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Innovations Practitioners Need for Circularity in the Swiss Architecture, Engineering, and Construction Sector

Catherine De Wolf, Deepika Raghu, Anton Sentic, and Corentin Fivet

EPFL cirkla ETH zürich

Transporting reclaimed materials on disassembly site at Oetwil am See.
Photo: Chair of Circular Engineering for Architecture, ETH Zurich

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Construction process: cut on demolition site
Photo: Structural Xploration Lab, EPFL

Summary

Although widely recognized as imperative for reducing global emissions and the amount of waste generated by the architecture, engineering, and construction (AEC) sector, a large-scale shift from a linear to a circular economy has not yet happened in practice. This paper highlights practitioners' needs for implementing circularity in the AEC sector in Switzerland, and how digital platforms could support it. We hosted two workshops with industry practitioners in the Swiss AEC sector to find out their needs from academia, government, and industry to implement such a shift. The first workshop revealed a need for digital reuse platforms, so we focused a second workshop specifically on digital platforms. Results from the second workshop made clear the need for better practices of gathering data and integrating platforms. Financial incentives, social innovation, policy measures, and digital tools were also identified as necessary to increasing circularity in the sector. Our findings reveal the promising potential of digital technologies and stakeholders' networks to better capture data on building products and methods for extending their life cycle.

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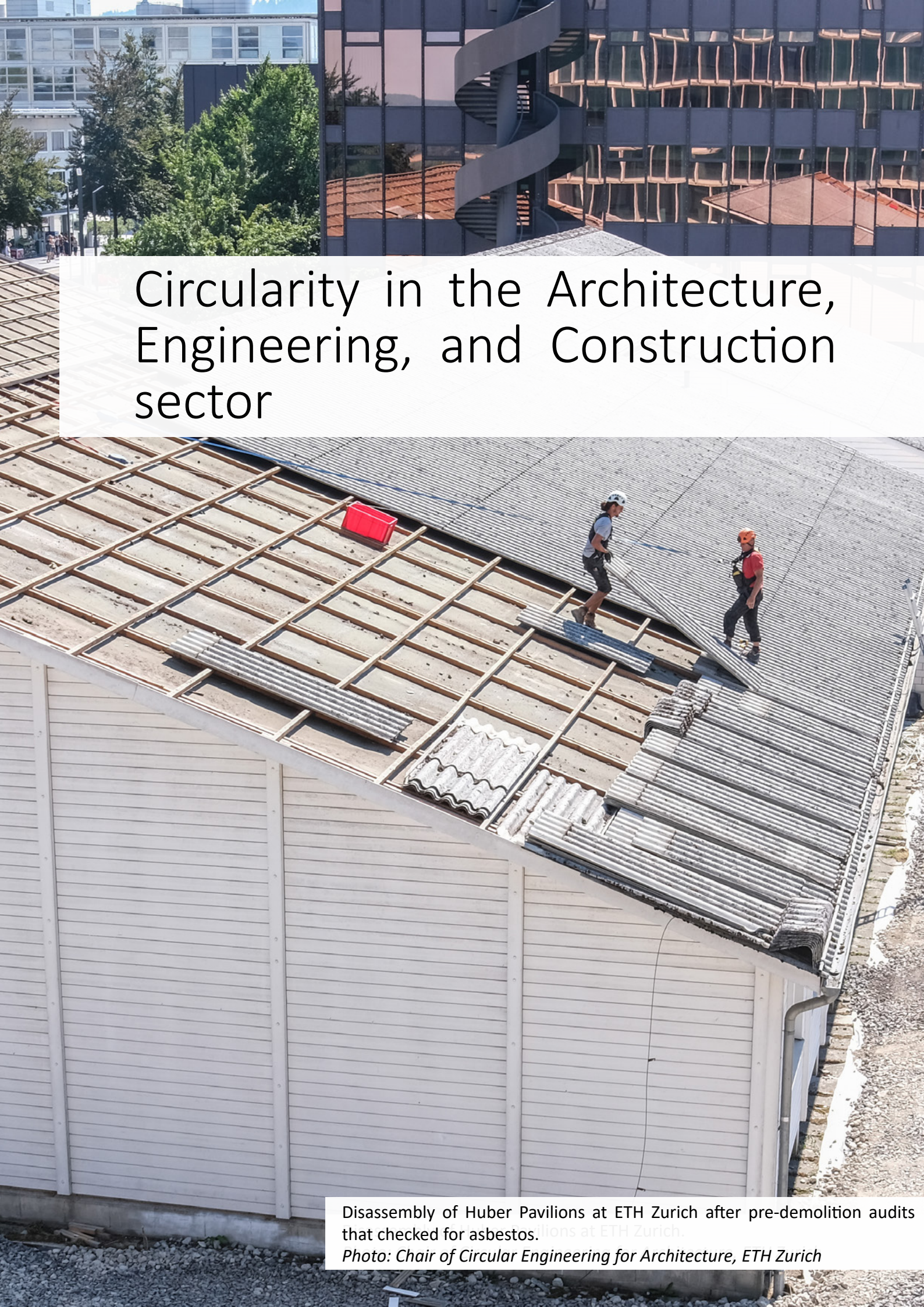
Circularity in the Architecture, Engineering, and Construction sector



Disassembly of Huber Pavilions at ETH Zurich after pre-demolition audits that checked for asbestos.
Photo: Chair of Circular Engineering for Architecture, ETH Zurich

Today's buildings emit 39% of our global greenhouse gas emissions [1]. They use 50% of all materials in Europe [2] and generate 80% of waste in Switzerland [3]. Currently, the construction sector follows a linear model in which building materials are extracted, produced, used, and disposed of. Instead, in a circular model, stakeholders would derive maximum value from building materials by reusing them at the end of their service life. While pioneering projects have been promising, circular building projects have not yet become mainstream. Despite increasing interest in the circular economy, the architecture, engineering, and construction (AEC) sector has been rather slow in moving from a linear, "take–make–waste" model to a circular model.

