analyzing here why it was a failure. In fact, the main problems were design flaws, ownership issues and land issues. Although the capsules were supposed to be easily replaceable, in practice they were assembled in a way that made it impossible to remove them without first removing those placed above. Each capsule had a separate owner, which meant that all

¹⁶¹ Tamari, T. "Metabolism: Utopian urbanism and the Japanese modern architecture movement." *Theory, Culture & Society*, 2014.

¹⁶² Schalk, M. "The architecture of metabolism: Inventing a culture of resilience." *Arts*, 2014.

¹⁶³ Lin, Z. Kenzo Tange and the Metabolist movement: Urban utopias of modern Japan. Taylor & Francis, 2010.



fig. 79

140 owners had to unanimously agree to the renovation. The high cost of renovation, reaching about 10 million yen per capsule in 2007, made this almost unrealistic. In addition, the building stood on rented land, and the landowner sought to develop it more profitably. Not a single capsule has been replaced since the building was completed in 1972. Attempts at modernization collapsed after the 2008 financial crisis. These factors meant that the project failed as a sustainable model of metabolic architecture.¹⁶²

Social preferences and architectural trends have changed over time. Compact, minimalist capsule apartments no longer met modern expectations for comfort. Investors, meanwhile, became discouraged with metabolic ideas and the movement faded away. The demolition of Nakagin in 2022 symbolized the end of Metabolism, a once visionary idea that struggled to connect concept and reality.

2. What can be done to make Material Passport really work?

The Material Passport concept, while promising for promoting sustainable construction and closed-loop economy practices, also still faces major challenges making difficult its widespread adoption. For it to truly transform the architecture and construction industry, efforts are needed on many levels. In order to conclude with a good memory of the changes needed to be made and to highlight the challenges facing the implementation of Material Passport, I will once again return to the aspects mentioned earlier and expand on those that were only mentioned in the text.

2.1 Criticism of Material Passport

The main complaint is the lack of standardized international standards in already fragmented and company-specific procedures, and the lack of widely available and easy-to-implement data formats that can be easily integrated with other building information management systems, such as Building Information Modeling (BIM) and Industry Foundation Classes (IFC). The incompatibility of data and the need to translate it each time results in a loss of structure and usually a lack of backward compatibility. Developing a comprehensive analysis of the materials used in buildings thus becomes very difficult and the data is fragmented and partially lost.¹⁶⁷

Another problem is access to reliable materials life cycle analysis tools and software. Existing technologies are not widely used and the companies involved are constantly developing their products. So this affects the high price of a niche service and their quality does not always cor-

164 Tatsuyuki Maeda and Yuka Yoshida, "The Real Reason Why Nakagin Capsule Tower Was Never Metabolized," *Docomomo Journal*, no. 65 (2021): 118-120.

165 Ellen MacArthur Foundation, "Circular Economy in Construction," 2020.

respond to the high cost. This is a stage of development and research, necessary to achieve a satisfactory level in the future, however, not every design company wants or has time for such practices. Thus, it can have the opposite effect and discourage customers from using their services in the future. In addition, differences in methods of assessing material properties result in poorly coordinated data collection, so that the information obtained is not very useful in practice.¹⁶⁸

Transparency of data management is also an issue from the perspective of intellectual property rights and unauthorized modification of data. Only effective mechanisms for verification and protection of information can increase the confidence of investors and end users. The future solution may be information. previously mentioned, however, blockchain is a point technology that, over time, is able to guarantee is not yet immutable in and use, and integrity we do not yet see prospects for its introduction.

2.2 Perseverance and readability of data in long perspective

Ensuring long-term durability and transparency of data is a major challenge when implementing a Material Passport system. Storing information on construction materials for an extended period of time requires file formats that are resistant to aging technology, such as IFC (Industry Foundation Classes) or ISO 19650-compliant formats. ¹⁶⁹ Consistent updates are equally important, but can become difficult on older projects where documentation may be incomplete or outdated. After all, we're talking about time scales sometimes reaching a century!

