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Novel Integration of Sustainable and Construction Decisions into the Design Bid Build Project Delivery Method Using BPMN

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Abstract

A recent study on the cost of green buildings indicated that Resource Reuse is the category of credits least often achieved in LEED-certified projects. The literature suggests that there are a number of constraints and barriers to resource reuse, but perhaps the most critical one is the lack of easily accessible information about resource availability and usability. The emerging industries of building materials reuse and de-construction in the United States suffers from the absence of a "system" that would streamline business processes, establish a supply-demand chain, and connect vendors and deconstruction contractors with architects. This research derives an innovative restructuring of the architectural design process that enables resource reuse in new construction. We developed this model by capturing expert knowledge using a Delphi research protocol and mapped the Building Materials Reuse Workflow in Business Process Modeling and Notation language. We set out the knowledgebase requirements that should be integrated with Building Information Modeling to support decision-making by architects and project stakeholders.

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Keywords: Resource Reuse; Decision Support System; Sustainable Design and Construction, BPMN Process Mapping

1. Introduction

The United States Green Building Council (USGBC) identified six categories in the Materials and Resources (MR) section of the Leadership in Energy and Environmental Design (LEED) program. One of these six categories

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is Resource Reuse (RR). A recent study conducted by Davis Langdon [1] indicated that resource reuse is the credit least often achieved in the LEED rating system. A survey conducted in the UK for the top 100 largest architectural practices revealed that holding environmental accreditation appeared to have no serious impact on design waste minimization performance and waste minimization. It is often a low priority in the strategic planning and design activities of projects. [2] According to literature, there are a number of constraints and barriers to resource reuse due to the complexity of buildings, liability and inconvenience but perhaps the most important obstacle is the lack of easily accessible information to architecture and design firms [3]. One of the main objectives of this study is first to capture expert knowledge related to the process of reusing building materials and second to build a Decision Support Framework (DSF) in order to assist the design team when considering, identifying and evaluating reclaimed and salvaged building materials and components into new projects. Since the involvement of multiple stakeholders is essential to the success of the decision-making process, the decision framework must be viewed as a group decision-making activity, which involves multiple, potentially competing utility structures. This DSF will address the sustainability factors that are critical in making decisions and weighing them against those of conventional new building materials and components decisions. The DSF will emerge from identifying all possible major constraints and barriers when using reclaimed and salvaged building materials and components in new construction, then develop a response to these constraints and barriers, then identifying all possible performance measures to the DSF, and finally apply decision-modeling knowledge.

1.1. Building A Material Reuse Knowledgebase Framework

Building a structured knowledgebase is essential to supporting critical decision processes, which form a series of activities in the proposed design process model. This knowledgebase consists of two main categories: explicit knowledge and tacit knowledge (the latter can be transformed into the former). Explicit knowledge has been articulated and is often captured in the form of knowledge artifacts such as text, tables, diagrams, product specifications, and so on. In this study we consider explicit knowledge as computerized data and information, or a database, which would consist of Building Information Modeling (BIM) files linked to our proposed Virtual Repository of Building Material Reuse (VRBMR). Tacit knowledge is difficult to transfer to another person by means of writing or verbalizing because it consists of insight, intuition and inspiration. [4] In the Architecture, Engineering and Construction industries (AEC), tacit knowledge can be identified as: design objectives, design concepts, and human knowledge in reuse and sustainability, the last of which is the main resource in qualitatively structuring a VRBMR (Figure 1).

The large amount of information and data involved in incorporating BMR in the architectural design process requires careful management. In building a structured workflow for BMR we recognized that there are people, processes, and technologies involved at all stages of a given project. Knowledge Management (KM), which includes classifying storing, retrieving, and transferring knowledge, should help organize this multi-disciplinary effort and increase the value of the decision making within it. Gamble and Blackwell argue that the ideas behind KM go back to the 1950s, with the use of quantitative management techniques and structured management approaches.[5] According to Rhem, KM consists of practices, new software systems, processes, and operating procedures developed to validate, evaluate, integrate, and disseminate information for users to make decisions and learn. Messner also presented detailed information architecture for structuring knowledge and information for the AEC industries. [6] To apply the knowledgebase framework to support a series of BMR business processes, we must develop a thorough understanding of businesses' needs which Sparx Systems defined as a "*collection of activities designed to produce a specific output for a particular customer or market*".[7] This definition puts a strong emphasis on determining how work is done within a system, then starts the knowledgebase creation process through collaborative sessions with experts and stakeholders. Through this collaboration, knowledge can be modeled (using a standard language) and tested to ensure that all team members have the same understanding of the steps in the knowledge acquisition framework. Once this understanding has been achieved, the required knowledge artefacts can be produced.