Transitioning from a linear economy to a circular one requires long-term, systemic consideration of social, environmental, and economic consequences. Circularity can be achieved by following a set of strategies to minimize waste generation and resource depletion, while promoting a sustainable future through regenerative business models. The United Nations Sustainable Development Goal 12, 'Responsible consumption and production', aims to mitigate the adverse effects of climate change [5]. Consequently, several governments have agreed to incorporate a circular economy into their long-term development goals at both the local and national level. Uruguay, Ecuador, Colombia, Peru, and Chile have drawn out roadmaps while other countries, like the United States, Australia, and China, have set forth directives that support circularity in the construction industry [6]. The circular economy action plan for the European Union emphasizes the long-term commitment required of local, regional, and national levels of government [7] and focuses on how the consumption of resources must be kept within boundaries [8]. The European Green Deal [9] proposes several actions to prolong product lifespans and intends to enhance the traceability of materials through digital product passports. Europe's Digital Strategy [10] promotes the safe development of digital technologies while taking into consideration the European Union's goal of climate neutrality by 2050.

Stakeholder needs for circular construction

Students inventorizing disassembled materials at Oetwil am See.
Photo: Chair of Circular Engineering for Architecture, ETH Zurich

Studies focusing on circular economy in AEC are only emerging, although there is already a consensus that it requires the joint efforts of various stakeholders, collaboration, and partnership-driven innovation, as a circular economy is intrinsically a sharing economy [11], [12]. Interviews and workshops with an identified expert network have been shown to help foster an understanding of digital technologies that enable circular construction [13], preconditions for circular building material and product flows [14], and industry-wide awareness of the concepts of a circular economy in construction [15]. AEC stakeholders have been interviewed to understand barriers to and enablers of circular construction in European countries including Belgium, the Netherlands, the United Kingdom, Denmark, and Italy [16]; in different regions of the United States [17]; and in China [18], for example. Yet a deep understanding between professional domains and supply chains for enabling a circular economy in the AEC is still lacking.

Over the past years, a number of initiatives for building component reuse have emerged or been strengthened in Switzerland. In 2019, several motions [29] were proposed to the Swiss parliament to extend the lifespan of products and obtain more information on their repairability. In Switzerland, the "Réemploi, Riutilizzo, Wiederverwenden" (ReRiWi) report [19] was a first attempt to understand AEC stakeholder needs at the national level. However, Switzerland's digital strategy does not explicitly relate to circular economy [30].

The AEC industry is one of the least digitized industries in the world [20]. However, a rapid digital transformation is underway [21]. Digitalization is producing co-creation and collaboration opportunities that can foster a circular economy with technologies such as robotic manufacturing, artificial intelligence, big data and analytics, blockchain technology, building information modelling (BIM), digital material marketplaces, digital twins, geographical information systems, material passports, and the Internet of Things for the built environment [13]. State-of-the-art solutions include digital material matching platforms such as Excess Materials Exchange [22], which serves as a mediator between reuse suppliers and potential customers. Although similar digital forums for exchanging unwanted items have existed since the 1970s [23], their potential is limited and they are in need of

re-evaluation. Other digital tools, such as BIM-based material passports, help document and optimize the use of reclaimed materials [24]. The integration of these tools with real-world business processes is still in its infancy due to the lack of replicable solutions for a variety of project types. Despite efforts towards digital integration, such initiatives fail to meet the needs of the practitioners that use them and the communities they serve [25]. The heterogeneity and fragmentation of digital platforms hinder the implementation of such initiatives in projects that require specific design and delivery approaches.

Reuse efforts in Switzerland

As reuse efforts are often local, we mapped existing organizations and initiatives in Switzerland to prepare for practitioner workshops (see Figure 1). We found that several existing online reused material marketplaces are gaining traction. For example, BauTeilLaden Winterthur Genossenschaft [31], a construction parts store cooperative, was founded in 2000. In 2001, Bauteilvermittlung Zürichsee-Oberland (BTVZ) [32], a component brokerage pilot project, started providing communities with weekly supply and demand lists. ReWinner [33] also began with the purpose of promoting a circular economy in 2014, taking charge of the complete sales process, from inventory and pick-up to final delivery. Bauteilverwertung [34] visits homes that are abandoned or marked for demolition to salvage materials and sell them on its online platform. Along with posting offers online, Wiederverwendung [35] maintains supervised collection points for reusable products. The material marketplace Salza GmbH [36], founded in 2015, enables sellers to upload photographs and detailed descriptions of the components they would like to sell. Matériuum [37] also offers reused material products on its website. Syphon [38], Bauteilbörse Basel [39], GGZ@Work-Bauteilladen [40], La Ressourcerie [41] and Bauteile Zürich [42] also have platforms for selling reused materials. The marketplace Useagain [43] is currently undergoing redevelopment by Sumami [44], based on the material exchange platform Bauteilclick.

Many of these reuse actors or marketplaces extend their services beyond the sale of reused materials. For example, Syphon, Bauteilbörse Basel and La Ressourcerie also look for storage for reused components; mediate between construction and demolition projects; reprocess materials in their workshops; and aid in the demolition, dismantling, and transport of building components. Steiner AG's [45], [46] Rives de la Baye project used Salza to sell some of the materials saved during the demolition phase. Matériuum [37] has specialists in material retrieval, management, and transport, as well as in circular design training and reuse policy implementation. One example of its involvement in circular projects was in assisting the architects Kunik & De Morsier in reusing carpentry for the extension of the Après-GE building [47]. Specialist planning practitioners for the circular economy have applied reuse principles in many architectural projects, such as projects by Zirkular [49] or Baubüro in situ's [48] K.118 project in Winterthur

[50]. Halle 58 [51], Leserf Architekten [52], Co. Architekten AG [53] and Umbra Architekten [54] in Bern have also taken on the challenge of reusing components in their building designs. Additionally, Meier Haushaltsapparate [55], Neue Holzforum AG [56], and Tischhauser AG [57] are expert builders with reused and recycled materials. The Rethink Materials Kollektiv [58] is also an interdisciplinary team of building professionals who promote reuse, visit buildings that are going to be demolished, document the different materials, and host workshops to raise awareness among the broader public to achieve the goal of making the reuse of components an everyday practice.