Today, archivists provide long-term access to information through such means as migration and emulation. Migration is the periodic conversion of documents from old forms or media to new, better supported standards. This can reduce the risk of losing access to documents due to technical obsolescence, although on the other hand it must be done very carefully, with quality control, so that some data is not lost or distorted. Emulation is the recreation of the original hardware and software environment in which the file was created; making it possible to open and read it without format conversion. This can be especially useful if the file has a unique, non-standard format (which may prove to be the case years later) but this approach requires a lot of work. Both solutions can be expanded to include a variety of media formats and the use of standard, well-documented file formats - such as PDF/A and TIFF - to guarantee access to data both in the future and in the long term.¹⁷⁰ Today, the use of these formats seems obvious to us, but we cannot assume that it will remain so in, say, 50 years.

166 European Commission, "Circular Economy Action Plan," 2020.

167 International Organization for Standardization (ISO), "ISO 19650 - Organization of Information about Construction Works," 2018

168 Shimray, Somipam & Ramaiah, Chennupati, "Digital Preservation Strategies: An Overview," Department of Library & Information Science, School of Media and Communication Pondicherry University, Puducherry, 2019.

Another key obstacle is maintaining the context of the data over time. Information about building materials must cover the entire life cycle of the material, including details about its origin, manufacturing process, technical properties and recycling potential. Only with this level of detail can the Material Passport effectively support a circular economy.

Finally, the system must keep up with changing building codes and standards. Archived data must comply with current sustainability regulations, requiring constant monitoring and updating of the database to maintain compliance.

2.3 Lack of will for long time investments

The construction industry is well known for its emphasis on cost minimisation, which makes the adoption of Material Passport technology much more difficult. With tight budgets and a strong emphasis on rapid return on investment, many stakeholders fail to see the benefits of a long-term approach to materials management. Material Passports are often perceived as expensive and time-consuming, offering no immediate financial benefit, further discouraging its implementation.

It may be worth considering targeted financial incentives, tax breaks, public subsidies or grants that could help reduce the upfront costs of implementing Material Passports. Experience with the introduction of BREEAM and LEED has shown that this approach can be effective. They have gained popularity in various countries thanks, among other things, to legislative and financial support. Implementing similar mechanisms for Material Passport technology could yield comparable results.¹⁶⁹

It is also worthwhile to ensure that stakeholders are educated to promote a deeper understanding of the long-term benefits associated with circular economy practices. Adopting Material Passport can lead to significant savings at the very end of an investment but also during its financing. It is crucial to present specific case studies and economic analyses demonstrating these savings in real-life scenarios (such as the financial reports for the Triodos Bank building after its completion or the Brummen Town Hall material leasing model).

2.4 Lack of cases that will prove the idea's credibility

Another challenge hindering the widespread implementation of the Material Passport is the lack of large, comprehensive projects that can conclusively prove its effectiveness and value. Although the article details the 'laboratory' case of UMAR and the two RAU Architects projects using Material Passport on the open market, it is difficult to assess their success unequivocally today. This is because the planned time horizon is many years and it remains to be seen whether the implementation has been successful. As there are no convincing examples of widespread implementation, many investors and decision-makers remain sceptical about the potential benefits of the technology.

The credibility of the added value of Material Passport is also not fully clear. In most cases, there is a lack of detailed economic analyses to demonstrate the potential savings associated with material recovery and waste reduction. Current pilot projects have focused on specific parts of the process, e.g. material recycling or traceability, rather than a comprehensive solution that covers all stages of the life cycle. To increase the credibility of the Material Passport, a large-scale demonstration project is required. Its aim would be to provide hard data on the impact of the Material Passport on the economic and environmental performance of construction. In particular, it would be useful to show how Material Passports can mitigate the costs of final demolition and recycling of materials. Subsequently, reports on the results of pilot programmes, conferences and the dissemination of case studies should be used to build mutual trust between stakeholders.

In fact, the lack of large-scale application examples is one of the biggest deterrents to Material Passport. The only remedy for this is simply to keep trying. Perhaps state-subsidised projects and research units could also step in as a way of blazing a trail and encouraging more private investors.

¹⁶⁹ International WELL Building Institute. "The Benefits of Green Building Certifications." IWBI Publications, 2022.

