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RESEARCH ARTICLE

Materials libraries as knowledge tools on the path toward a circular construction industry

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Abstract · Extensive factual and target knowledge about the need for a turnaround in the construction industry and a circular building sector must be effectively communicated to stakeholders and translated into practical knowledge. Materials libraries that are geared toward circularity and embedded in supra-regional networks have the potential to positively influence teaching, science, and practice: through the direct haptic experience of a real sample collection of building materials and associated research-based information databases in digital, location-independent form.

Materialbibliotheken als Wissenswerkzeuge auf dem Weg zu einer zirkulären Bauwirtschaft

Zusammenfassung · *Umfangreiches Fakten- und Zielwissen über die Notwendigkeit einer Bauwende und eines kreislauffähigen Bauwesens muss in Handlungswissen übersetzt und den Stakeholdern wirksam vermittelt werden. Materialbibliotheken, die auf Zirkularität ausgerichtet und in überregionale Netzwerke eingebettet sind, können eine positive Wirkung auf, Lehre, Wissenschaft und Praxis haben: Sie ermöglichen das unmittelbare haptische Erfahren einer realen Mustersammlung von Baumaterialien und bieten Zugang zu dazugehörigen forschungsbasierten Informationsdatenbanken in digitaler, ortsungebundener Form.*

Keywords · *materials library, building materials transition, turnaround in the construction sector, circularity, circular construction industry*

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Challenges of a materials transition

The European construction industry is responsible for half of primary raw material consumption, half of total energy consumption, and a third each of water consumption and waste generation (EC 2019). By processing raw materials into composite materials, the construction industry also comes up against insurmountable limits when it comes to the disposal and recycling of materials. Most of the materials and their constructive use in existing buildings are not designed to be (re)introduced into the biological or technical cycle. The existing building stock has a correspondingly low, even declining, circularity rate (Circle Economy Foundation 2024). A materials transition in the construction industry, based on technological innovation and the use of recyclable building materials, is overdue. Rather than concentrating on a small selection of conventional material groups, a constantly expanding variety of circular materials must be approved for the renovation, redensification, and expansion of our built environment, so that current building practices do not drive climate change, but rather combat it. The need for research and education in the field of building materials arises primarily from the fact that the construction industry must move toward a responsible use of limited resources (Hebel et al. 2023, p. 69).

The tasks of implementing a building materials transition and shaping a sustainable construction industry that does not harm the climate, the environment, and living beings require the involvement of a wide range of actors in research and practice, such as architects, builders, project sponsors, building materials manufacturers, and teaching institutions. Moreover, political actors should be involved, as in the 'Climate Pact' of Karlsruhe's universities and city administration, which aims at a targeted thematic orientation of teaching, research and management, and local networking (KAT 2021).

What do these actors need to advance the materials transition? One of the most fundamental levers is knowledge: about the status quo in the construction industry, about risks and problems associated with the production, use and disposal of some established building materials, and, above all, extensive knowledge about available materials and their properties and possible applications.

Against this backdrop, our article discusses the potential of materials libraries to make a significant contribution to promoting a knowledge-based, productive dialogue on sustainable materials transition. The presentation, discussion, and evaluation of the – revisited – concept of the materials library as such, illustrated by the example of the KIT Materials Library, is at the core of this article and leads to the following key questions: How can an encounter with such a library inspire the development of new ideas, both among practitioners in the construction industry and among university students, who leave a collection enthusiastic about the materials they have experienced? How can the libraries' informative power encourage experts, political decision-makers, students, and users to rethink the building sector?

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What is a materials library?

In analogy to a conventional library, the specific type of a materials library as a non-commercial pedagogical place for the exchange and storage of knowledge offers extensive independent information through the systematic collection and display of building material samples "from an archival, economic, and synoptic point of view" (Ewert and Umstätter 1997, p. 10, translated by the authors). Its aim is to make materials comprehensible in several ways by providing information in data sheets about their application possibilities and physical and chemical properties (e.g., insulation capacity, density, combustibility, and corrosion resistance) as well as about life cycles and environmental impacts of the materials, such as the extraction of the resources needed, and other key figures. As a memory organization (Brandtner 2011), it provides scientific knowledge from publicly available sources about a variety of current building materials, both on site and online. The main target groups are students and teachers, planners, craftsmen, multipliers, and decision-makers in the construction industry, to whom it offers a platform for critical discussion and to strengthen their ability to make judgements.

