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RESEARCH ARTICLE

A Decision Support Model for Building Material and Component Reuse in the Context of Circular Buildings

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ABSTRACT

Construction activities cause significant environmental impacts such as waste generation, pollution, resource consumption, and land use, which are expected to increase with global construction demands. To mitigate these environmental problems, the circular building occurs as an emerging concept depending on in the circular economy, which aims to minimize waste and redefine the "end-of-life" concept by reducing, reusing, recycling, and recovering materials. The reuse of building materials and components (BMCs) from existing structures represents a crucial strategy for achieving circularity in the built environment. Within this framework, design plays a key role. However, designing with reclaimed BMCs remains complex due to non-standardized dimensions, uncertain geometry, and insufficiency in accurate and reliable digital data regarding damage conditions, leading to limitations in quality, cost, and timing etc. There are knowledge-sharing platforms such as the Building as Material Bank Project and Madaster provide material passports containing information on material origin, performance, environmental impact, and recyclability. Despite these platforms, reuse implementation still remains limited, labour-intensive and technically demanding. Addressing these research gaps, this study focuses the research questions as: How can architects take design decisions effectively for reusing BMCs?; How can architects decide the best matching donor for BMCs while preserving design decisions and aesthetic considerations? To answer these questions, this study develops a Decision Support Model for Building Material and Component Reuse (DSM_BMCR) guiding architects in making appropriate design decisions aiming to reuse of building materials and components. DSM_BMCR is tested through a façade cladding design scenario using Multi-Criteria Decision-Making Methods integrated into the model. The results show that DSM_BMCR is effective in producing transparent, data-driven, and iterative decisions. Future integration with Building Information Modelling, digital twins, and AI-supported systems is expected to enhance process optimization and real-time material matching, strengthening its potential as a decision-support tool for circular buildings.

Keywords: Circular building, Building material and Component reuse, Decision support model, Circular architectural detailing, Architectural detailing with reclaimed building material and component

1. Introduction

Construction activities cause various environmental impacts such as waste generation, pollution, resource consumption, land use, etc. Construction activities are one of the largest waste streams that are consistently produced in urban areas, and responsible for 38.4% of total waste generation in Europe [1, 2]. It also requires a significant number of resources during the construction of a building, which constitutes approximately 50% of all extracted material. It is predicted to nearly double between 2017 and 2060 [3, 4]. So far, aiming to eliminate all these environmental impacts, there have been established various concepts and approaches, such as sustainable buildings, green buildings, zero-energy buildings, energy-efficient buildings, etc. Recently, the concept of "circular buildings" has been asserted, which is

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based on the circular economy. The circular economy (CE) is a system approach that enables materials and products keeping in circulation in the production system [4]. CE aims to avoid waste generation, and to change the 'end-of-life' concept by reducing, reusing, recycling, and recovering materials in the process of production, distribution, and consumption [5]. The design is the key process to implement a circular transition in construction industry [6]. There are several circular building design strategies in literature. Design for deconstruction and design for disassembly constitute fundamental parts of these strategies. Accordingly, reuse of building materials and components (BMCs) from existing structures is an important strategy to create a circular system in the built environment [7]. However, designing with reclaimed BMCs is a complex and challenging issue due to the various constraints, such as the non-standardized nature depending on the predefined dimensions and geometry and the lack of adequate information about the damage status, which causes quality limitations, cost, timing problems, etc. [8–11]. Also, most of the existing buildings don't meet the criteria of Design for Deconstruction and Design for Disassembly, which decrease the efficiency of reuse activities of BMCs. And how to deal with existing building stock, which is not designed for deconstruction, is an important issue. Therefore, most of the existing buildings consist of composite materials, which makes the reuse process more challenging due to the contamination of the BMCs, which mitigates the quality of the reclaimed product. Therefore, the nonexistence of relevant supply chain and logistical processes is another important obstacle against reuse activities [12]. There are some knowledge-sharing platforms aiming to create a network among stakeholders and material passports, which present data for different construction materials, products, and buildings, such as origin, performance, environmental impact, and recycling information, etc. [12, 13]. These can be exemplified as the "Building as a Material Bank" (BAMB) Project, Madaster (2017), Concular (2020), and Platform CB'23 (2022) [13]. However, scarcity of established procedures for producing sufficient, accurate, and trustworthy digital information for the characterization and evaluation of reclaimed materials for reuse is an important obstacle [7]. Although there are some existing digital platforms that establish the required contact between demand and supply for reclaimed building components, the supply and demand in the expanding secondary materials and products market are still not sufficiently matched by digital platforms for circular construction [14].

Material passports are important tools to supply circularity in the construction industry in which products are designed to be a part of the constant recovery and reutilization process by setting technical metabolism by imitating natural metabolic cycles [13, 15]. Adding to material passports and sharing platforms, digital technologies, or in other words, Industry 4.0 technologies, are accepted as essential components for the transition to a circular economy for the construction industry [16]. Building Information Model (BIM) is a widely accepted emerging digital tool that enables collaborative working and decision-making across different disciplines and stakeholders and supplies integration between the design and construction process. Digital twins, which refer to digitally produced replicas of physical objects, are also a promising technology for the construction industry in terms of supplying circularity [12]. The other examples can be sorted as Rotor, Cycle Up, and Baubüro [16]. Such innovative platforms are crucial initiatives for enhancing reuse activities, as they are important dynamics of circularity. However, despite the existence of various platforms supplying data about finding an appropriate match among different stakeholders, such as architects, contractors, facility managers, certifiers, etc., it is still more than an issue. Globally, implementation of these initiatives has not been successful yet in the construction industry. However, digital transformation can contribute to finding solutions [17]. In this context, emerging research areas such as artificial intelligence-based solutions, matchmaking algorithms for supplying recovered materials, and extended reality currently attract the attention of researchers. Hence, material recovery stays labour-intensive and challenging due to technical difficulties, such as measuring and cataloguing the material to be recovered manually. The process is complex and presents numerous technical challenges. Due to such underlying reasons, to apply circular strategies broadly in construction practice is a challenging issue.

Selecting appropriate BMCs for a specific purpose is a complicated, laborious, and costly process due to the large number of available materials and the complex relationships among selection parameters. The conventional way of design is also time-consuming because of the complexities involved in the reuse and reclamation process of BMCs [16, 17].

Therefore, although architects recognize the relevance of the circular economy, they often lack the methodological and practical expertise needed to incorporate circular principles effectively into their design processes [18]. Given that current construction approaches are still highly linear, substantial shifts in both design and implementation processes are required to advance toward mature circular systems [19]. In the literature, there are different studies addressing the reuse of reclaimed building materials and components relating to digital technologies and matchmaking algorithms. Wu et al. [20] proposed a workflow that generates and optimizes the layout design of floor tiles, aiming to minimize the material waste rate within BIM and parametric environments. De Wolf et al. [17] presented a digital circular workflow designed to coordinate the material "matchmaking" process by systematically connecting reclaimed-material supply with project-specific demand. Järvenpää et al. [21] proposed matchmaking software for production system design, which enables resource allocation. Menny et al. [14] defined a policy-oriented digital matchmaking model that supports stakeholder coordination. Tomczak et al. [10] developed matching algorithms for reclaimed elements, and the optimization framework relies primarily on geometric and environmental parameters. However, in literature, there still remains a need for a holistic approach that supports architects in selecting reclaimed BMCs in ways that align with both technical constraints, such as reuse-oriented performance parameters, and architectural design objectives as aesthetic considerations. To addressing these research gaps, this study aims to explore the following research questions:

Research Question 1: How can architects take design decisions effectively for reusing of BMCs?

Research Question 2: How can architects decide the best matching donor for BMCs while preserving design decisions (aesthetic considerations, etc.)?

In this study, a design decision support model for reuse of BMCs (DSM_BMCR) is developed to address the research questions. The DSM_BMCR offers a framework to enable making effective design choices aiming to reuse BMCs, for architects. DSM_BMCR also aims to guide architects in navigating the complexities of reuse decisions while maintaining design stance. DSM_BMCR aims to increase the potential for reclaimed materials to be incorporated more systematically and used, thereby supporting the transition toward more circular construction practices.

The paper is organized as sections as follows. Section 2 presents an overview of the architectural design and detailing process, as well as architectural detailing using reclaimed BMCs, through literature review. Section 3 introduces the methodological approach of the study. Section 3.1 proposes a Decision Support Model for Reuse of BMCs and the stages of the proposed Decision Support Model for Reuse of BMCs are introduced. In Section 4, the decision support model is applied to a case study that depends on a developed scenario, as a proof-of-concept application. Section 5 discusses the results and is followed by the conclusions part in Section 6.