3. Conclusion

Material Passport is an idea that pushes the boundaries of traditional approaches to construction. It represents not only an answer to the challenges of limited resources, but also an opportunity to build a completely new model of material management. Its widespread introduction, however, requires numerous changes in thinking and a revised approach and awareness among all stakeholders. The future of Material Passport requires a change in thinking - both in the context of design and building management. A fundamental change is the perception of buildings. Currently, buildings are static utilitarian objects, while after the introduction of the Material Bank idea, their perception should go beyond this definition and turn them into dynamic resource banks that can repeatedly serve future generations. Implementing such solutions requires investment in digital technologies, but also the courage to change existing habits and business models.

We must not forget the key role of education - both among professionals and the public. A good understanding and active adoption of the assumptions and potential of the circular economy is the foundation for lasting change and good soil for the development of Material Passport and Material Bank ideas. What's more, other innovative solutions such as smart data systems, automated inventories of existing buildings or block-chain implementation can make this process even more efficient and so cost-effective that people will naturally choose this path themselves.

It will still be a long time before that moment comes, unfortunately, the prospect of a more conscious and sustainable construction industry is encouraging so the focus at the moment should be on developing the idea as best as possible, preparing it for widespread adoption, educating and showing the benefits.

What is needed is a concerted effort and commitment from industry, government and society that will make Material Passport the standard and another example of how innovation serves society and the environment. What seems like an ambitious plan today could be the norm tomorrow - if only we decide to act consistently with the idea of positive incentives and create a Material Passport so inviting and beneficial that any investor starting a new venture will find it natural to implement the idea.

4. Master project opening

With the growing challenges of dwindling natural resources, the unfolding climate crisis and the increasing demands of the construction sector, the need to transform the industry has never been more urgent. Today's construction industry, which accounts for a significant proportion of global raw material consumption and carbon emissions, must undergo a radical metamorphosis towards sustainability. In my view, the key to this transformation is the circular economy and, in particular, the concepts of Material Passport and Material Bank.

The theoretical ideas presented in the text and the analysis of the diverse case studies are certainly a solid knowledge base for the development of the PDM project. It has been clearly shown that the implementation of Material Passport alone will fail without an appropriate design of the architecture, taking into account how components are assembled and disassembled. It is not only the choice of materials that is important, but also the adoption of a suitable reuse strategy and the adoption of appropriately standardised components. The case studies additionally show a variety of models, from laboratory situations to commercially constructed buildings where, of course, the number of compromises was greater and the solutions somewhat more typical. I think an important aspect of the project will be the modular and decoupled aspect of the structure, something that has been solved in each of the case studies in their own specific way. The standardisation of components, the use of modular systems and design in the spirit of 'Design for Disassembly' (DfD) are the most important aspects for the circular economy (as defined by this project). It will also be important to integrate digital tools such as Madaster's analytical tools (assuming proper BIM hygiene) and to think about long-term methods of storing and managing material data.

The overall work demonstrates that successful implementation requires a comprehensive and holistic approach that combines advanced technologies with a pragmatic approach to design and building lifecycle management. I would like my PDM project to be a model example of how to combine innovation with practical solutions, building a bridge between theory and practice towards the sustainable development of the AEC industry.

Bibliography

Commoner, Barry. The Closing Circle: Nature, Man, and Technology. New York: Knopf, 1971.

Daly, Herman E. Beyond Growth: The Economics of Sustainable Development. Boston: Beacon Press, 1996

Raworth, Kate. Doughnut Economics: Seven Ways to Think Like a 21st-Century Economist. White River Junction: Chelsea Green Publishing, 2017

Durmisevic, Elma. "Transformable Building Structures: Design for Disassembly as a Way to Introduce Sustainable Engineering to Building Design & Construction." PhD diss., Delft University of Technology, 2006.

MacDonald, William L. The Architecture of the Roman Empire: An Urban Appraisal. New Haven: Yale University Press, 1986.

Kostof, Spiro. A History of Architecture: Settings and Rituals. New York: Oxford University Press, 1995.

Schneider, Tatjana, i Jeremy Till. Flexible Housing. Oxford: Architectural Press, 2007.