Some companies, such as Madaster [59], focus on documenting buildings and material life cycles on a digital platform, and calculate circularity in the construction, use, and end-of-life phases of buildings. Recently, Visits [60] has developed a web-based applications that help digitize the real estate market by systemically keeping records and evaluating buildings, producing detailed reports on the individual components and maintenance costs to be expected in the future. Nomoko [61] also aids in the digitalization of building information through digital twins by building an ecosystem that uses spatial data and location intelligence to deliver actionable insights.

More recently, a Swiss umbrella organization for reuse in the construction industry took shape under the name Cirkla [62]. Cirkla aims to connect multiple stakeholders involved in building material reuse, including academics, private companies, and public bodies. Cirkla collects examples of AEC projects that have facilitated the reuse of materials to demonstrate the potential of designing with such materials.

Research is also being carried out by several Swiss science institutions. For example, the Swiss Federal Laboratories for Materials Science and Technology (EMPA), developed the Urban Mining and Recycling unit [63] to construct buildings with reusable, recyclable, or compostable materials and the Sprint unit [64] to find solutions enabling circular construction with reclaimed materials and design for disassembly techniques. Furthermore, at the Ecole Polytechnique Fédérale de Lausanne (EPFL), the Structural Xploration Lab [65] is developing new reuse applications for load-bearing components, including a footbridge made of concrete blocks cut from existing walls [65], algorithms for optimizing the reuse of given stocks in steel or timber structures [66], [67], and a new modular system for highly versatile slabs [68]. Following a mandate by the Swiss Federal Office for the Environment (FOEN), the lab published a book on selective deconstruction and reversible construction with case studies from Switzerland [69]. The Laboratory of

Elementary Architecture and Studies of Types [70] at EPFL engages with academics to document experiences, visions, and practical conceptions of reuse in teaching. At the Swiss Federal Institute of Technology Zurich (ETH), several architecture studios tackle the topic of reuse: the Reuse studio of Barbara Buser [71], the Center for Advanced Studies in Architecture of Elli Mosayebi [72], the design studio of Tom Emerson [73], and the design studio of Jan De Vylder [74], among others. In the civil, environmental, and geomatic engineering department of ETH Zurich, the circular economyA lab [75] conducts research on digitalization of the built environment to enable reuse – for example through Machine Learning [76], Scan-to-BIM material inventories, computational design, and digital fabrication of buildings with reused materials – and tracking and tracing materials through material passports [77].