2. Literature review

The literature review section provides a brief introduction to the architectural design and detailing process. It also summarizes architectural detailing with reclaimed BMCs, focusing on the matchmaking process.

2.1. Architectural design and detailing

Designing is a problem-solving process that includes many constraints and requirements. It is aimed to meet these requirements through design solutions. In literature, numerous design approaches have developed over time. In the 1960s and 1970s, the design process was regarded as a highly rational and objective process; however, it is now recognized as a negotiation process involving several parties where individuals and systems interact in the exchange of knowledge and information that is frequently insufficient, inconsistent, incomplete, and incompatible [22]. Designing is also a continual process of selecting and organizing components to determine which are most essential and how each might contribute to the development of the new product. Ideas will unavoidably evolve as new possibilities are added or eliminated and as proposals are thought through and evaluated. According to Lawson [23], the design process as "... a negotiation between problem and solution through the three activities of analysis, synthesis, and evaluation" (Fig. 1). Design is also a process in which the problem and solution emerge together [23].

Analysis process is organizing and structuring of the problem, which involves exploring relationships, identifying patterns in available information, and categorizing the objectives. Synthesis is the stage where solutions to the design problem are produced [23]. Synthesis is also the process of reassembling components to create a meaningful 'whole' [24]. The evaluation phase is the critical evaluation of the proposed solutions according to the objectives

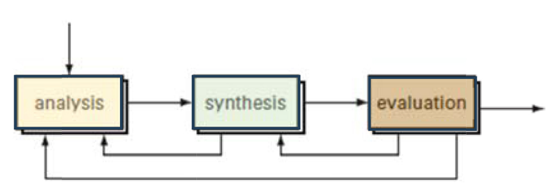


Fig. 1. A generalized map of the design process [23].

determined in the analysis phase. These processes are iterative, which means they don't progress in a linear form [23].

Architectural design is a unique and complex process that integrates alpha (morality and aesthetics), beta (logic and facts), and gamma (social and cultural values) sciences. Therefore, the architectural design process needs a logical, intellectual, rational review of the problem [24]. An architect is the only individual with authority and independence to develop design thoughts and ideas during the architectural design process [23, 25]. There are different architectural design approaches, such as conventional [23, 26–28], performance-based [29, 30] and evolutionary [22, 31] etc. However, there is no consensus or standardized way of working in practice among architects. But it is accepted that every architect has a "design stance," which is described as a set of strongly held beliefs and values of the architect. Throughout their life, an architect may maintain the same design stance [22].

The design phase is conventionally classified as a concept design and a detailed design. The concept design is the initial response of designers to the project brief. Outlines of function and form are produced in the concept design phase. Some designers consider also a "scheme design" phase. In this approach, the 'concept' represents the original design idea, while the 'scheme' expands on it by incorporating more practical and functional factors. However, these two processes have now been merged into the single stage "concept design," or "concept," in the majority of project designs. Tunstall [24] classifies design phase as scheme design and detail design. Detailed design, which is also referred to as 'developed design,' is the process of developing the concept design, in which the design is dimensionally corrected and coordinated, defining all the main components of the building and how they fit together. However, technical aspects of the design may require further development, design by specialists may not yet have been fully incorporated into the design, and it will not have been packaged for tender. Generally, the phrase 'technical design' refers to project activities that take place after the detailed design (or 'developed design' or 'definition') has been completed but before the construction contract is tendered or construction begins. The technical design phase covers developing the relevant information for the manufacture and construction of the building in RIBA [32].

Designing has been very closely connected with making (design and build) in the vernacular building production. However, design has become a professional activity with the industrialization and separated from making. Accordingly, the role of the designers has evolved from making the object to communicating to the people who will make in post-industrial design process. The communication is supplied through drawings. Architectural design is also the process of the accomplishment of an idea or resolving the requirements using communication methods such as drawings, plans, specifications, and models. The process of drawing and redrawing could continue until all the design problems are solved. The shortcomings of the design by drawing approach became increasingly apparent as the design process became more innovative and modern, especially in the field of architecture. It became clear that new methods of modelling the finished design were desperately needed if we were to keep separating designing from creating and maintain the quick pace of change and invention. Design process became more revolutionary and progressive, so the failures of the design by drawing process became more obvious, particularly in the field of architecture. It became apparent that if we were to continue separating designing from making, and also to continue the rapid rate of change and innovation, then new forms of modelling the final design were urgently required [23].

Due to the significant technological innovations in Information and communications technology in the past decades, there are developed various support tools for architects to generate different design choices, optimize the design alternatives, integrate solutions, corporate different actors in the process etc. even though these technologies are used by designers and the construction industry, there is still resistance to their complete adoption, due to the designers' perceptions that they are losing control over the design process. However, day by day, it becomes inevitably vital to harness these tools to be adopted the changing way of communication way in construction industry. So, it emerges a prominent research area finding an optimal way of control mechanism of architect in building production process [33]. The utilization of digital technologies which enhances the quality, productivity and safety is an emerging concept both construction industry and academia. Building information modelling (BIM), 3D printing, drones, virtual reality, artificial intelligence, and machine learning are some of the ways that digitalization the process of managing digital data and utilizing the potential of digitization in construction can be accomplished. BIM is an innovative information modelling technology which enables project information exchange and management in Construction industry [34, 35]. BIM is a wide spreading technology therefore It is becoming important that any technology produced in the construction sector is compatible with BIM. BIM is defined as "digital representation of the physical and functional characteristics of a facility" The output of Traditional 3D CAD model covers independent graphical representations of plans, sections, elevations and 3D views which are crated with the graphical entities such as circles, arcs, and lines. In case of any modification need of these graphical representations, all of them should be modified accordingly. On the other hand, a BIM proposes a collection of "smart objects" by integrating semantically rich information, including its geometric and functional aspects during its entire life cycle [36, 37].

2.2. Architectural detailing with reclaimed BMCs

Designing with reclaimed BMCs is essentially different from conventional design methods. In conventional design methods, the architects initially conceptualize the building's systems and elements and then defines the materials and components which provides essential performance properties. Thereafter architect usually supplies the relevant BMCs from existing construction market. In conventional design, the concept design process is not depended on the materials supply. However, the concept phase is influenced and driven by the available reclaimable BMCs from existing building stocks [9] which means architects should imagine different design parameters regarding reclaimable BMCs from existing building stocks and market availability while utilizing reclaimed components designing process with reclaimed BMCs differs from conventional design process in terms of [8, 9].

Before detailed design, it is essentially vital for the designers to determine the source of suitable building materials and components, which means that the reuse operations were restricted the to a market niche in mass production age [8, 38]. The usage of reclaimed BMCs increases the level of complexity of the Project [39].

There are also problems within the coordination of demand and supply of reclaimed BMCs, which means the reclaimed BMCs may not be supplied at desired time, in the relevant amount and dimension etc. Reclaimed BMCs may not be readily available in stock and performance properties may not be clearly known). This situation affects design and construction process creating a redesign process requisite with available reclaimed BMCs. Therefore, the reuse of BMCs often requires flexibility and change in the design approach and process [39]. According to Gorgolewski and Morettin [40], design process is highly affected by the supply of suitable reclaimed building materials. The decision for using of reclaimed BMCs be made early in design phase such as concept design stage. If the decision is left to detailed design stages there is possible to occur problems with the construction process and the cost [40]. To prevent this situation and eliminate possible problems, the solution may be to starting the design process by detailed research on available reclaimed BMCs in the market and shape the design accordingly [39].

There are different challenging issues on reuse of BMCs such as current European regulatory uncertainties which also causes increases in construction process time, costs [9]. The factors such as longer time need for demolition/deconstruction and engineering, uncertainties regarding to product documentation of reclaimed BMCs makes the construction process more complex and costly [41]. There are also different constrains such as performance assessment of reclaimed BMCs and prejudices of end users' about the reclaimed BMCs' quality. Reclaimed BMPCs should supply relevant performance criteria's according the current standards, regulations etc. both structural and non-structural ones [9].