MacArthur, Ellen. Towards the Circular Economy: Economic and Business Rationale for an Accelerated Transition. Cowes: Ellen MacArthur Foundation, 2013.

Heisel, Felix, i Philip Rau-Oberhuber. "Designing for Disassembly and Circularity: Case Study of a Transformable Building Prototype." Journal of Cleaner Production 245, 2020

Adams, Katherine T., Michael Osmani, John Thorpe, i Charles Thornback. "Circular Economy in Construction: Current Awareness and Challenges." Proceedings of the Institution of Civil Engineers – Waste and Resource Management 170, no. 1, 2017

Dufresne, A. 2014. Recycled Building Materials for a Sustainable Construction Industry. Construction and Building Materials 68: 124-133.

Nakamura, T., & Halada, K. Potential of Urban Mine, Urban Mining Systems (pp. 7–29). Springer Japan , 2015

McKinsey Global Institute. Reinventing Construction: A Route to Higher Productivity. McKinsey & Company, 2017.

"AI And Digital Transformation for AEC Executives: A More Practical View," n.d. <https://unanet.com/blog/ai-and-digital-transformation-for-aec-executives>.

Hall-Cotton, Matthew. "Overcoming Resistance to Digital Tools in Construction: A Path to Modernisation & Commnia." Commnia Construction Software From Pre-Construction to Handover, June 17, 2024. <https://commnia.com/blog/blog/overcoming-resistance-to-digital-tools-in-construction-a-path-to-modernisation/>.

Kalantari, Saeid. "Transforming the AEC Industry: a Closer Look at Digitalization Challenges," May 3, 2023.

"Harnessing Innovation: How Technology Is Reshaping Architectural Design," theconstructor.org, October 18, 2023

Davis, Daniel. "Modelled on Software Engineering: Flexible Parametric Models in the Practice of Architecture." Design Studies 34, no. 6 (2013): 753-773.

Burry, Mark. Scripting Cultures: Architectural Design and Programming. Hoboken: John Wiley & Sons, 2011.

Heisel, Felix and Allexxus Farley-Thomas. 2022. "Building Capacity and Knowledge in the Local Economy: The Catherine Commons Deconstruction Project" in Circular Construction and Circular Economy: Better Less Different Building by Felix Heisel and Dirk E. Hebel (Basel: Birkhäuser).

Heisel, Felix, "2022/23 SoA Lecture Series: Felix Heisel", Lecture Series, Charlotte College of Arts and Architecture, 7 november, 2022

Heisel, F, J McGranahan, and A Boghossian. 2022. "ScanR: A Composite Building Scanning and Survey

Method for the Evaluation of Materials and Reuse Potentials prior to Demolition and Deconstruction." IOP Conference Series: Earth and Environmental Science 1078

Mansour Esnaashary Esfahani et al., "Using Scan-to-BIM Techniques to Find Optimal Modeling Effort; a Methodology for Adaptive Reuse Projects," Proceedings of the ... ISARC, May 24, 2019

Heisel, Felix, Joseph McGranahan, Joseph Ferdinando, and Timur Dogan. "High-Resolution Combined Building Stock and Building Energy Modeling to Evaluate Whole-Life Carbon Emissions and Saving Potentials at the Building and Urban Scale." Resources, Conservation and Recycling 177 (February 1, 2022): 106000.

Minner, Jennifer, Susan Holland, Christine O'Malley, Felix Heisel, Diane Cohen, Wyeth Augustine-Marceil, Jason Rearick, and Courtney Bower. "Toward Building Sustainable Communities and Circular Economies: A Local Government Policy Guide to Alternatives to Demolition through Deconstruction and Building Material Reuse." Unpublished, 2023.

Jakle, John A., Robert W. Bastian, and Douglas K. Meyer. Common Houses in America's Small Towns: The Atlantic Seaboard to the Mississippi Valley. Athens: University of Georgia Press, 1989.

Stevenson, Katherine Cole. Houses by Mail: A Guide to Houses from Sears, Roebuck and Company. New York: John Wiley & Sons, 1986.

ASHRAE. Standard 90.1-2013 Appendix G: Performance Rating Method. Atlanta: ASHRAE, 2013.