Yet, the concept of the materials library is also, and explicitly, about the materials' aesthetic and haptic qualities by offering its visitors a physical experience on site that goes beyond mere reading: By looking, touching, smelling, and even listening, one can find out how rough or smooth, light or heavy, shiny or matt, fragrant (or not), sound-absorbing or sound-reflecting a material is; even the true color of a material cannot be faithfully reproduced in print or digital media. Encountering the original creates an incentive to do one's own research, as these libraries, analogous to museums, "offer an effective way to learn" and "help bring change and development to communities" (Schiele 2018, translated by the authors).

Dealing with biases

University materials libraries should basically follow a public library's commitment to neutrality, but at the same time be aware of its fundamental impossibility (Leyrer 2019) and therefore create transparency by explicitly addressing and dealing with unavoidable biases. This includes

- presenting a wide range of materials of general interest, limited by spatial conditions, which should be supplemented by information on the research focus of the operating institution;
- being aware that users can be tempted to use primarily the materials presented;

Fig. 1 Interior view of the KIT Materials Library. *Source: KIT Department of Architecture (Copyright: Zooey Braun)*

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- refraining from advertising specific branded products and factual, restrained reference to manufacturers in favor of a sober presentation of materiality and properties;
- knowing that available data can only be partially recorded and updated (e.g., disposal costs);
- striving for impartiality with regard to ethical evaluation, expressed through the display of materials that are considered more environmentally friendly (e.g., clay building boards) as well as ecologically rather questionable materials (e.g., polystyrene);
- being aware that any on-site offer is subject to access restrictions in terms of travel distance.

Case study: the KIT Materials Library

The KIT Materials Library (Fig. 1) is not a static facility with a constant inventory, but rather responds to developments and needs in research and practice. It is in a constant process of evaluation, expansion, and reorganization, with an ongoing search for building materials that could potentially be added to the collection. These can be marketable materials from manufacturers or newly developed materials (including those from research institutes) whose evaluation has not yet been completed.

The library shows a wide range of 'materials' in the form of panels, profiles, tiles, rods, mats, or granules that allow a certain freedom of interpretation and use. In principle, most of the materials on display could also be called 'products', as they are usually also available as products in DIY stores. However, the term 'material' is preferred since a 'product' is often associated with a very specific use or manufacturer.

A material may be considered obsolete if it can be replaced by alternatives with better properties or if it is no longer used for various reasons. In these cases, however, careful consideration is given to whether keeping it in the collection is useful for (namely historical) research or comparison purposes.

Materials selection

This library does not claim to be complete, since it aims to be an open institution that is constantly evolving. The presented selection is not arbitrary as the collection consists on the one hand of widely used, established, or traditional building materials that have been rediscovered and reinterpreted using modern technologies, and on the other hand of new alternative building materials made from renewable and secondary raw materials.

The information provided free of charge on site and online leads to a pooling of expertise in the field of architecture and the use of building materials. Convenient and ubiquitous access to the content makes it easier to engage with sustainability-oriented material alternatives, which can ultimately contribute to a circular construction industry if the exhibits are pure, reusable, or recyclable. The definition of a sustainable material includes, among other things, the renunciation of environmentally harmful practices in raw material extraction and the avoidance of hazardous substances in the manufacturing process, culminating in pure building materials that can circulate endlessly in the technical or biological cycle.

The materials in the library are classified into four categories and presented systematically, subdivided into material groups and subgroups (Fig. 2): organic-biotic, organic-fossil, inorganic-mineral, and inorganic-metallic building materials.

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Although also collecting conventional building materials, the KIT Materials Library focuses on materials that can either be kept in the biological cycle of composting (typical example: lightweight reed panels) or in a technical cycle (typical example: pure metallic materials such as copper) of various recycling processes. Another focus is on materials that consist of secondary raw materials from a second or even third use cycle, such as panels made from recycled waste glass.

Knowledge transfer

The targeted examination of resource scarcity and a climate-friendly transformation of construction is intended to make this library, integrated in a nationwide network, an international focal point for corresponding research and teaching (KIT 2024). The decision to present 'materials' rather than 'products' limits the possibilities of application-orientated advice and the recommendation of specific commercially available building materials in the sense of a direct knowledge transfer from science to industry. However, this risk is accepted as the focus is on a knowledge-based examination of the origin and resources, the manufacturing process, and application recommendations as well as the possibilities for subsequent use.