The stockpiled materials may constitute a substantial supply of resources [42]. For instance, in building industry; beams, columns, claddings, bricks etc. various structural and non-structural building elements can be reclaimed from existing buildings to be used in different building [9]. Therefore, the data is also main element which directly affects reusage of BMCs. During reuse there is a need knowledge about various data such as structural properties which are affected by previous function and life of BMCs, previously applied assembly methods, geometrical properties etc. To guarantee that repurposed materials may be used just as well as standardized materials, the time and sequence of production and the transfer of recovered materials for assembly are important factors [11]. All these data should be managed and variables which cause non standardization should be taken in consideration during design process which makes the process more complicated compared to conventional design. Accordingly, different initiatives have set various online databases and platforms which supplies information about demand and supply of reusable BMPC' such as Roto, Lendager, Superuse Studios, Salvo Ltd [9], OPALIS etc. Utilizing reclaimed components and materials has a big impact on both the "process" of building design and construction. Conventional design procedures may not be best suited to maximize material reuse [40]. Design optimization strategies are also employed when there is a wide range of potential designs and unclear relationships between parameters and characteristics. Material matching algorithms are effective tools which used for design and construction process of buildings to detect the appropriate components from existing (donor) buildings for reuse. These algorithms employ a variety of potential optimization objectives depending on non-defined ideal matching. These matches' effectiveness is evaluated according to different variables such as waste, logistics, and structural application. Matching optimization tools can play prominent role in integrating recovered BMPCs to new projects. However, Informed industry and technology assistance to deal with the non-standardized nature of these materials will also be necessary for a wider integration of recovered BMPCs into new construction projects [11]. Match making between the designed products with in parallel to raising attention to the importance of digitalization to enhance reuse activities supplying circularity in construction industry, Matchmaking process for reusable building component and the new building is an emerging research area in construction industry. Accordingly, Huang et al. [43] proposed a Grasshopper-based tool for reuse of structural elements of buildings on linear timber elements. De Wolf et. al. [17] proposed a workflow for digital transformation for reuse of building materials. Workflow is comprised of five-step as Detection, Disassembly, Distribution, Design and Deployment. The workflow they proposed intends to supply digital integration to Matching process of supply materials (reclaimed) with demand (appropriate construction projects) by connecting different stakeholders. They propose to use machine learning, computer-vision (CV) algorithms for detection. For dissemble proposes reality capture, scan-to-BIM and, CV to enable robotics and extended reality (XR). For distribution digital product passports is offered. For design processes Artificial Intelligence (AI) and computational design algorithms is used for designing and matching the design with reclaimed produce. For deployment they offer the usage of "…Use subtractive and additive manufacturing to integrate bespoke reclaimed elements, assembling them in new constructions with XR techniques…" [17]. Accordingly, Menny et al [14], proposed a matchmaking model for circular for construction to overcome the existing challenges related the data supply chain and coordination among stakeholders in French. Tomczak et al. [10] compared usage of mathematical algorithms (greedy algorithm, linear programming, MaxBM) in replacing an existing structural element (beams) with the reclaimed ones. Gordon and Wolf [17] conducted a study to reveal the efficiency and practicality of material matching optimization techniques through a case of a geodesic dome. Olumo and Haas [44] proposed an optimization framework for new and reclaimed building materials.

3. Methodology

Building design is a complex process that involves various decision processes among a variety of design aspects. In terms of circularity, design objectives may also be conflicting, which makes the decision maker's role important to find the solution for the design problem. Decision support models can a play a vital role in determining optimal design alternative which meets the design objectives, and also ensure to conduct the decision-making process in more efficiently, productively and effectively [45, 46].

In this study, Decision Support Model for Building Material and Component Reuse (DSM_BMCR) was developed to take appropriate design decisions aiming to reuse of building materials and components.

DSM_BMCR is applicable during design of new building; renovation of existing buildings and modification of existing buildings. DSM_BMCR is intended to be used by architects who are decision makers during detailing process of buildings. DSM_BMCR supplies architect to decide best matching donor building materials, components and parts, while preserving the design decisions (aesthetical considerations etc.) during the design process. Multi-Criteria Decision-Making Methods (MCDM) supplies an important facility for decision making to find the optimum decisions through design, materials, and manufacturing processes [47]. MCDM were integrated into the model to support structured evaluation and prioritization among alternatives. The flow diagram of the DSM_BMCR, which covers two basic level of hierarchy as component and material, is presented in Fig. 2. In this section the phases of proposed DSM_BMCR are explained in detail. Before starting the DSM_BMCR, Preliminary Phase is completed.

3.1. Preliminary phase: Determination of building material/component to be detailed (BMCTD)

Conventionally, information about building used to be obtained from the sources such as building blueprints, datasheets, photographs etc. However, these sources don't supply satisfying information about the usage of building material types and its volumes [48]. Today there're different data sources suppling detailed information on BMCs such as Product Datasheets, Project Specifications, Environmental Product Declarations etc. Various technical information such as dimensions, composition, performance characteristics, and environmental impact enables through these data sources [7, 49]. In this process the project (BIM output, blueprint etc.) of recipient building is examined and accordingly Building

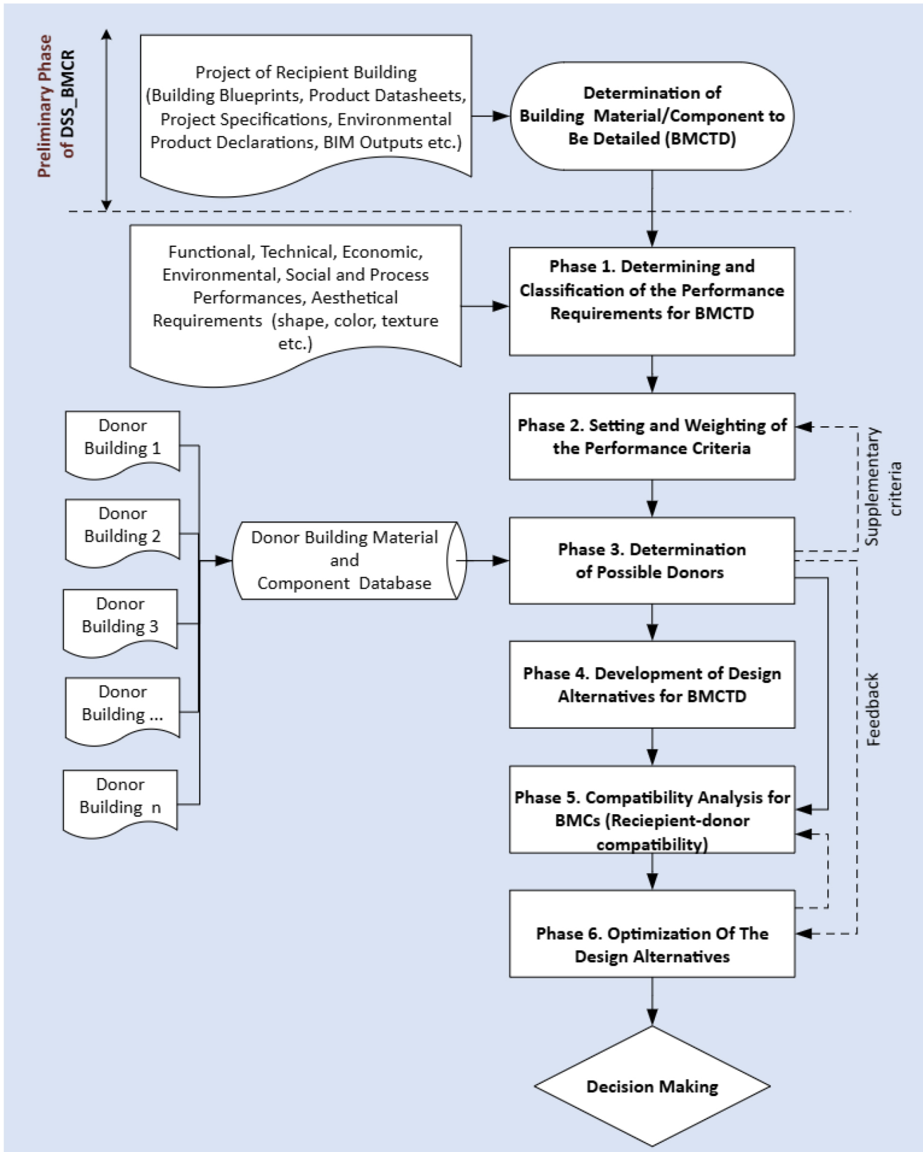


Fig. 2. Decision support model for building material and component reuse (DSM_BMCR).

component to be detailed (BCTD) is determined. After this Preliminary Stage, Phase 1 is applied.