P. Birrer-Heimo, 'Économie circulaire. Amélioration et étiquetage de la réparabilité des produits', Motion 19.4597 to Swiss Parliament, 2019, <https://www.parlament.ch/fr/ratsbetrieb/suche-curia-vista/geschaeft?Af-fairId=20194597>.

Salza with Matériuum, 'Aktuelle Situation und Perspektiven: Der Fahrplan', Wiederverwendung Bauen, 2020, <https://reriwi.ch/wp-content/uploads/2021/02/>

Matériuum. Circular Economy in Construction: Local Solutions for Global Impact. Geneva: Matériuum, 2022.

M. Jammers, "BIM as a tool for reuse", Enoncé Théorique, Ecole Polytechnique Fédéral de Lausanne Architecture section, 2023

Catherine De Wolf, Deepika Raghu, Anton Sentic, and Corentin Fivet, " Innovations Practitioners Need for Circularity in the Swiss Architecture, Engineering, and Construction Sector", EPFL, ETH, Cirkla, 2023

Gundavaram, Raghav. Web Scraping with Python: Collecting Data from the Modern Web. 1st ed. Birmingham: Packt Publishing, 2007.

L. Gschweilt, M. Lang-Raudaschl, D. Daleyev, M. Stavric4, "ReUse with BIM Connecting architectural salvage centres to your BIM software" TU Graz, Institute of Architecture Technology, TU Wien, Department for integrated Planning and Industrial Building, TU Graz, Institute of Architecture and Media, eCAADe, Volume 2 – Data-Driven Intelligence, 2022

Heisel, F., Hebel, D. E., & Sobek, W. (2019). Resource-respectful construction – the case of the Urban Mining and Recycling unit (UMAR). IOP Conference Series: Earth and Environmental Science, 225, 012049.

Empa 2015 Introducing NEST, <https://www.empa.ch/web/nest/aboutnest>

McDonough W and Braungart M 2002 Cradle to cradle: remaking the way we make things (New York: North Point Press)

BNP Paribas Fortis 2017 Heritage <https://www.montagneduparc-warandeborg.be/en/news/2015/09/03/heritage>

Madaster Platform. 2018b. "Building Circularity: Material Passports for a Circular Economy"

Waal, Rianne de. 2018. "Economic and Circular Indicators for Sustainable Architecture"

Brand, Stewart. How Buildings Learn: What Happens After They're Built. New York: Viking Penguin, 1994.

Madaster Platform. 2018b. "Classification of Materials and Building Layers".

International Organization for Standardization (ISO). ISO 12006-2:2015: Building construction — Organization of information about construction works — Part 2: Framework for classification.

Madaster Platform. 2018b. "Integration of Building Data for a Sustainable Future".

Munaro, Melissa. 2019. "Towards a Comprehensive Material Passport: Security, Usage, and Disassembly".

Druij, Bertus. "BIM-Based Material Passport in Madaster during the Operational and Maintenance Phase of a Building," 2019.

Ellen MacArthur Foundation. Circularity Indicators: An Approach to Measuring Circularity. Ellen MacArthur Foundation, 2015.

Madaster Platform. Circular Indicator. Madaster, 2018.

Madaster Platform. Madaster User Guide, 2018.

Fabozzi, F. J. (2014). Foundations of Financial Markets and Institutions. Pearson Education.

Madaster Foundation. "Material Passport: Enabling Circular Construction." Accessed December 17, 2024.

Madaster Platform. Residual Value Methodology. Madaster, 2018

Ellen MacArthur Foundation. "Circular Economy in Construction." Accessed December 17, 2024.

"Investment Portfolio Management in Construction," European Commission. Accessed December 17, 2024.

"CO2 Impact Assessment in Construction," European Commission, Accessed December 17, 2024.

"Optimization of Building Investment Portfolios Using Material Data," Journal of Sustainable Finance, 2024.

BREEAM Official Website. "Guidelines for Sustainable Building Certification."

Pomponi, Francesco, and Alice Moncaster. "Circular Economy for the Built Environment: A Research Framework." Journal of Cleaner Production 143 (2017): 710–18.