In the KIT Materials Library, the materials are presented in a standardized and abstract way on anthracite-colored sample panels (Fig. 3). This places the material itself in the foreground

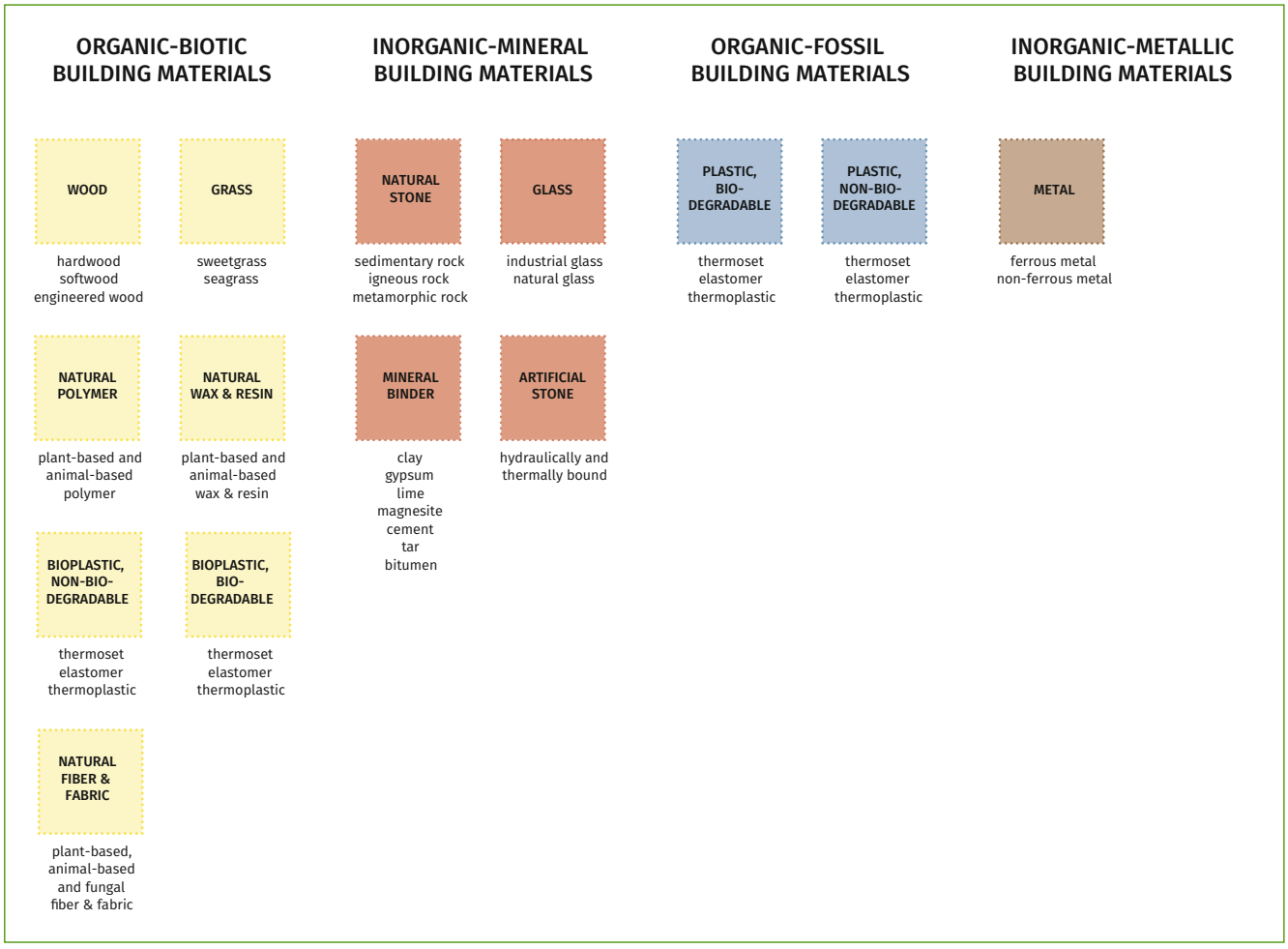

Fig. 2 Material classification of the KIT Materials Library and the Materials Library of German Universities (MDH). *Source: KIT Department of Architecture*

and detaches it from its usual function in construction, opening up spaces for inspiration and interpretation. Specialist books and journals complement the offer on site, and media stations link the analogue with the digital cosmos.

A materials library cannot directly influence to what extent and where it is integrated into design teaching processes, but it can help raise awareness of materials and the consequences of their selection. This approach aims to re-establish the importance of materiality and haptics in architectural design, akin to Bauhaus principles (KIT 2024). According to the authors' observations, these were neglected in architectural teaching for a longer period of time, despite their essential importance in fostering a comprehensive understanding of materials. During this time, prospective planners primarily relied on digital research instead of seeing and experiencing a material in its real form.