3.2. Phase 1. Determining and classification of the performance requirements for building material/component to be detailed (BMCTD)

There are various parameters affecting building design decisions such as atmospheric effects, mechanical properties, material properties and user's preferences etc. These parameters are grouped as performance requirement. According to Lützkendorf et al. [50], there are six major performance categories for buildings as functional, technical, economic, environmental, social and process performances [50]. The users can also define various performance requirements according their design stance which may depends on the site analysis and designer's cognitive heuristic. This feature supplies flexibility to the users of the DSM_BMCR. In this study it is referred as aesthetical performance. Aesthetical performance may cover physical properties such as shape, colour, texture etc. The performance categories which are proposed to be used for DSM_BMCR is presented in Table 1.

In this phase, initially the performance Requirements for BMCTD are determined by using the data sources such as building regulations, building standards, building specifications, construction contracts, and other special condition, user needs etc. by the

Table 1. Description of performance categories [Adapted from Lützkendorf et al., 50].

Performance Categories	Descriptions
Functional Performance	Functional performance of a building covers the considerations such as the surface and space program's appropriateness for the intended use, accessibility and barrier-free design, flexibility to accommodate evolving user needs and applications, etc.
Technical Performance	Technical performance describes structural, physical and other technical features and characteristics such as load capacity, maintenance and revitalization capability, suitability for the planned service life, fire resistance, control of noise transmission, heat insulation of building shell, etc.
Economic Performance	Financial expenses covering designing, building, operating, maintaining, demolishing, or disposing or during a facility's life cycle are referred to as cost and financial performance.
Environmental Performance	Describes and assesses the building's features and characteristics relevant to its impact on the environment on both the local and global scale.
Social Performance	Social Performance covers health, comfort and safety of users, visitors, residents and neighbours of the building. In addition, the building's cultural value is also usually assessed.
Process Performance	Process Performance in Strategic Planning, Design, Construction, Operation, Maintenance, Management and Use
Aesthetical Performance	Aesthetical Performance covers the performance requirements which is determined according the design stance and cognitive heuristic of architects, which may cover physical properties such as shape, colour, texture etc.

users (architects). The users can also define various performance requirements according their design stance which may depends on the site analysis and designer's cognitive heuristic. This feature supplies flexibility to the users of the DSM_BMCR. The aesthetical performance requirement can be detected by using the drawing architectural conventional sketching method. The sketches may both prepared in conventional designing methods, computational drawing tools.

In this phase secondly the performance requirements are categorized as rigid and soft categories. According to Farag [51], performance requirements of materials are classified as rigid and soft performance requirements. While rigid requirements refer the obligatory or accurate ones, the soft refers the requirements which can be negotiable. Rigid requirements are used for the initial screening of material options to avoid the unsuitable options [51]. While Rigid Requirements are aimed to increase the applicability of the developed detail by eliminating unsuitable options, the soft Requirements are aimed to enable the users (architects) flexibility in decision making process for reusage especially in terms of aesthetical consideration in this decision support model.

3.3. Phase 2. Setting and weighting of the performance criteria

In this phase, the performance requirements that is determined in Phase 1 are converted into measurable performance criteria. These measurements can be in the form of a relative evaluation; positive/negative or in the form of measurable units (m^2, lx etc.). Weighting factors for the different Requirements are determined. Requirements are weighted by the user. There are various methods for comparing and ranking alternatives such as Weighted Property Method, Analytic Hierarchy Process and Digital Logic Method etc.

3.4. Phase 3. Determination of possible donors

In this Phase the possible donors are detected. The possible donors are searched on a database according to as rigid and soft performance criteria values. After finding the possible donors, supplementary criteria are determined according to different properties of possible donors, such as distance of the BPCTR to project site, available time of the BPCTR, cost of BPCTR etc. The Supplementary criteria are also Weighted by the user. The An evaluation process is conducted according the Weighted of the Performance Requirements and Supplementary criteria. Most suitable possible donors are determined.

Finding the materials and products (matchmaking) which meet the required properties for any product to be designed is accepted an important engineering problem. Accordingly, the matchmaking proses aims to find alternative resource combinations for specific product requirements [21]. So far, various mathematical algorithms and software and tools based on these algorithms are used to find the best matches in different production systems. There are also mathematical algorithms which is used in matchmaking problems in components reuse in buildings such as Greedy Search, Genetic Algorithm, Mixed Integer Linear Programming, Hungarian Algorithm, Dynamic Relaxation [43]. In order to find resources or resource combinations that meet the necessary capabilities, the matchmaking procedure entails scanning the matchmaking search space. For the matchmaking system to take it into consideration, it must get the search space as an input. In the process of matchmaking, the Product Requirement Description (PRD)

Table 2. Steps of Ashby approach [51].

The Descriptive Questions for Function, constraints, objectives and free variables	
Function	What does the component do?
Constraints	What non-negotiable conditions must the material meet? (rigid requirements)
Objectives	What aspects of performance are to be maximised or minimized (rigid requirements)
Free variables	What parameters of the problem is the designer free to change? (soft requirements)

and the collection of Resource Descriptions (resource pool) should be taken into account [21].

There are various circular building initiative, networks and, research and innovation projects which supplies knowledge about available BMPCs such as Buildings as Material Banks (BAMB), CityLoops, CINDERELA, Circular Construction in Regenerative Cities (CIRCuIT) etc. [7, 14, 17, 52]. In this study it is accepted that an available and expedient circular building database is harnessed in the decision support model. It is also accepted as the databases includes the relevant information about the BPCTR (Building Part Components To be Reused) compatible with the proposed Decision Support Model. In this phase to find the best possible donors Ashby Approach proposed to be used. Ashby Approach is a selection method which aims to fined best match in material selection and process in engineering design (mechanical). Ashby Approach is constituted from four main steps as translation, screening, ranking and supporting information. Translation step is the process where the design requirements are converted into useful tools to conduct the material selection process efficiently. This is succeeded by the Function, constraints, objectives and free variables (Table 2). Functions is the main aim of the product to be designed. Constrains refers the non-negotiable properties of materials to be selected. Objectives refers the desired maximized and minimized properties of material. Free variables are related the designers' choices.

3.5. Phase 4. Development of design alternatives for BMCTD

In this phase Scheme design alternatives are created according to possible donors and Weighted Performance Criteria by the user. Level of detailing can be decided by the user which supply flexibility for the user. The design outputs can be created in both using conventional technic and BIM based software and the other computational programs. The design alternatives can be varied according to design stance and aesthetical consideration of the user utilizing soft performance requirement.

3.6. Phase 5. Compatibility analysis for BMCs (Recipient-donor compatibility)

In this phase, the Design Alternatives for BMCTD are assessed in terms of compatibility to determine the best-matching donor materials and components. Initially, the compatibility criteria are defined based on the performance requirements, their weights, and classifications derived from the data created in previous phases (Table 3). Compatibility analysis is then

Table 3. Compatibility criteria for BMCs.

Compatibility Criteria
A. Aesthetic Compatibility
○ Texture Compatibility,
○ Color Compatibility,
○ Brightness
○ Smoothness
○ Form
○ . . .. .
B. Performance Compatibility
○ Mechanical Performance Compatibility (Strength, tensile et.)
○ Thermal Performance Compatibility
○ Water Resistance Performance Compatibility
○ Acoustic Compatibility
○ Lightening related performance compatibility
○ Fire Resistance Compatibility
○ Durability Performance Compatibility (Corrosion Resistance, UV Resistance etc.)
○ . . .
C. Technical Compatibility
a. Modular (Dimensional/ Size) Compatibility,
b. Shape Compatibility,
D. . . .

Table 4. Recommended optimization criteria.

Optimization Criteria
A. Contamination Level of Material/Part/Component (–)
B. Damage Status or Repair Requirement of Material/Part/ Component (–)
C. Repairability
○ Repairable with the process having high environmental impact or cost (–)
○ Repairable with the process having low environmental impact or cost (+)
D. Embodied Energy of Material/Part/ Component (low: +–; high:–)
E. Expected Life time of the Material/Part/ Component (low:–; high: +)
F. Recyclability (+)
G. Distance to the Construction Site (low: +–; high:–)
H. Availability (low:–; high: +)
I. Cost (low: +–; high:–)

applied separately for each criterion according to the weights determined by the user (in Phase 2). First, the analysis is conducted for the rigid performance criteria, beginning with the highest-weighted criterion and proceeding in descending order. Each rigid criterion is evaluated individually to assess the degree of alignment between the design alternatives and potential donor materials. Next, the analysis is performed for the soft performance criteria following the same order from the most to the least significant criterion. At this stage, the user may choose to apply compatibility analysis selectively among the soft criteria, depending on design priorities. It is assumed that as the degree of compatibility increases, the potential environmental impacts such as the need for additional treatments, repair, or adaptation decrease accordingly. Various matchmaking algorithms can be found in the literature, and the most appropriate algorithm may be selected according to the type and characteristics of the criteria used. If necessary, this phase can include a feedback loop that allows returning to the determination of possible donors phase. Through this iterative process, the user can verify and refine the matching results, ensuring that the most compatible donor options are accurately identified.