F. Heisel, S. Rau-Oberhuber, "Calculation and evaluation of circularity indicators for the built environment using the case studies of UMAR and Madaster", Journal of Cleaner Production 243, 2019

European Commission, 2012. Laying Down, Pursuant to Directive 2006/66/EC of the European Parliament and of the Council, Detailed Rules Regarding the Calculation of Recycling Efficiencies of the Recycling Process of Waste Batteries and Accumulators. European Commission, Brussels, Belgium. Commission Regulation No. 493/2012.

Madaster, 2018b. Explanation Madaster Circularity Indicator. Madaster Services B.V, Utrecht, The Netherlands.

Heisel, Felix, Hebel, Dirk E., Sobek, Werner, 2019a. 'Resource-Respectful construction e the case of the urban mining and recycling unit (UMAR)'. In: SBE19 Brussels- BAMB-CIRCPATH 'Buildings as Material Banks- A Pathway for A Circular Future', 5-7 February 2019, Brussels, Belgium.

Matejka, P., & Tomek, A. (2017). Ontology of BIM in a construction project life cycle. Procedia engineering, 196

Becker, R., Falk, V., Hoenen, S., Loges, S., Stumm, S., Blankenbach, J., Brell-Cokcan, S., Hildebrandt, L., & Vallée, D. (2018). BIM–Towards the entire lifecycle. International Journal of Sustainable Development and Planning, 13, 84-95.

buildingSMART Switzerland. IFC und offene Standards. Accessed December 30, 2024.

SIA. Standard SIA 2051: Building Information Modelling (BIM). Zürich: Swiss Society of Engineers and Architects, 2017.

BIMshares. „GUID – Definition and How It Works in BIM Projects." BIMshares (blog), 9 wrzeńnia 2024. <https://bimshares.com/blog/guid-definition/>.

NEN. NL/SfB Classification System. 2018. Accessed December 30, 2024. <https://www.nen.nl>.

Çetin, S., et al. "Data Requirements and Availabilities for Material Passports: A Digitally Enabled Framework for Improving the Circularity of Existing Buildings.

Trubina, N., Leindecker, G., & Askar, R. "Digital Technologies and Material Passports for Circularity in Buildings: An In-Depth Analysis of Current Practices and Emerging Trends."

Ungureanu, Viorel, François Fohl, Jie Yang, Oliver Hechler, Vlatka Rajčić, and Raluca Buzatu. "Recovery and Reuse of Salvaged Products and Building Materials From Existing Structures." In Springer Tracts in Civil Engineering, 93–120, 2024

"A Building That Can Be Reused: Brummen Town Hall," January 11, 2022. <https://www.ellenmacarthurfoundation.org/circular-examples/brummen-town-hall>.

Marijn, Emmanuel " Material passports for the built environment", Madaster Lecture Series, Baltimore Sister Cities, 11 april, 2021

Gerding, Ditte P, Hans W. Wamelink, and Els M. Leclercq. "Implementing Circularity in the Construction Process: A Case Study Examining the Reorganization of Multi-actor Environment and the Decision-making Process." Construction Management and Economics 39, no. 7 (July 3, 2021): 617–35

Madaster Global. "TRIODOS BANK: A MATERIAL BANK - Madaster Global," August 18, 2022. <https://madaster.com/inspiration/triodos-bank-a-material-bank/>.

Marie de Klijn-Chevalerias, Saqib Javed, "The Dutch approach for assessing and reducing environmental impacts of building materials" Building and Environment, Volume 111, 2017, Pages 147-159,

Espazium. "Prime À L'anticipation | Espazium," June 18, 2021. <https://www.espazium.ch/fr/actualites/prime-lanticipation>.

Tamari, T. "Metabolism: Utopian urbanism and the Japanese modern architecture movement." Theory, Culture & Society, 2014.

Schalk, M. "The architecture of metabolism: Inventing a culture of resilience." Arts, 2014.

Lin, Z. Kenzo Tange and the Metabolist movement: Urban utopias of modern Japan. Taylor & Francis, 2010.