Beyond the campus

The library's collection is displayed on the university campus in dedicated premises, where samples can be borrowed by students and other interested parties and used as source of inspiration or for visualization in the design process. Although the library is open to all interested visitors, not all potential target groups – especially those from outside the university – find their way to it. Therefore, various ways of disseminating its contents have already been tried. Extracts from the collection are regularly presented at construction trade fairs, at forums of the building material, furniture or design industry, in art and design museums, or at political events aimed at setting the course and establishing sustainable strategies for the construction industry.[1] At these events, the contents of the library are conveyed in a direct haptic and visual way in order to open up the discussion about the materials transition in building practice to a broader public. The type of a travelling materials library (see below) can also point out new perspectives and needs for action for the 'stationary' materials libraries and effectively communicate their contents to the public. The different formats are mutually beneficial and, to

1 Three examples of exhibitions: (1) 'BAU 2023' in Munich, Germany; (2) 'IBA'27 2023' in Backnang, Germany; (3) 'Junge Kunsthalle Karlsruhe' 2024 in Karlsruhe, Germany.

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Fig. 3 Selection of material samples from the KIT Materials Library. *Source: KIT Department of Architecture*

a certain extent, make it possible to compensate for the existing biases of such libraries.

Prototypical examples already built in a university context, such as the RoofKIT project (Boerman et al. 2023), winner of the 'Solar Decathlon Europe' 2021/22 competition and today a tangible demonstrator of interdisciplinary, circular, and future-orientated construction, show a radical rethink in the construction industry. During its design process, the KIT Materials Library served as an advisory institution for the selection of materials. For its part, it benefited from this project as students discovered alternative building materials, or reinterpreted established ones, and reported their results back to the library.

Digital and physical networking

Since the libraries have limited space, they must restrict the number of physical samples, which requires a cooperatively organized and far more comprehensive digital offering. In this way, they can offer a wide range of opportunities for subject-specific and interdisciplinary exchange and expand the range of information available at each participating university in order to overcome boundaries in materials science.

To this end, KIT, the University of Wuppertal, and the Münster School of Architecture, founded the 'Materialbibliothek Deutscher Hochschulen' initiative in 2022, which aims to develop into a Germany-wide network with international appeal in the coming years. MDH's stated aim is to share knowledge and expertise and to provide scientifically researched information that contributes to responsible, socially relevant, and future-oriented planning and teaching (Hebel et al. 2023, p. 69). The data shared within the network is fully documented in the form of product-independent data sheets and made available to the public for research purposes; only publicly accessible sources are cited.[2]

2 Such as 'Ökobaudat' (BfWSB n.d.) or 'Ökologisches Baustoff-Lexikon' (Linden and Witten 2024).

The establishment of a supra-regional network is intended to create a meaningful link between individual research focuses and counter the limitations regarding type and quantity of materials offered individually. Planned linking of material data records with the existing university library catalogs aims to improve findability, so that in future the lending of material samples will work in the same way as the lending of printed matter and they will be placed on an equal footing with other catalog finds; e.g., entering the search term 'oak' will not only bring up literature on the cultural significance of this tree species or on forest dieback but also a cross-reference to the corresponding material sample 'oak.' In this context, interlibrary loan can also be considered as a future development component of the initiative.

Excursus: related materials collections

There are similar institutions from which the materials libraries described here – namely that of the KIT or the 'Materialarchiv' founded by Swiss universities and museums – can learn from, or which in turn can benefit them. In academic and scientific contexts, for example, collections of artefacts are frequently stored in inaccessible archives, hidden from public view. They are often only used for research purposes or presented in selected parts. Such collections exist in particular in natural science disciplines such as biology, botany, zoology, geology, medicine, and mechanical engineering (Brüning and Raulff 2021). Historically anchored collections, such as the 'Werkbundarchiv' in Berlin, museums, or smaller private collections, draw attention to a specific era of design practice through a variety of objects and link them to current topics.

There are further organizations that are comparable to the aforementioned materials libraries, but have a different focus. Examples include 'Raumprobe' in Stuttgart, which connects architects and building owners with construction companies and material manufacturers for commercial reasons. Others include databases with an associated warehouse for recycled building materials such as 'Concular', or 'Rotor DC', or warehouses for used materials without databases such as the 'Haus der Materialisierung' in Berlin. DIY stores – as 'materials libraries to go' – also offer inspiration both physically and digitally, but have a relatively rapidly changing product portfolio and commercial motives, and obviously lack scientific reappraisal.