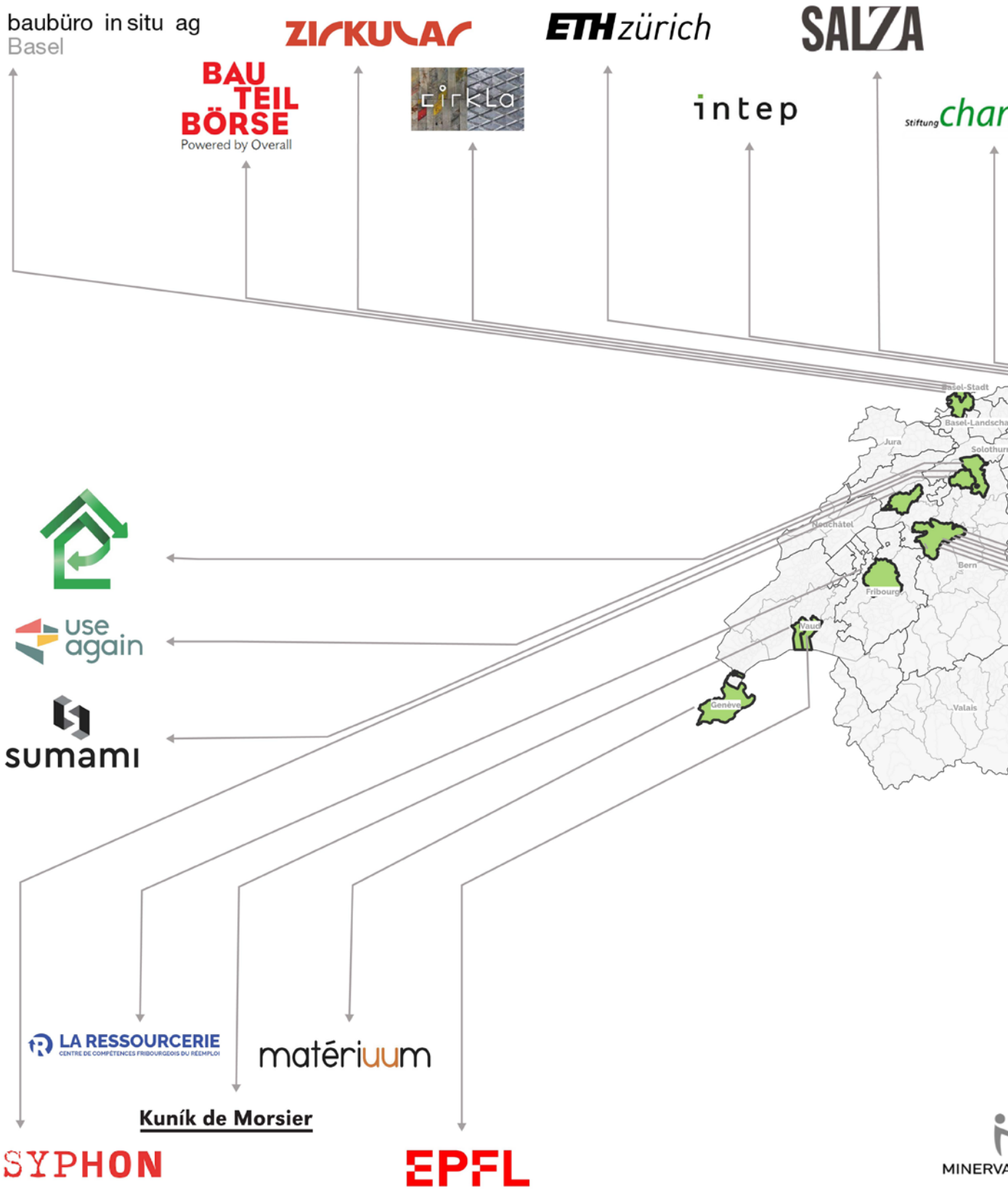
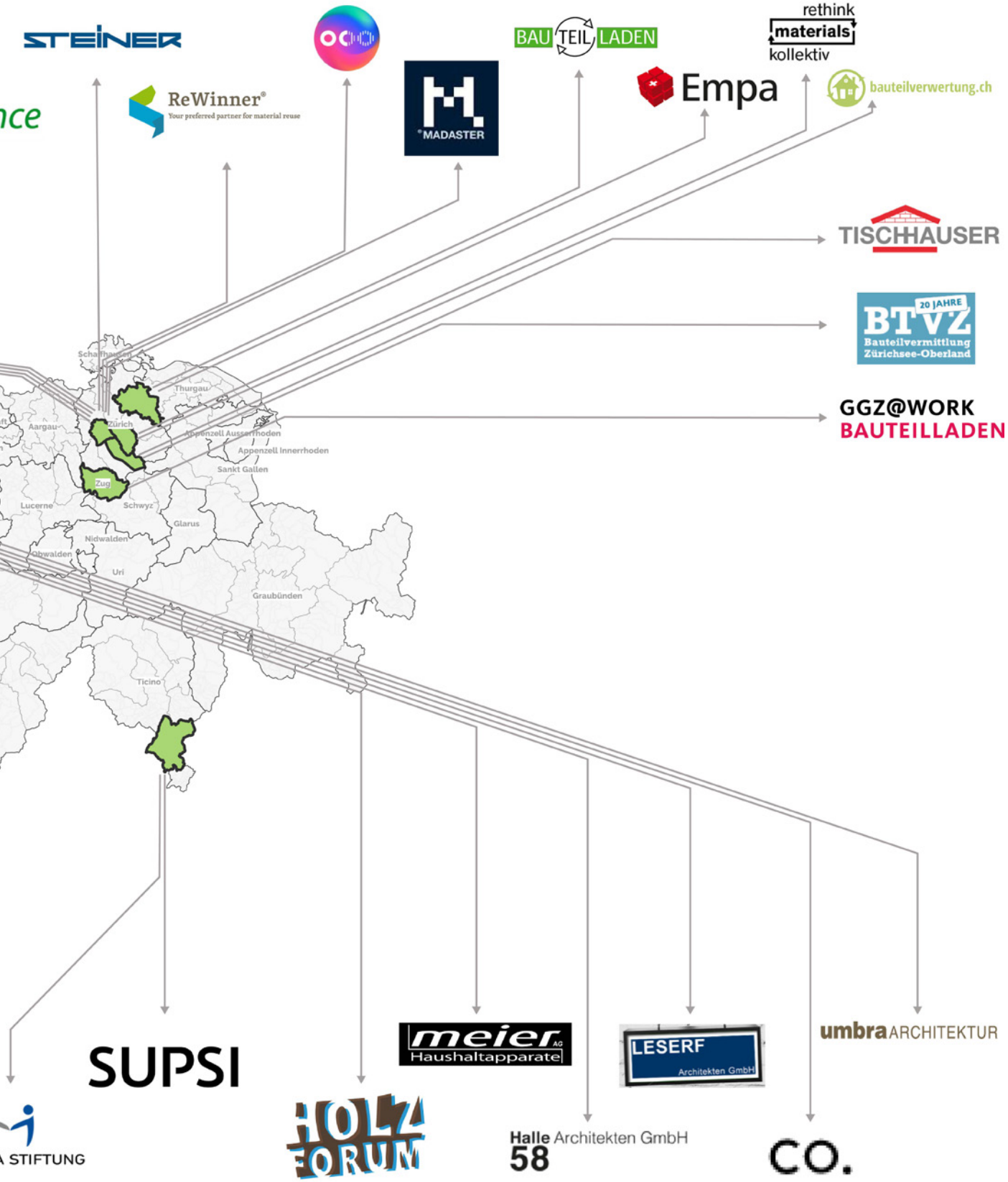


Figure 1: Circular economy stakeholders in Switzerland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Workshops on circularity with Swiss stakeholders

"How can research help enable the reuse of building materials and components in Switzerland?"

Workshop participants at ETH Zurich.
Photo: Chair of Circular Engineering for Architecture, ETH Zurich

On July 2, 2019, the Structural Xploration Lab at EPFL organized a workshop with experts from academia and industry to discuss challenges for reusing building materials in Switzerland. They hosted three brainstorming sessions, two with randomized groups and one with expert groups. The first workshop focused on offline practice and understanding what tools practitioners use to evaluate the benefits of reuse, what data is needed to increase reuse in practice, what platforms are needed to find reused materials, and what drivers are needed to launch a reuse network in Switzerland. The analysis focused on architects and the design tools they use or wish to use; engineers and their role in a circular construction industry, especially in terms of responsibility for the structural stability of a reused structure; and unaddressed topics on reuse by researchers.

On December 6, 2021, the Circular Engineering for Architecture Lab at ETH Zurich hosted a follow-up workshop to discuss how researchers could support practitioners and to understand how researchers can support existing digital reuse platforms. This second workshop discussed online practice and digital platforms that already exist. It highlighted the potential for collaboration through digitalization. After presenting the first workshop's results, we held feedback rounds, an interview, and a brainstorming session using an online participatory whiteboard. The analysis was based on how these platforms are used, who is planning which future developments, what the digital needs are, and what support can be provided by researchers.