3.7. Phase 6. Optimization of The Design Alternatives

In this phase, the design choices are optimized according to the detected optimization criteria. Firstly, the optimization criteria are identified. Various criteria can be employed for optimizing the design choices (Table 4), and additional optimization criteria may also be defined according to different variables related to the design alternatives or the donor building materials and components.

Secondly, the most compatible alternatives, as identified in Phase 5, are evaluated based on these optimization criteria. At this stage, multi-criteria decision-making methods such as the Analytic Hierarchy Process (AHP) are recommended to be used to obtain weighted and comparable results. This phase also operates within a feedback-based (iterative) structure. If the optimization results indicate a need for revision, the process allows a return to the previous phases to reassess or modify the design alternatives. Similarly, if new or more suitable donor materials or components are required, an additional search process can be initiated within the donor identification phase, ensuring that the optimization process remains flexible and responsive to updated data and design constraints.

3.8. Phase 7. Decision making

In this phase decision making process is completed

4. Proof-of-concept application of DSM_BMCR

In this section, a proof-of-concept application of DSM_BMCR is conducted according to a scenario developed by the author. The façade cladding case scenario, which is explained in the preliminary stage, is introduced as a proof-of-concept application, aiming to illustrate the functional workflow and evaluative capacity of the DSM_BMCR model. Due to the lack of accessible comprehensive material-passport databases, real performance measurements, and detailed material records, the scenario depends on hypothetical data that align with the methodological structure of the model. Accordingly, the application is intended to demonstrate potential use rather than constitute a full validation. A more complete implementation would require real-world datasets, expanded criteria, and empirical testing.

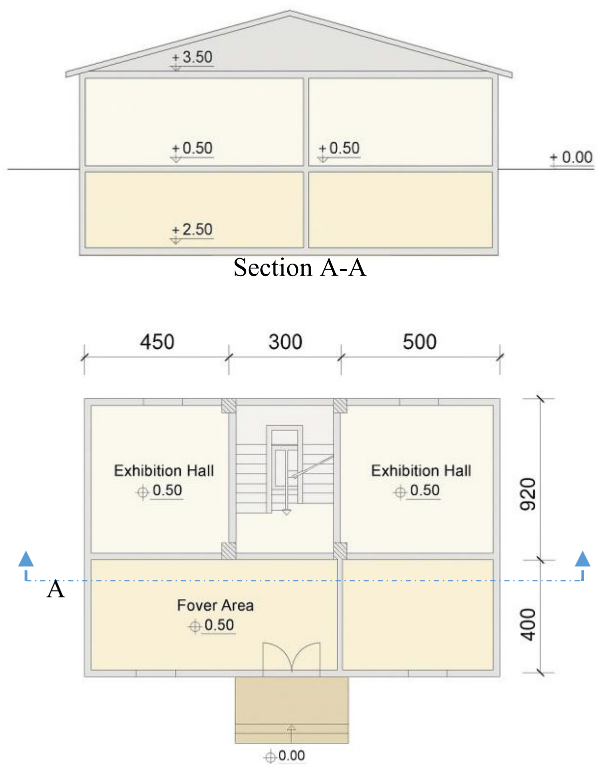


Fig. 3. Plan scheme and schematic elevation of the scenario case building.

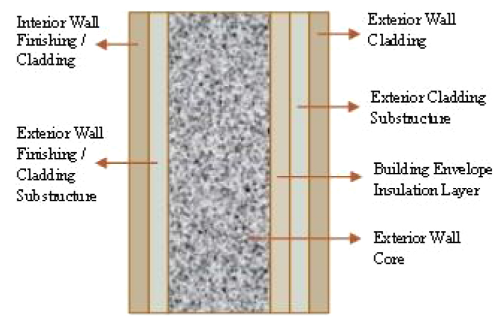


Fig. 4. Layers of a exterior wall component.

4.1. Preliminary phase: Determination of building material/component to be detailed (BMCTD)

Façades are flat, vertical constructions that separate the internal and exterior spaces, which is accepted to be renewed every 20 years due to the aesthetical etc. consideration [53, 54]. Shorter life time than the buildings itself and the high surface area in the total building structure which makes it important in term of circularity and material efficiency, the façade cladding is selected as the case study. According to the scenario, the building façade cladding is aimed to be designed using reused/reclaimed building materials in accordance with circular building principles. According the scenario, İt is aimed to design the facade cladding for a reinforced concrete building which is constituted basement and ground floors. The plan scheme and schematic elevation is presented in Fig. 3.

The building envelope consists of several layers as exterior wall cladding, exterior cladding substructure, insulation layer, exterior wall core, interior wall cladding, and interior cladding substructure (Fig. 4). These layers function as a composite system in which each layer contributes to the overall performance of the wall component, such as the overall heat transfer coefficient (U-value), water vapor permeability etc. However, considering all of these layers within a single scenario would significantly increase the complexity of the model implementation process, due to the constrains such as lack of a comprehensive material and component database and a software. Therefore, to ensure clarity and to effectively demonstrate the implementation of the model, the façade cladding design, representing the outermost layer of the building envelope, has been defined as the scope and boundary of the model implementation phase.

4.2. Phase 1. Determining and classification of the performance requirements for building material/component to be detailed (BMCTD)

Façade surfaces share a variety of general features and principles regardless of the materials they are composed of. Building facades are constituted from various flat or curved surface elements which set up different combination of relations such as intersect or touch each other or roof surfaces of the building. A facade's design and construction details have highly affected by the organization and position (vertical, angled, or almost horizontal) of these surface elements (Fig. 5). Knowing these features and principles are prominent for the design process [54]. It can be also mentioned about the dimensional grids or modular grids which is important in façade detailing. Architects use these grids both for aesthetical design and dimensionally coordination of components. The components are designed as to allow for joint and site assembly supplying required tolerances [55].

In this phase, Architectural sketching method was used due to the aforementioned reasons and only the aesthetical performance requirements were detected. The architectural sketches were developed in a digital environment by utilizing the organization and position classification of façade surface elements proposed by Herzog et al. [54]. Within this framework, three different alternative Organization and position of Façade surface elements were developed,

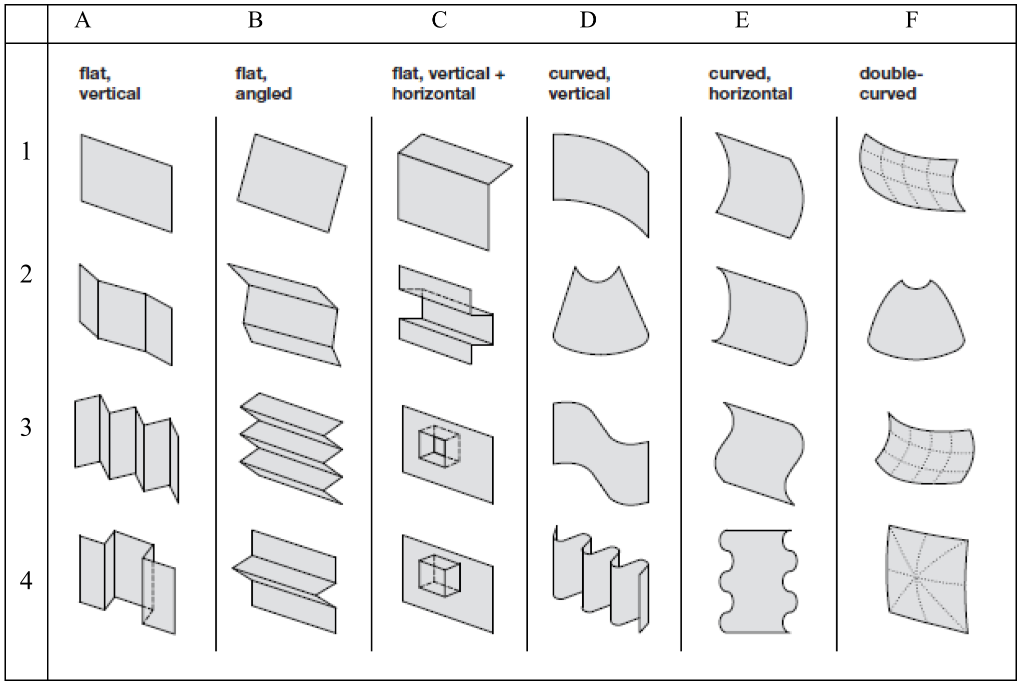


Fig. 5. Organization and position Façade surface elements [54].