The range of materials libraries is complemented by printed collections, such as the compendia by Peters (2011, 2019) or reference works like 'Atlas Recycling' (Hillebrandt et al. 2018); they also provide well-founded, researched information and can inspire design and encourage critical reflection.

Advisory potential for society and politics

Technology assessment examines the interplay between scientific and technical advancements – such as in building materials –

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and the social phenomena they influence, e.g., their adoption by building owners and craftsmen. It identifies both the potential benefits and risks, and provides actionable recommendations based on these insights. On the one hand, the advisory potential of materials libraries provides social groups (students, craftsmen, planners, political decision-makers) with an opportunity for training and further education, whose feedback can be incorporated into changes in production and use. On the other hand, they provide a basis for further studies (e.g., in the field of materials sciences, manufacturing processes, and economic studies) and represent a large pool of knowledge production that can satisfy research desiderata: for example, the question of how and why a change in materials or manufacturing processes has occurred historically; what ecological footprint individual materials entail; what impetus can arise in the field of policy advice in terms of regulatory measures or on the way to reducing path dependencies (ecological innovation, non-ecological exnovation); what role lobbying has played in enabling certain materials and technologies to establish themselves on the market; and what range of experts should be involved in development and market introduction.

The libraries' educational and participatory approach of providing and critically evaluating information on the raw materials of building materials and their manufacturing processes, use, emissions, and potential for reuse in a plain, open, and non-profit manner can help prevent serious economic and health risks. The dangers of asbestos fibers, whose harmful effects on health were known in research long before appropriate countermeasures were taken and its use was banned in the construction industry, can serve as an example.

A tool for advice: the travelling materials library

The need for communication and advice on materials for the transformation of the construction industry is addressed through formats that, like a 'scientific hawker's tray', actively go out into the public and present thematically focused exhibits as an independently operating platform. Such a project was realized in cooperation with the 'Karlsruhe Real-world Lab for Sustainable Climate Protection' (KARLA) in the form of a travelling materials library (Fig. 4). An illustrative collection of samples of façade insulation materials, accompanied by fact sheets on technical and economic performance, enables a dialogue with the urban community at open-air events about the pros and cons of ecological alternatives compared to conventional insulation materials. Notable were the very specific and practical enquiries from the participating building owners, who were open to rethinking construction practices and less concerned with physical metrics (e.g., heat transfer coefficient) than with costs for installation and future disposal, the potential loss of usable space due to increased insulation thickness, and the availability of skilled craftsmen.

Fig. 4 The travelling materials library in Karlsruhe, Germany. *Source: KAT/KIT*

This illustrates both the need for this application-oriented type of information and the different demands placed on the exhibits, depending on the library's clientele. It also highlights the role of political guidance: Ecologically more acceptable materials are more likely to be adopted despite their possible disadvantages if environmentally harmful and climate-damaging materials become more expensive (e.g., through CO_2 pricing) or if changes in building codes compensate for the disadvantages. Also, the need for a detailed differentiation of the advantages and disadvantages of different materials becomes clear (Böhm 2023).

Experiences and findings

Against the backdrop of climate change, scarcity of resources, and the related efforts toward a materials transition, the use of materials libraries has changed fundamentally and is currently experiencing a renaissance in teaching and research. While in the past, the focus was primarily on design aspects and surface qualities of materials, today there is a particular and growing demand for information about the environmental impact or recyclability of materials. As an interdisciplinary space for knowledge exchange and practical discussion for all kinds of professionals to experience, touch, and understand building materials, it should not be underestimated and cannot simply be replaced by the internet.

The positive evaluations of the research seminars offered in the KIT Materials Library demonstrate the importance and quality of such an institution. The number of instances in which material samples are included in exhibitions, design presentations, and courses at architecture departments can also serve as an indication of the plausible benefits of such facilities. Other criteria can include the external demand for visits or for introductory courses on using such a facility, or the total number of visitors to the physical materials library and the digital database.

The widespread revival of such libraries could eventually pave the way for commercial equivalents, as end users of building materials and planners who commission them are also increasingly

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asking critical questions about the type of materials used in their property. For them too, the information content about the product range and the professional training of sales staff must be expanded.

Supported by sites that can be experienced both through the senses and as a meeting place, cross-fertilization, interdisciplinary action, teaching and research as well as learning from each other are central elements of an activating process in which a wide variety of actors must participate and contribute in order to make the materials transition in the construction industry a success.

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