In both workshops we asked, "How can research help enable the reuse of building materials and components in Switzerland?" We wanted to find out how academics can support practitioners in the transition from a linear to a circular model in the AEC sector. We used an inductive, exploratory research design method that combined primary data collected from a panel of experts with qualitative data analysis by taking secondary data gathered through a systematic review of published research as well as industry and government reports [26]. Primary data was obtained from the focus group in Workshop 1, followed by consensus-building on the workshop's output using Delphi Method principles [27]. Both workshops were recorded and subsequently transcribed. We followed up on intermediate results from Workshop 1 by reviewing academic and grey literature to learn more about the topics that were brough up. This led to the topic of Workshop 2: digital tools for reuse in practice.

Workshop 1: Identifying challenges and opportunities for circularity in AEC

RE:CRETE footbridge prototype.
Photo: Structural Xploration Lab, EPFL

In first step of our research, we analysed scientific studies and public sector literature about construction, reuse, and waste management. This analysis helped us predetermine a set of codes (see Table 1) for later analysing the results of the first workshop. The literature review also helped us set up Workshop 1, particularly regarding the selection of participants and the questions which were raised.

Table 1. Codes derived from Workshop 1

Code #	Description
1	Research on circular economy in Swiss construction
2	Data gaps on reuse
3	Platforms for materials exchange
4	Incentives and barriers for reuse practice
5	Role of stakeholders in circular construction
6	Guarantees for reused (structural) material
7	Design tools supporting reuse processes

A series of questions related to pertinent issues of reuse were discussed in three rounds in the workshop: two rounds with randomized groups and the final, non-randomized round with the participants grouped together based on their professional background (engineers, architects, researchers, and others). All discussions and presentations held during Workshop 1 were recorded, transcribed, and coded by two members of the research team working independently of each other, using a thematic coding approach [28]. Following an initial round of coding, the researchers cross-checked their findings, adjusting the coding as necessary. By analysing responses from the Workshop 1 by using the codes we had developed beforehand, we identified the following six main themes discussed during the workshop.

Theme 1: Data gaps and research needs

Participants identified a need for comprehensive datasets of buildings in Switzerland. These datasets can be used to create specific benchmarks for reuse, based on the various functions and typologies of buildings, when associated with their material conditions, quantities, and types.

"We need information on what is actually on site, not on paper or in the BIM model – which is often inaccurate today."

Practitioners mentioned needing examples of built projects that implement circular economy principles:

"We need examples; we need good projects so we can dream about what we can develop and improve."

Currently, uncertainty as to how the reclaimed elements can be integrated into new design solutions holds practitioners back.

A unified, industry-standard approach for measuring circularity and its financial benefits must be put in place. This includes identifying the costs of whole-life carbon, building life cycles, demolition, and disassembly, as well as estimating material resale values. Participants mentioned a lack of data:

"We need data on available stocks and pricing."

The need for novel business models to avoid costs from landfilling and to encourage local materials marketplaces was also highlighted.

Theme 2: Platforms for materials exchange

In addition to needing better data, workshop participants also pointed out a strong need for databases that reflect the reuse potential of elements retrieved from old buildings. Several standalone platforms exist, but increased collaborative efforts between them would allow for better matching supply and demand at larger scales:

"The idea could be to use the data from [material passport platforms] for something similar to an Amazon marketplace, where every owner of a building has his own marketplace to sell and buy [reused] materials."

Most platforms enable users to access a catalogue of reusable materials from within a given radius of a site. However, detailed information on the element life cycle is still missing, a necessary detail to make decisions on its inherent potential for a second life. Participants also mentioned the need for these databases to take regional price variations into consideration, since prices vary widely in different countries depending upon the quality of the product and the method of its recovery.

Theme 3: Incentives and barriers to reuse in building practice

Due to low supply and demand for reclaimed materials, procurement costs are high. Hence, participants pointed out that the reusable materials fail to be sold at competitive prices and are generally more expensive than virgin material:

"The problem is that [raw] materials are too cheap."

"Construction [with raw materials] needs to become more expensive."

Accurate value estimations of materials at the building end-of-life can help building owners make more informed decisions on retaining elements. Optimizing deconstruction costs and strengthening the market for reclaimed materials would make demolition a less attractive solution. Contractors lack the impetus to adopt new practices for a circular economy unless they are shown prospects for making better sales and having the necessary performance and safety guarantees:

"Apart from safety, cost trumps everything."

Additionally, logistical challenges must be dealt with:

"We are lacking a big storage at low costs for [reused] materials so that we can have a big availability/stock of materials to choose from, in order to make reuse possible."

The participants from the workshop also believe that the costs of transport, remanufacturing, labour, and storage need to be made more transparent. Additionally, interim, or long-term storage depots should be positioned near the construction or deconstruction site to reduce transport from, and to, the building site.

Theme 4: Role of stakeholders in circular construction

The participants concluded that collaboration and communication between stakeholders along the value chain is essential:

"All actors should work together to change the current mindset."

Bringing together relevant stakeholders – including architects, engineers, developers, deconstruction companies, facility managers, policymakers, and researchers – helps identify specific roles and share knowledge. Governments can play a crucial role by introducing new regulations. Circular construction also presents an opportunity for creating new jobs. Soon, there will be an increased demand for materials assessors, storage facility managers, remanufacturers, digital platform developers, communications managers, and more. Investing in new, specialized technical skills will be necessary.

Theme 5: Guarantee of reused materials

There is an absence of both experience and trust in working with materials from third-party suppliers. Certifications guaranteeing the performance of materials would help proliferate reuse. Structural engineers are trained to be risk averse. This makes it difficult to use products that do not come with a manufacturer's assurance or technical specifications and performance parameters. Participants acknowledged that indicators for deconstruction, reuse, and adaptability need to be included in building policies. It is also important to set up qualitative targets to ensure safety and performance of the reclaimed materials using risk-assessment tools. This can help facilitate the cyclical use of building elements beyond just wall finishes, including for major structural components. Ideally, material passports should contain all the necessary information for deconstruction, including details of the components' composition, history, and reuse potential.