Tatsuyuki Maeda i Yuka Yoshida, "The Real Reason Why Nakagin Capsule Tower Was Never Metabolized," Docomomo Journal, nr 65 (2021): 118-120.

Ellen MacArthur Foundation, "Circular Economy in Construction," 2020.

European Commission, "Circular Economy Action Plan," 2020.

Shimray, Somipam & Ramaiah, Chennupati, "Digital Preservation Strategies: An Overview" Department of Library & Information Science, School of Media and Communication Pondicherry University, Puducherry, 2019

International WELL Building Institute. "The Benefits of Green Building Certifications." IWBI Publications, 2022.

Ellen MacArthur Foundation. Circular Economy in the Built Environment. London: Ellen MacArthur Foundation, 2020.

List of figures

- fig. 1 Concrete Jungle, photography (source: Henry Do[])
- fig. 2 Material stock (source: CIRCE2020)
- fig. 3 Eckersberg Christoffer Wilhelm - L'interno Del Colosseo 1 - Danish School XIX-XX
- fig. 4 XX century concrete slab (source. evimshahane.com)
- fig. 5 XXI century concrete slab (source. albau.com.pl)
- fig. 6 percentage of waste in different market branches
- fig. 7 Simplified data flow for Material Passport creation (source. Madaster 2019a)
- fig. 8 Steel maximum concentration in the Urban Mines of Amsterdam, (source: code.waag.org)
- fig. 9 Estimating material mass in urban scale Material Bank, city of Ihaca (source: F. Heisel).
- fig. 10 Steel maximum concentration in the Urban Mines of Amsterdam, (source: code.waag.org)
- fig. 11 Copper minimal concentration in the Urban Mines of Amsterdam, (source: code.waag.org)
- fig. 12 IFC format evolution over the years (source: bimcorner.com)
- fig. 13 Costs and benefit from BIM implementation - to compare with potential Material Passport imple-
mentation (source: "Cost–benefit analysis of building information modeling implementation in construction
projects" by M. Azizir, T. Sahar, V. Faghihi)
- fig. 14 Circular Economy Action Plan cover (source: Publications Office of the European Union)
- fig. 15 BAMP report, Framework for material passport cover
(source: EPEA Netherland BV, SundaHUS i Linkoping AG)
- fig. 16 Global investments in AEC tech grew to \$50bln 2020-2022 (source: McKinsey Global Institute)
- fig. 17 McKinsey Global Institute industry digitalisation index (source: McKinsey Global Institute)
- fig. 18 Benefits from Material Passport implementation (source: Madaster)
- fig. 19 In the literature, professional fragmentation and specialization is called "skill stacking"
(source: photo by Maël BALLAND on CC)
- fig. 20 Building form optimisation for best visibility in Galapagos (source: architosh.com)
- fig. 21 Ithaca Houses (source: Felix Heisel)
- fig. 22 Panelled deconstruction vs demolition
(source: Illustration by Allexxus Farley-Thomas, Circular Construction Lab)
- fig. 23 using iPad pro to 3D scanning (source: Felix Heisel)
- fig. 24 data collection in ScanR formular (source: Joseph McGranahan)
- fig. 25 stages of 3D model development (source: Felix Heisel)
- fig. 26 combined data (source: Circular Construction Lab labs.aap.cornell.edu)
- fig. 27 materials from deconstruction at local Reclaimed materials Centre
(source: Circular Construction Lab labs.aap.cornell.edu)
- fig. 26 Ithaca Houses (source: Felix Heisel)
- fig. 29 6 examples of construction archetypes (source: Felix Heisel, Joseph McGranahan)
- fig. 30 lead pollution tester (photo credit: Felix Heisel)
- fig. 31 panelled deconstruction (source: photo credit: Felix Heisel)
- fig. 32 amount of potential materials to mine from the analysed urban area
(source: Felix Heisel, Joseph McGranahan)
- fig. 33 material stock (source: amcarchitecture.com)
- fig. 34 ReRiWi Swiss report cover (source: reriwi.ch)
- fig. 35 view on Materium website - online store with reclaimed materials)
- fig. 36 repartition of actors in reuse in Switzerland (source: ReRiWi report))
- fig. 37 Summary of available material properties in DSCs
(source: L. Gschweilt, M. Lang-Raudaschl, D. Daleyev, M. Stavric))
- fig. 38 dataflow diagram and the whole idea diagram
(source: L. Gschweilt, M. Lang-Raudaschl, D. Daleyev, M. Stavric)
- fig. 39 prototype BIM interface (source: L. Gschweilt, M. Lang-Raudaschl, D. Daleyev, M. Stavric)
- fig. 40 differences in conventional and circular economy transition (source: © Archis / VOLUME)
- fig. 41 UMAR facade view (source: wernersobek.com)
- fig. 42 brick wall constructed without mortar (source: EMPA)
- fig. 42.1 whole modules are designed to dissassembly - on rails (source: Wojciech Zawarski)
- fig. 43 Selected material samples from UMAR (source: Rene Muller)
- fig. 44 UMAR's floor plan (source: Werner Sobek, Dirk E. Hebel, Felix Heisel)
- fig. 45 interior view with visible modular charakter of the finishing (source: Zooey Braun)
- fig. 46 UMAR's disassembly axonometry (source: Werner Sobek, Dirk E. Hebel, Felix Heisel)
- fig. 47 Madaster marketing materials (source: madaster)
- fig. 48 dataflow in Madaster (source: smartwp.nl)
- fig. 49 Flowchart of building disassembly and circular reuse
(source: Hui Zhu, Shuenn-Ren Liou, Pi-Cheng Chen)
- fig. 50 Madaster platform window with 3D explorer view (source: madaster webinar)