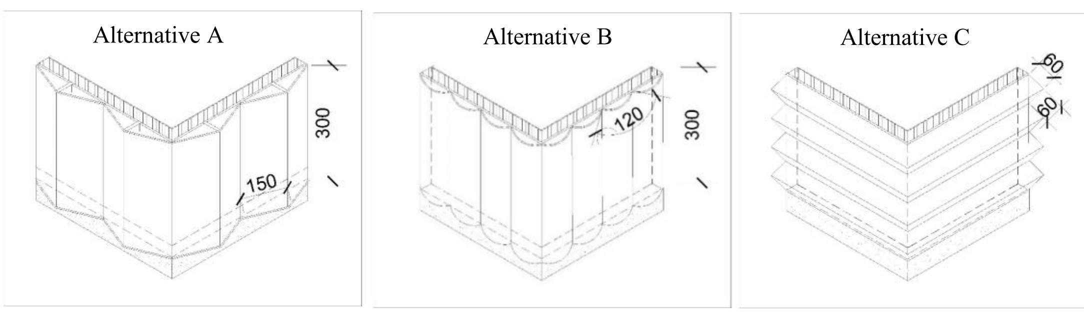


Fig. 6. Organization and position of Façade surface elements alternatives.

to explore material reuse and aesthetic performance within the proposed scenario (Fig. 6).

The aesthetical performance criteria were detected as follows by the user. The aesthetic performance criteria for façade cladding were defined to ensure the visual and dimensional coherence of the alternatives while maintaining constructability and material feasibility. These criteria address the proportional and geometric characteristics of the façade elements, such as vertical continuity, module width, panel depth, and curvature, as well as material-related properties such as bendability and surface expression. For each alternative, the requirements were derived from the building's dimensional parameters a storey height of 3.50 m, a plinth height of 0.50 m, and a net cladding height of 3.00 m to ensure that the façade panels could span the full vertical height without intermediate horizontal joints. For the planar façade alternative (Alternative A), the panel width was defined not to be less than 1.50 m, ensuring proportional clarity and minimizing vertical joint repetition. In the horizontally layered alternative (Alternative C), the panel width shall not be less than 0.60 m, providing both visual rhythm and manufacturability. In the curved alternative (Alternative B), the façade geometry is defined by an arc segment of approximately 120 degrees, establishing the formal identity of the façade and the bending limits of the selected material. Additionally, the criteria emphasize the legibility of joint patterns, corner articulation, and the consistency of curvature and layering, which collectively shape the aesthetic and spatial perception of the façade within the reuse-oriented design framework (Table 5).

Table 5. Determined and classified performance requirements for the Case of Façade cladding.

No	Aesthetic Performance Requirements	Description/Requirement in the Scenario	Requirement Type	Related Alternative(s)
1	Vertical cladding height/ Minimum panel length (vertical)	The visible façade cladding shall cover the storey height continuously between the plinth (0.50 m) and the soffit line (3.50 m), resulting in a net cladding height of 3.00 m. Therefore, to ensure uninterrupted vertical continuity, the panel length shall not be less than 3.00 m.	**Rigid**	A, B
2	Panel width (module dimension)	The panel width defines the façade rhythm and manufacturability. For the planar façade Alternative A, the panel width shall not be less than 1.50 m;.	**Rigid**	A
3	Panel width (module dimension)	For curved façades, the surface must remain smooth and continuous, with a bending radius compatible with material capacity; the curved façade represents an arc angle: 120°. Panel width should not be less than 1.25 m to preserve the visual balance.	**Rigid**	B
4	Panel width (module dimension)	For horizontally layered façades, the module width shall not be less than 0.60 m to preserve visual balance and construction feasibility	**Rigid**	C
5	Panel depth and relief	Folded or stepped profiles should create shadow effects while staying within structural and water protection limits.	Soft	A, C
6	Curvature and continuity (horizontal)	For horizontally layered façades, the alignment of successive layers must maintain continuous horizontal articulation without deformation.	Soft	C
7	Bendability / flexibility of material	The façade material must allow bending or pre-curving without cracking or deformation; this property directly affects feasibility. Bending radius should be compatible with the minimum bending radius specified for the selected material.	**Rigid**	B, C
8	Joint pattern and legibility	Joints must align with the façade geometry (folds, curvature, layering), contributing to overall visual order and continuity.	Soft	A, B, C
9	Corner articulation	At corner transitions, the cladding shall form a visually continuous edge with aligned panel intersections.	**Rigid**	A, B, C
10	Surface expression (shape, texture, color etc.)	The façade's visual character defined by shape, texture, and color reflect the architect's design intent and aesthetic stance.	Soft	A, B, C

4.3. Phase 2. Setting and weighting of the performance criteria

In this phase, the Digital Logic Method was used for the weighting process. The Digital Logic Method is an important tool to avoid intuitive decisions even if the relative importance of each option isn't clear. It also supplies ease of usage for the users [51]. Firstly, the performance requirements were turned to Performance Criteria and coded. Secondly pairwise comparations were applied for soft and rigid criteria. Lastly, rigid and soft criteria weights were calculated. The calculation steps and related tables are presented in Fig. 7.

4.4. Phase 3. Determination of possible donors

In this phase, it was aimed to find the possible donors by applying the performance criteria and their corresponding weights defined in the previous stage. However, since a real Donor. Building Material and Component Database does not currently exist, the model could not be directly validated through an actual database search. Instead, a hypothetical scenario was created to simulate the determination of possible donors. In this scenario, four possible donor materials; light oak wood, medium walnut brown wood, rusted metal (Corten steel), and metallic steel sheet were selected based on the rigid and soft performance criteria previously established. Each material is defined by its dimensional and visual characteristics consistent with the predefined criteria. Additionally, supplementary criteria such as distance to project site, availability, and cost efficiency were introduced to evaluate the materials in a realistic framework (Table 6). In this phase the model may follows an iterative process with the second phase of the model. Supplementary criteria can also be weighted through the Digital Logic Method. In this phase, since the number of supplementary criteria was limited, it was not considered necessary to return to the previous phase for an additional weighting process using the Digital Logic Method.

4.5. Phase 4. Development of design alternatives for BMCTD

In this phase design alternatives were created according to possible donors which are detected using

* Firstly, rigid and soft criteria are coded and ranked as most important to least important: Rigid: R1 >R2 > R4 > R5 > R3 > R6, Soft: S3 > S4 > S2 >S1
*Secondly Criteria Pairwise Comparisons are applied for both soft and rigid criteria
*Thirdly Criteria weights are calculated and presented in tables for rigid and soft Criteria.

Type	Criteria	Code
Rigid	Vertical cladding height (A,B ≥3.00 m)	R1
	Minimum panel width (A ≥1.50 m)	R2
	Minimum panel width (A ≥1.25 m)	R3
	Minimum panel width (C ≥0.60 m)	R4
	Bendability / flexibility of material (B, C)	R5
	Corner articulation (A, B,C)	R6
Soft	Panel depth and relief (A,C)	S1
	Curvature and continuity (horizontal) (C)	S2
	Joint pattern and legibility (A, B, C)	S3
	Surface expression (A, B, C)	S4

Rigid Criteria Pairwise Comparison	Soft Criteria Pairwise Comparison
Pairwise comparison results (winner in each pair) • R1 vs R2 → R1 • R1 vs R3 → R1 • R1 vs R4 → R1 • R1 vs R5 → R1 • R1 vs R6 → R1 • R2 vs R3 → R2 • R2 vs R4 → R2 • R2 vs R5 → R2 • R2 vs R6 → R2 • R3 vs R4 → R4 • R3 vs R5 → R5 • R3 vs R6 → R3 • R4 vs R5 → R4 • R4 vs R6 → R4 • R5 vs R6 → R5	Pairwise comparison results (winner in each pair) • S1 vs S2 → S2 • S1 vs S3 → S3 • S1 vs S4 → S4 • S2 vs S3 → S3 • S2 vs S4 → S4 • S3 vs S4 → S3
Number of "wins" and weights There are $\frac{6\cdot5}{2}$ = 15 comparisons in total	Number of "wins" and weights. There are: $\frac{4\cdot3}{2} = 6$ comparisons in total

Code	Rigid criterion (short)	Wins	Weight $w_i = \frac{\text{wins}}{15}$
R1	Vertical cladding height (A,B ≥3.00 m	5	0.33 (5/15)
R2	Min. panel width (A ≥ 1.50 m)	4	0.27 (4/15)
R4	Min. panel width (C ≥ 0.60 m)	3	0.20 (3/15)
R5	Bendability / flexibility of material	2	0.13 (2/15)
R3	Min. panel width (A ≥ 1.25 m)	1	0.07 (1/15)
R6	Corner articulation	0	0.00 (0/15)
Sum of weights ≈ 1.00			

Code	Soft criterion (short)	Wins	Weight $w_i = \frac{\text{wins}}{6}$
S3	Joint pattern and legibility	3	**0.50** (3/6)
S4	Surface expression	2	**0.33** (2/6)
S2	Curvature and continuity (horizontal)	1	**0.17** (1/6)
S1	Panel depth and relief	0	**0.00** (0/6)
weights sum to 1.00.			