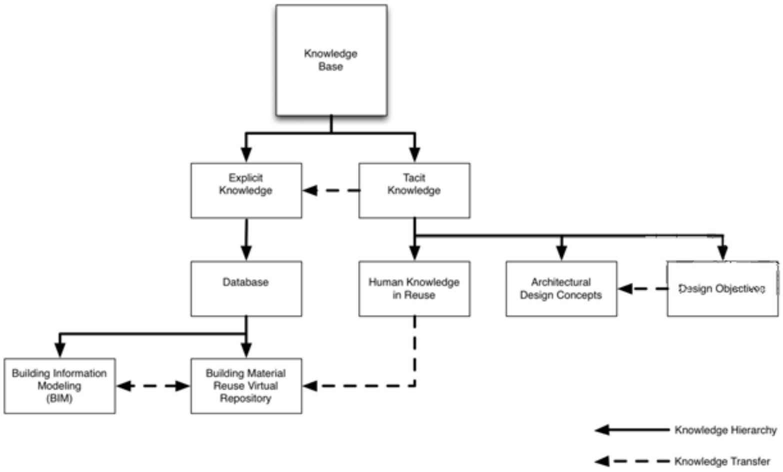

Fig. 1. Knowledgebase Components for Building Materials Reuse [8]

1.2. A Proposed BMR Design Scenario

Our proposed design scenario is envisioned as follows: an architect designs a new building while utilizing Building Information Modeling (BIM) software. The proposed building is "dissected" as a process in BIM and an inventory of the building components is generated. This component inventory is archived for future reference and is used as input to the decision-support process. Concurrently, other buildings nearby or within a "harvesting map" proximity either have been or are in the process of being de-constructed.[9] An inventory of the available components from these de-constructed buildings is generated, including essential information of the necessary decision-making attributes, along with similar information from manufacturer refused products (wasteflows) and salvaged warehouse stores and vendors. A platform for all of the above information is called a "Virtual Repository," which will be an online local/national/global library of reclaimed and salvaged building materials and components. This Virtual Repository will be linked to all available Physical Repositories (reclaimed materials warehouses, deconstruction sites and industrial manufacturers) and constantly updated with all available materials with necessary information the design team needs in the design process. A simple representation of the workflow can be seen in (Figure 2). (Note that the architectural design process is not linear but investigative in its nature).[10]

In the future, the previously mentioned BIM inventory from today's design will be activated when the building is de-constructed to provide an efficient mechanism for inventorying salvaged components. For the proposed new design, each component in the new building is compared with components in the Virtual Repository. Here comparisons are processed through the decision-support framework using the decision-making attributes.[11] These attributes include, but are not limited to, assessment of age, possible fatigue and weathering of the reused component, structural integrity, history, appearance, size and dimensions, and ease of alteration.

The matching process will be both direct and indirect based on the processing of the attributes. Direct matches are when a needed component, such as a steel beam, is matched to an available component. Indirect matching will occur when the evaluation of attributes identifies a salvaged component that can be potentially adapted for use as a new component [12]. This process can be referred to as "creative re-purposing" (for example, when a set of exterior wall panels can be reused as suspended ceiling panels). In addition, the decision support process evaluates and compares other decision-making factors such as purchase costs, embodied energy, and transportation distance and cost. As part of the attributes for reused components, digital information such as images, as-built drawings, de-construction drawings, specs and other visual information of the component, are also accessible to the design team. The result is that the architect is now better informed about the option to reuse deconstructed building materials and components and can make sound decisions to incorporate them in new designs.