Theme 6: Design tools for reuse

BIM makes it possible to assess the recovery, reuse, and recycling potential of materials quickly and accurately. The value propositions of these models can be incorporated into material passports. Most architects are yet to fully integrate BIM solutions in practice because of the specialized skills and unique workflows required to use this technology. Digital platforms providing online material inventories with material-specific information were identified as crucial accelerators to a circular economy in the built environment. Designers could then select and choose

reclaimed materials based on different criteria. In the conceptual and design development stages, optimization algorithms could help designers shape their buildings with the available stock of materials. Research contributions to identify the optimal combination of new and reused components are becoming more prevalent; however, their implementation in real-world design is still limited.

Additional feedback: scheduling challenges and risks of reuse

Another central challenge around the reuse of elements relates to time. Negotiated schedules between investors and contractors are put into action as soon as contracts are formalized. Any deviation results in high penalties for the builders. The complexity of reuse projects makes following timelines extremely difficult. Hence, reusing building elements must be considered early in the project to determine the feasibility of timelines. Pre-demolition audits need to be completed as soon as a building is scheduled for demolition and would require a building asset analysis to help retain high-value components. Legal and financial aspects should be given due importance. In some cases, pre-demolition operations on-site could damage the materials selected for reuse. Thus, the benefits of insurance should not be disregarded. Detailed risk assessments should be conducted and the relevant stakeholders who will take full responsibility for the damages should be identified. Workshop participants believe it is critical to obtain information from specialists on material dimensions, quantity, condition, environmental impact, and disassembly. They also emphasized the importance of giving involved stakeholders easy access to the data, especially those unfamiliar with advanced digital technologies. In summary, a favourable legislative and financial environment must be created. Other innovative circular business models, such as “take-back” or “product-as-a-service” approaches, can also offer solutions.

After analysing the qualitative outcomes of the workshop, we held a two-stage consensus-building process involving the workshop participants. We sent a synthesized version or our results and requested written feedback from all workshop participants to explore common ground among the different stakeholder groups and to reach a number of consensus positions. After this consensus-building process, we conducted further secondary data analysis to prepare for the next workshop.

Workshop 2: Digital platforms for reuse in practice

Mock-up of ‘Tinder for reuse’ digital matching application.
Photo: Chair of Circular Engineering for Architecture, ETH Zurich

Workshop 2 was organized based on the results of Workshop 1. As identified by the first workshop's results – as well as the significant boost to digital innovation and need for virtual, digitalized solutions in response to the Covid-19 pandemic – the need for digital platforms and tools for circularity was explored in Workshop 2. To do so, we inventoried digital tools and platforms available in Switzerland, including documentation databases, pilot projects, prototypes, and knowledge hubs. To gain additional expert insights, we invited platform owners and managers to Workshop 2.

First, we held an introductory session to review the existing platforms that promote reuse in Switzerland. Next, we conducted a brainstorming session to identify the drivers and constraints of the existing digital tools and platforms, while considering the current state of practice and its future potential. Participants were asked to critically analyse core priorities and deficiencies of the platforms with the help of an online, interactive whiteboard. Participants were asked questions regarding the data used, stakeholders involved, scope and scale of the platforms, existing bottlenecks, and future prospects (see Table 2). Last, we held a roundtable discussion with the expert group to understand how academia could benefit practice, mirroring one of the core topics from Workshop 1.

Responses in Workshop 2 revealed that platforms in Switzerland are primarily used for brokering, resource management, or for connecting experts in the industry. Platform usage ranges from the material/ component scale to the building scale, even to city development. Stakeholders include architects and planners, demolition companies, building owners, private enterprises, product managers, and logistics companies. Materials and products most often reused include windows, doors, bathroom and kitchen equipment, staircases, tiles and slabs, and wood beams.

Table 2. Main questions for Workshop 2

What digital platforms exist?	What are platforms used for? What data is used in platforms? Who are the stakeholders involved? Which aspects are missing? What region (city/country/continent) do the platforms focus on? What is the level of digitalization of the existing platforms? At what scale (material/product/building) are the platforms used? Which materials/products are mostly reused?
Who is planning which developments on digital platforms?	
What are the needs of practitioners in terms of digital platforms?	
What can research offer to practitioners in terms of support for digital platforms?	

We learned that existing digital platforms are already planning many developments, including stock exchange, deconstruction management, promoting reuse and spreading awareness, connecting with municipal authorities, finding case study projects. An online platform to connect all existing platforms and one to show all reuse services is also planned. One will be rebuilt based on user requests, and an alert function will be created to inform users of available elements. Workshop respondents mentioned many additional possibilities for platforms to contribute to circularity, as well as what aspects are still needed to use digital platforms effectively towards that aim. (See Table 3.)

Table 3. Uses and needs of digital platforms for circularity in AEC

How are the existing platforms used for circularity in building materials?	Financial valuation Circularity measure studies Reporting and project management Reuse planning Finding buyers Requesting and offering building components Sharing information on reclamation Connecting stakeholders and experts Brokering Matching availability and demand Storing reusable elements Auctioning private and commercial sales Material management

Which aspects are missing from existing platforms that would support circularity in building materials?	Precise quantities Savings potential Energy consumption Thermal, acoustic, and fire-protection properties 3D CAD data Information on needs of user Cooperation amongst involved stakeholders Environmental impact analysis Ecosystem working
What are the needs of practitioners in terms of digital platforms?	Standards and regulations Unification amongst stakeholders Data collection techniques Ease of adaptability/flexibility Sharing information with all involved in value chain Data on demand, availability, logistics, quality, quantity Awareness of how to design with reclaimed elements New design workflows Long-term storage solutions Connections between platforms Time planning methods Collaborations with industry and academia
What can academia offer to practitioners in terms of support for digital platforms?	Documentation of examples of reuse projects Secured database with detailed information Open-source data Inventory protocols Methods to incorporate reuse in design Procedure to standardize process Expand on architecture of reuse Collaboration in real-world projects Toolbox that aids the reuse process Promotion of reuse systems and techniques Guidelines for working with reused materials

The sessions from Workshop 2 were recorded and transcribed. Coding the sessions of Workshop 2 helped identify five main themes. The transcription was coded by two members of the research team working independently of each other, using the same thematic coding approach as with Workshop 1. The following five themes emerged.