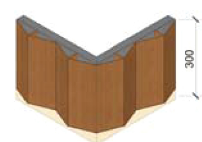
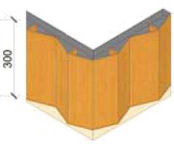
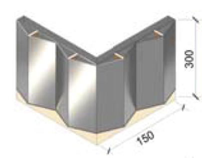
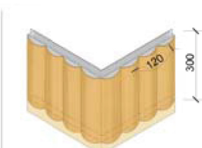
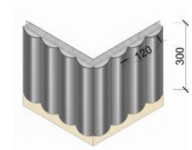
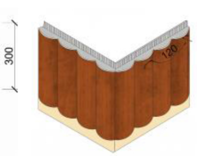
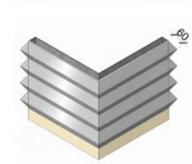
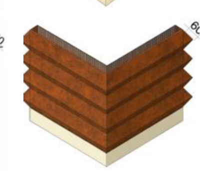
Fig. 7. Usage of digital logic method for the weighting performance criteria.

Table 6. Hypothetical scenario: Possible donor materials.

Material	Type	Dimensions (Rigid Criteria)	Visual/Soft Properties	Supplementary Criteria
Light Oak timber panel	Natural wood	Panel width: 1.50 m; Height: 3.00 m; Thickness: 0.06 m	Warm tone; moderate surface relief; visible joints	Distance: 15 km; Availability: High; Cost: Medium
Medium Walnut Brown Timber	Natural wood	Panel width: 1.25 m; Height: 2.80 m; Thickness: 0.05 m	Dark tone; smoother surface; low curvature	Distance: 40 km; Availability: Moderate; Cost: Medium
Corten steel cladding	Metal	Panel width: 1.60 m; Height: 3.20 m; Thickness: 0.04 m	Rusted surface; high texture articulation; strong continuity	Distance: 20 km; Availability: High; Cost: High
Brushed stainless steel panel	Metal	Panel width: 1.50 m; Height: 3.00 m; Thickness: 0.03 m	Smooth surface; high reflectivity; sharp joint definition	Distance: 10 km; Availability: Very high; Cost: High

Weighted Performance Criteria according to Scenario. Although, Level of detailing can be decided by the user which supply flexibility for the user, within the scope of this study, exemplification through colour and material selections has been considered sufficient in terms of avoiding complexity. The design alternatives were created according to design stance and aesthetical consideration of the writer according to available reclaimed material properties in scenario (Table 7).

Table 7. Design and material alternatives (with colour options).

No.	Design Alternative	Material	Description/Notes	Color Option 1	Color Option 2
1	Design Alternative A (Material Option 1)	Timber Panel Cladding	Warm texture and natural appearance emphasizing material sustainability. Color Option 1: Medium Walnut Brown Timber Finish, Color Option 2: Light Oak Timber Finish		
2	Design Alternative A (Material Option 2)	Metal Sheet Cladding	Contemporary and industrial aesthetic with high durability and reflectivity. Color Option 1: Brushed stainless steel, Color Option 2: Corten steel finish.		
3	Design Alternative B (Material Option 1)	Timber Panel Cladding	Curved form creates a soft visual rhythm and natural continuity. Color Option 1: Medium Walnut Brown Timber Finish, Color Option 2: Light Oak Timber Finish		
4	Design Alternative B (Material Option 2)	Metal Sheet Cladding	Metallic surface enhances the sculptural effect of the curved geometry. Color Option 1: Brushed stainless steel finish Color Option 2: Corten steel finish.		
5	Design Alternative C (Material Option 1)	Timber Panel Cladding	Horizontal layering creates a modular, rhythmic façade emphasizing warmth. Color Option 1: Medium Walnut Brown Timber Finish, Color Option 2: Light Oak Timber Finish		
6	Design Alternative C (Material Option 2)	Metal Sheet Cladding	Layered metal surfaces accentuate light reflections and modernity. Color Option 1: Brushed stainless steel, Color Option 2: Corten steel finish.		

4.6. Phase 5. Compatibility analysis for BMCs (Recipient-donor compatibility)

In this stage compatibility analysis was limited within the framework of Aesthetic Compatibility. Accordingly, The Colour Compatibility and Shape Compatibility aspects were assessed according to the architect's design stance. Accordingly, two material and colour alternatives were selected as Design Alternative C: Material Option 1, represented by Medium Walnut Brown Timber with a natural wood finish, and Material Option 2, represented by Corten Steel Cladding with a rusted metallic surface.

4.7. Phase 6. Optimization of the design alternatives

In this phase design choices are optimized according to optimization criteria. Firstly, the optimization criteria are identified as Distance to the Construction Site (low: +–; high:–) Availability (low:–; high: +), Cost (low: +–; high:–). Secondly, the most compatible alternatives, as identified in Phase 5, are evaluated based on these optimization criteria. Design Alternative C: Material Option 1, represented by Medium Walnut Brown Timber with a natural wood finish, and Material Option 2, represented by Corten Steel Cladding with a rusted metallic surface are evaluated according to three optimization criteria. weighted sum model is used for the evaluation process (Fig. 8). For the qualitative attributes (Availability and Cost), an ordinal scale is used: Availability: Moderate = 2, High = 3. Cost: Medium = 2, High = 3.

4.8. Phase 7. Decision making

According to the calculated weighted scores, Material Option 2 (Corten Steel Cladding) achieves a higher total score (0.89) compared to Material Option

Criterion	Type	Option 1 Timber	Option 2 Corten Steel
Distance to the Construction Site	Cost-type	40 km	20 km
Availability	Benefit-type	Moderate	High
Cost	Cost-type	Medium	High

Normalized Values		
Criterion	**Normalized (Timber)**	**Normalized (Corten Steel)**
Distance	0.50	1.00
Availability	0.67	1.00
Cost	1.00	0.67

Weighted Scoring Model
Assuming equal weights for the three criteria ($w_1 = w_2 = w_3 = 1/3$), the overall score (S_j) for each option is calculated using the formula:
$S_j = \Sigma(w_i \times \hat{p}_{ij})$ where $\Sigma w_i = 1$
Timber (Option 1): $S_1 = (1/3) \times (0.50 + 0.67 + 1.00) = 0.72$
Corten Steel (Option 2): $S_2 = (1/3) \times (1.00 + 1.00 + 0.67) = 0.89$

S2>S1(0.89>0.72)

Normalization of the criteria
To make the criteria comparable, the values are normalized into the interval [0,1].
*For **cost-type** criteria (Distance, Cost), lower values are better, so:

$$\hat{p}_{ij} = \frac{\min(x_{ij})}{x_{ij}}$$

*For **benefit-type** criteria (Availability), higher values are better, so:

$$\hat{p}_{ij} = \frac{x_{ij}}{\max(x_{ij})}$$

Applying these formulas:
***Distance (cost-type)**

$$\min(40,20) = 20$$

Timber: $\hat{p}_{1,1} = 20/40 = 0.50$
Corten: $\hat{p}_{1,2} = 20/20 = 1.00$
***Availability (benefit-type)**

$$\max(2,3) = 3$$

Timber: $\hat{p}_{2,1} = 2/3 \approx 0.67$
Corten: $\hat{p}_{2,2} = 3/3 = 1.00$
***Cost (cost-type)**

$$\min(2,3) = 2$$

Timber: $\hat{p}_{3,1} = 2/2 = 1.00$
Corten: $\hat{p}_{3,2} = 2/3 \approx 0.67$

Fig. 8. Usage of weighted sum model evaluation the design alternatives according to three optimization criteria.

1 (0.72). Therefore, Corten Steel Cladding is selected as the optimized material option under the defined criteria. However, depending on the priority weighting of cost or availability, the decision outcome may vary, allowing flexibility in model application.