- fig. 51 set of example's indicators (source: madaster webinar)
- fig. 52 Madaster circularity indicators in generated report (source: madaster manual)
- fig. 53 financial indicators set, price of material mass vary over time (source: madaster manual)
- fig. 54 steel embodied in project price over time (source: madaster manual)
- fig. 55 Scheme of data input, hierarchy, calculation, output and connection to external partners on the
Madaster platform.(source: Felix Heisel, Sabine Rau-Oberhuber)
- fig. 56 generated madaster report (source: Felix Heisel, Sabine Rau-Oberhuber)
- fig. 57 Volume and mass of materials used in the UMAR unit categorized according to material families and
applications/locations (source: Felix Heisel, Sabine Rau-Oberhuber)
- fig. 58 IFC export windows in Revit with desired settings (source: madaster manual)
- fig. 59 assigning the right material parameter in Revit (source: madaster manual)
- fig. 60 IFC inheritance schema (source: BIMcorner.com)
- fig. 61 extension facade view (source: rau.eu)
- fig. 62 ground floor plan - temporary intervention in blue
(source: plan by RAU Architekten, edited by Kewin Niewiarowski)
- fig. 63 exploded view, divided in madaster view categories
(source: RAU Architekten, edited by Kewin Niewiarowski)
- fig. 64 schematic aerial view (source: RAU Architekten)
- fig. 65 view on the inner courtyard and the demountable wooden structure (source: architectuur.nl)
- fig. 66 view on the inner courtyard and the demountable wooden structure (source: Janice Lobo)
- fig. 67 Building perspective (source: rau.eu)
- fig. 68 Total shadow cost of thebuilding (source: M.Chevalerias)
- fig. 69 fixing the wooden structure (source: RAU Architects)
- fig. 70 model of building with foundation poles(source: jpvaneesteren.nl)
- fig. 71 view on the tree-like interior structure (source: Marcel van der Burg)
- fig. 72 structure fixing details (source: Marcel van der Burg)
- fig. 73 axonometry of the ground floor (source: RAU Architekten)
- fig. 74 atypical office floor (source: RAU Architekten, edited by Kewin Niewiarowski)
- fig. 75 ground floor plan (source: RAU Architekten, edited by Kewin Niewiarowski)
- fig. 76 basement plan (source: RAU Architekten, edited by Kewin Niewiarowski)
- fig. 77 east elevation (source: RAU Architekten, edited by Kewin Niewiarowski)
- fig. 78 longnitudal section (source: RAU Architekten, edited by Kewin Niewiarowski)
- fig. 79 Nagakin Tower (source: archeyes.com)