Theme 1: Data collection and management

Participants expressed that efficient data collection on reused materials remains a significant challenge.

To improve the exceedingly labour-intensive and time-consuming process of gathering information on building materials during on-site audits, data entry (on-site, then off-site in the office, and finally on the digital platforms themselves) needs to be optimized. Another key factor to consider is the data format and end-user of the platform:

"Sometimes the inventory information is just a sheet of paper or just a few pictures that were taken on-site."

"We need to make life easier for our customers in terms of typing in data of the products that they want to sell."

Some digital platforms are used for internal project management and client acquisition. Others cater to the general public for selling the materials. Finding specific materials from the several online marketplaces can be difficult. Accessing well-defined information at different stages of the building project and a harmonization of data across platforms is necessary.

Theme 2: Networking and collaboration

In Switzerland, many digital platforms exist but they do not interact with one another, thus missing out on the benefits of cross collaboration. Consequently, the need to combine information from multiple existing marketplaces is underway was expressed:

"Maybe web crawlers can bring information together, while the individual local platforms can still keep their identity."

"A key need for us is the unification of the data, because if we are talking the same language, I can then send my data to all the web platforms easily and I can also grab data from the web platforms for my own use."

Participants mentioned the need to foster stakeholder networking in order to form strong links between the existing platforms. The current engagement within stakeholder networks is insufficient, cumbersome, and devoid of structure. Communication is generally carried out through phone calls and emails, making it

difficult to record and share information easily. Strategies to create daily or weekly alerts about available reusable materials are being explored.

Importantly, local platforms should not have to compete with one another, as they are each unique and vary in reach as well as revenue models. With such a variety of platforms, notifications of materials available for reuse on all platforms could be automated:

"For every time that materials are updated onto the platforms, a method for notifying potential clients is necessary."

Practitioners are also working on improving engagement within stakeholder networks. Active communication is important to avoid confusion and ensure that work is not unnecessarily duplicated in the value chain.

Theme 3: Regulations and standards

Over the last few years, several online marketplaces have emerged. Hence, the problem is not the lack of initiatives, but rather an understanding of how to increase the prospect of material reuse. Components such as windows, doors, staircases, tiles, and beams are currently sold on the platforms that operate in Switzerland. To merge, link, or combine information on reclaimed materials, standards are required for each material or product type:

"We need different information on steel beams than we need on windows."

For large-scale reclamation of buildings and components across Europe, cooperation with legal bodies would be essential. Participants also expressed the need for a more transparent certification process. The lack of regulations and standards concerning reuse makes it difficult to define the correct course of action to be taken.

Theme 4: Logistics of reusable materials

"Sometimes, you have the material but there is actually no demand [for it] so then you throw it away."

Significant effort is required to procure materials from buildings that are not designed to be dismantled. Participants argued that the matching of supply and demand before reclamation processes are carried out can help reduce wastage of

materials, labour, and energy. Warehouses are quite expensive. Efficient methods to organize transportation, storage, and distribution need to be established. Material detection, extraction, and procurement timelines need to be coordinated. According to the participants, reports on cost savings and environmental impacts can incentivize the formulation of long-term reuse planning and systematization.

Theme 5: Awareness and education

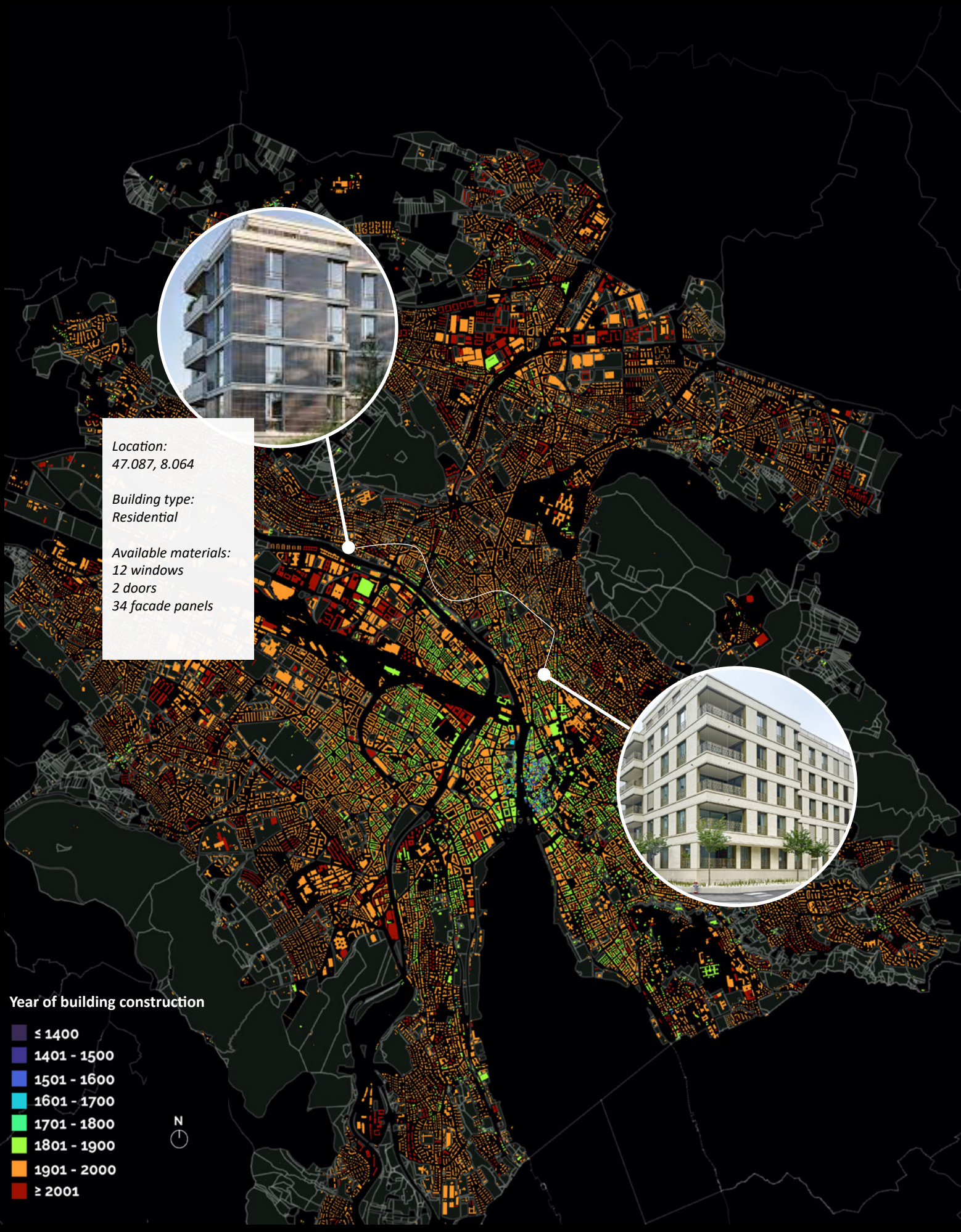
The participants also expressed concern over the lack of examples that demonstrate the potential of reuse. The workshop participants emphasized that lessons learnt should be communicated to all involved stakeholders:

"I think one of the best ways that we can begin to do something is by showcasing [reuse] projects and also explaining how they work."

Traditional practices of sharing information rely on sheets of paper or digital spreadsheets, while academic research is largely focused on the powerful, expensive method of 3D scanning tools. There is a need create a middle ground whereby technology reduces time spent on-site while also being easy and affordable to use. There is also a significant knowledge gap regarding how the elements can be used in architectural design. Academia can support practice by generating toolboxes for reuse that showcase alternate design possibilities through research and industry collaborations on real-world projects. Academics can support practitioners in developing optimization and evaluation algorithms to facilitate designs with reused materials. Training, education, and awareness must also be prioritized.

Additional feedback

The platforms usually capture the dimensions, quality, and quantity of the reclaimed materials but still lack detailed information about the precise savings potential, energy consumption, fire protection, and acoustic properties of the elements. They also lack BIM models or any sort of 3D digital representation. Most documentation is done manually, which can be laborious and time-consuming. As a result, new platforms for documentation, design, and dissemination are currently being developed.



Urban-scale material matching.
Image: Deepika Raghu, ETH Zurich

Future directions for circularity in AEC

This paper highlights needs for enabling circularity in the AEC sector in Switzerland. The most important practical findings from the workshops with business experts can be summarized as follows:

Focus research on *gathering data* about building stocks
Collecting data is necessary for improving the transparency and reach of reusable materials in value chains. Tracking and tracing these materials throughout their life cycle is essential to obtain information on material-specific characteristics, such as their location, quality, and cost.

Develop and advance *digital tools* to facilitate materials exchange
Aggregation of digital material passport information from various existing platforms can help create a robust database of reusable materials. Overcoming the challenges of interoperability between different technologies and the lack of a common infrastructure needs to be prioritized. Digital tools can provide smart, optimized solutions which enable knowledge sharing at all stages of the decision-making process.

Strengthen the provision of *financial incentives* for practitioners to adopt circular initiatives
The need for high upfront investment, a lack of financial support for circular business models, and low virgin materials prices currently discourage material reuse. Rewarding value chain collaboration by promoting take-back incentives, creating subsidies for refurbished products, and providing tax incentives can support a circular economy.

Prioritize *social innovation* by establishing multi-stakeholder partnerships
Business models that engage a multi-stakeholder ecosystem can improve collaboration and communication, which are crucial to understand value-based motivations and to establish joint interests. Economic perspectives, along with social and legal dimensions of all involved actors, requires careful consideration.

Introduce effective *policy measures* to assess and make use of reused materials
The ambiguity around the assessment of reusable material and lack of theoretical knowledge on their methods of implementation in construction is a pressing

challenge. Inconsistencies hinder existing material reuse. The industry will benefit from developing coherent regulations with consistent definitions that include a wide range of actors.

Establish *logistical systems* to enable a closed loop of material flows
Supply chain management systems are needed to reduce the ecological footprint, collection costs, time delays, storage, and transport operations of reused materials. Clear guidance and monitoring are important to avoid social, environmental, or economic damage.

Organize *dissemination activities* to spread awareness in the public domain
We need to share awareness and knowledge on the social, economic, and environmental opportunities to be gained from the extension of material life cycles, efficient deconstruction, and end-of-life management. To encourage greater implementation of circular construction, training and education is paramount.

The shift toward circularity is a pressing need but remains a legal, logistical, and economic challenge. By changing the perspective on materials and acknowledging their continuous economic value, the built environment becomes a depot of materials that can be effectively reused. The main challenge is in matching supply and demand. Without accurate information, value-based decisions cannot be made. Notwithstanding the efforts to promote reuse, there is still a need to connect these developments with fundamental research that can assist in bringing a clearer understanding of the process of reuse. This involves not just expert knowledge on existing buildings but also knowledge-sharing on possible outcomes of reusing materials in new projects. Closer cooperation between academic researchers and industry platforms will have a tremendous influence on the future of circular construction.

While the climate emergency is worsening at a rapid pace, the construction industry is known for its traditional inertia in terms of innovation. There is a need to accelerate the application of circular principles, and this can only be done through close and permanent collaboration between academia and the public and private sectors. There is no time for ineffective research developments: novel implementations must be tested rapidly to privilege solutions that are economically viable. This paper illustrates the need for collaborative developments between academia, the public sector, and private companies.

This paper presents many ways for improving a circular economy in AEC. Our findings indicate the promising potential of digital technologies and stakeholders' networks to better capture data on building products and methods for extending their life cycle. Stimulating demand by spreading awareness remains a critical step in creating a viable market for circular construction.

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