5. Results and discussion

The building envelope consists of several layers functioning as a composite system in which each layer contributes to the overall performance of the component, such as thermal conductivity, sound insulation, and moisture permeability etc. Although performance aspects such as thermal conductivity, sound insulation, and moisture permeability were recognized as essential for the comprehensive evaluation of material suitability, they were excluded from this study due to the requirement for advanced simulation-based analysis tools. Therefore to ensure clarity and to effectively demonstrate the implementation of the model, the façade cladding has been defined as the scope and boundary of the model implementation phase, due to the constrains such as lack of a comprehensive material and component database and a software The proposed DSM_BMCR was applied according to the scenario for the building façade cladding which is aimed to be designed using reused/reclaimed building materials in accordance with circular building principles, also.

The study prioritized materials that exhibit reusability, ease of disassembly, leading to the consideration of timber and metal as primary candidates. During the assessment process, it was determined that the curvilinear façade configuration proposed in the design scenario was less compatible with wooden materials, primarily due to their limited bending capacity. From an aesthetic standpoint, the dimensional boundaries of façade panels were also defined to ensure visual harmony and proportional coherence.

In the implemented case, DSM_BMCR efficiently identified and evaluated potential donor materials through a structured, stepwise process. The application of the Digital Logic Method enabled a transparent weighting of performance criteria, balancing rigid (non-negotiable) and soft (flexible) requirements. The Weighted Sum Model provided a quantitative evaluation of two selected alternatives; Medium Walnut Brown Timber (Option 1) and Corten Steel Cladding (Option 2) based on three optimization criteria: distance, availability, and cost. The results of this evaluation indicated that Corten Steel Cladding (S = 0.89) outperformed Medium Walnut Brown Timber (S = 0.72), suggesting that the former represents the more feasible reuse option under the defined conditions. The model facilitated systematic decision-making by incorporating both aesthetic and along with supplementary factors such as distance, cost, and availability, through a multi-criteria evaluation framework. Despite its higher cost, Corten Steel's high availability, shorter transportation distance, and strong aesthetic compatibility enhanced its overall suitability. This outcome highlights the model's capability to generate rational, data-driven results even when qualitative and quantitative factors coexist within the same evaluation framework. However, different weighting scenarios applied to supplementary criteria could produce alternative results. In this study, equal weighting was used across criteria; nevertheless, in different projects or user-defined contexts, varying importance factors could yield diverse outcomes. This demonstrates the model's flexibility and adaptability to changing design priorities and reuse conditions. The flexibility of DSM_BMCR also allows the model to be adapted not only for end-of-life reuse scenarios but also for "living donor" contexts, where materials from ongoing or recently completed projects can be reassigned to new uses.

The results of the study reveal that The DSM BMCR offers a holistic architectural approach which enables the architects to evaluate reuse potentials at multiple scales from individual materials to complex building components by integrating various performance criteria simultaneously. The significance of this study lies in its capacity to address not only a single component but also different elements of the building systems within the same methodological framework. Moreover, the DSM_BMCR is designed to be applicable across diverse architectural contexts, including the design of new buildings, the renovation and modification of existing building.

The integration of digital methods including BIM compatibility, potential algorithmic matchmaking, and database-driven material selection indicates that the DSM_BMCR can serve as a foundation for AI-supported decision-making environments in future studies. This integration can be achieved by mapping the model's evaluation parameters to the corresponding data fields within these databases, enabling the direct transfer of verified material information into the decision-making workflow. As digital material passports and circular construction databases evolve, the model can interact with these infrastructures, reducing data scarcity and enhancing decision accuracy. The structured weighting and optimization stages can be automated using AI algorithms, enabling architects to conduct real-time material matching during the design process. Furthermore, the integration of artificial intelligence (AI) into architectural design processes may significantly extend the capabilities of the proposed model.

The detection of aesthetic performance requirements in this study was achieved through the use of architectural sketching methods, which can be performed both through conventional drawing techniques and digital computational tools. Alternatively, design alternatives may also be generated using artificial intelligence-based design systems, enabling the simultaneous exploration of multiple reuse-oriented solutions. When trained on data derived from the DSM_BMCR workflow, AI systems could automate design alternative generation, donor-material matching, and reuse prediction, thereby transforming the current model into a data-driven decision-support framework. While the existing model establishes a logical and transparent decision flow, future iterations are envisioned to evolve into AI assisted decision-making environments, where both human designers and machine-learning systems collaboratively contribute to circular design strategies.

The study also underlines the growing need for architectural control in circular design processes. As digital and deconstruction-oriented design approaches (e.g., Design for Disassembly, Design for Deconstruction) become more prominent, architects' responsibilities expand from form generation toward data-based material coordination and reuse planning. This shift suggests an imminent transformation of architectural practice, where designers act as curators of material flows. Accordingly, regulatory frameworks and construction standards should evolve to define clearer guidelines on reclaimed material integration, database interoperability, and design documentation standards in BIM based workflows.

An important insight obtained from this study concerns the component based approach to design and reuse. As architectural production increasingly shifts toward modular and demountable systems, the reuse process will also evolve to operate primarily at the component level rather than the whole building scale. This transformation implies a potential redefinition of architectural authorship and creative ownership, as the intellectual and technical identity of architecture will extend from the holistic composition of form to the design, adaptation, and reconfiguration of reusable building components such as wall or façade modules. This paradigm shift aligns closely with the emergence of digital twin technologies, which provide opportunities to track, evaluate, and predict the life cycle and reuse potential of building elements. Through digital twins, the compatibility of reclaimed components with new design configurations can be dynamically assessed throughout time. Parallel advancements in robotic fabrication and digital construction technologies further enhance these opportunities by allowing reclaimed materials to be reshaped, reassembled, and reintroduced into new projects with precision.

6. Conclusion

Selecting appropriate BMCs for a specific purpose is a complicated, laborious, and costly process due to the large number of available materials and the complex relationships among selection parameters. The conventional way of design is also time-consuming because of the complexities involved in the reuse and reclamation process of BMCs. According to these research gaps, this study aims to explore the following research questions: Research Question 1: How can architects take design decisions effectively for reusing of BMCs?

Research Question 2: How can architects decide the best matching donor for BMCs while preserving design decisions (aesthetic considerations, etc.)?

In this study, a design decision support model for reuse of Building Materials and Components Reuse (DSM_BMCR) is developed to address the research questions.

DSM_BMCR consists of a series of interrelated phases that structure the decision-making process for BMC reuse, encompassing performance definition, criteria weighting, compatibility assessment, and optimization processes. A multi-criteria decision-making (MCDM) framework was employed to ensure that both qualitative and quantitative aspects could be systematically analysed. Within this framework, methods such as the Digital Logic Method and the Weighted Sum Model (WSM) were applied to determine performance weights and evaluate alternative materials based on rigid and soft performance requirements. Through this structured process, the model enables architects to make transparent, data-driven design decisions that balance aesthetic, technical, and environmental factors.

The importance of the DSM_BMCR lies in its ability to assist architects in evaluating reuse potentials at multiple scales from individual materials to components while preserving design flexibility. This multi-layered assessment supports the existing transformation of architectural design toward a circular paradigm in which the architectural authorship and creative ownership extend beyond formal composition to include the design, adaptation, and lifecycle management of reusable material assemblies. The model aligns with the principles of Design for Disassembly and BIM-integrated deconstruction, indicating that architects will increasingly act as multiauthor designers responsible for coordinating material data and circular design processes. Accordingly, comprehensive legal and regulatory frameworks addressing reclaimed material integration, architectural authorship and creative ownership rights, and data management within BIM-based environments will be essential.

In conclusion, this research presents a decision-making model that demonstrates the potential of integrating circular design principles within architectural practice. The proposed DSM_BMCR currently offers a alternative methodological foundation for architects to evaluate and optimize the reuse of building materials and components through structured, data-driven processes. Its current configuration effectively combines material databases, BIM interoperability, and multi-criteria decision-making techniques, establishing a coherent bridge between architectural design intent and circular construction strategies. Future developments will focus on expanding this framework into a comprehensive decision support software capable of integrating AI-driven optimization and user-interactive features. As BIM-based projects and digitally recorded material datasets continue to increase, the capacity for accurate donor recipient matching will grow, enabling both end-of-life and living-donor reuse scenarios. Ultimately, the ongoing evolution of the DSM_BMCR into a software-based platform is expected to strengthen its role as a practical and intelligent tool contributing to a more efficient, transparent, and sustainable approach to material circularity and reuse in architectural design.

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These and the Reference headings are in bold but have no numbers. Text below continues as normal.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Conflict of interest

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