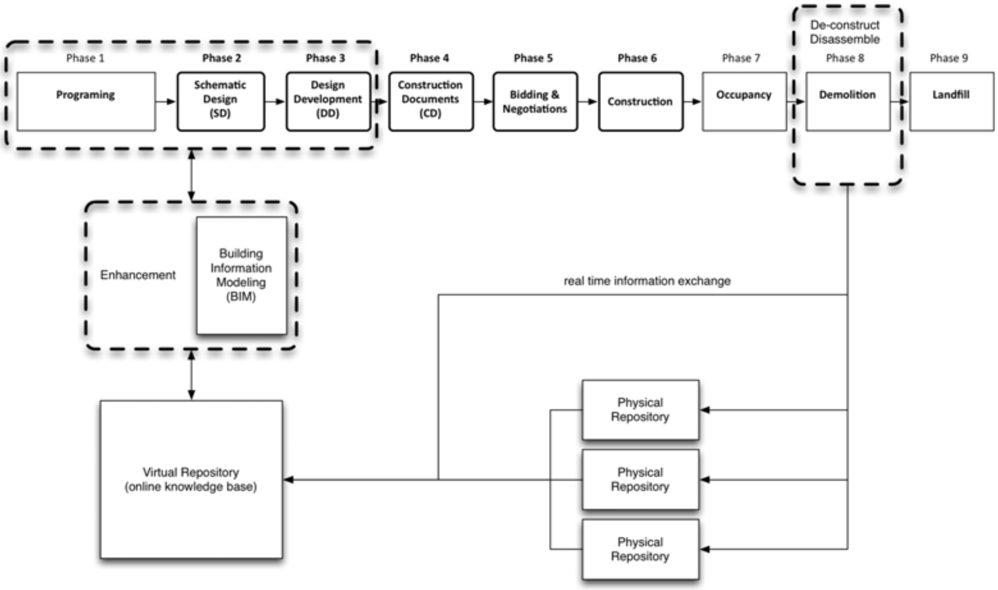

Fig. 2. The Proposed BMR Design Scenario [8]

2. Knowledge Capturing Process

In our study, we attempted to capture data and information specifically related to Building Materials Reuse (BMR), then identified and organized it into a framework for the building design process. Ultimately, this will lead to developing a computerized database, but that is beyond the scope of the current work. The database is envisioned as an external source of knowledge that will be linked to the existing BIM database (Figure 2). We first identified the knowledge, data, and information critical to the activities and identified processes performed by multiple stakeholders. This information represents both inputs and outputs to the process model, and we organized it into four data categories: type (drawings, text documents, computerized models, etc.), ownership (client, architect, consultant, vendor, etc.), location (where the data resides and is stored), and format (human data, computerized data, etc.).

The first phase of the Knowledge Capturing Process started with a forecasting preliminary questionnaire. Two main goals were set for the survey questions, first was to get a general and diverse opinions from all building stakeholders on the research problem, the second is to solicit a focus group from the industry experts to carry forward the Delphi process. The soliciting invitation was sent to 138 stakeholders whom they were divided into seven panels. Each panel included a number of industry experts related to the building design and construction industry in general and to the BMR in particular. The panels were organized as follows: Academics and Researches (20), Architects and Designers (30), Deconstruction Contractors (19), Government Agencies and Building Officials (18), USGBC Materials & Resources Technical Advisory Group (MR TAG) (13), Salvage Vendors and Reuse Stores (19), and Built Case Studies Architects (19 members). The final actual number of participants to our survey was 61 members. Following the procedures of the Institution Review Board (IRB), the questionnaire was successfully distributed via email invitations with a total of 35 questions were divided into 4 sections that ranged from general and background information to design process and decision-making. We presented our study participants with initial mapping of the Design-Bid-Build process which we illustrated using UML activity diagrams. We then asked them for their feedback and input on the workflow, which we incorporated back into our BPMN maps. After that we developed the updated maps and went back to our participants to see if they would add, delete or change any type of information in the workflow. We repeated the Delphi process until consensus was reached among participants. In this paper we only reported on the first round of the Delphi process.

2.1. Results from the first phase of the Delphi process

- Architects represented the highest participation with 25% followed by participants who identified themselves as “other disciplines” ranging from brokers to non-profit organization representatives with 23% participation. The lowest participation was from building material manufacturers and contractors. Architects, owners and other building stakeholders shared equal responses for initiating the idea of BMR with 33% each. Contactors represented the lowest category.
- Small-size practice represented the majority of responses with 46 %, while large practices represented the lowest percent of responses with 12%. Other stakeholders represented the highest responses with 37% were from product developer and public agent, followed by architectural design with 31%. The lowest representation was from demolition, construction services and engineering. Participants in the survey whose practice specializes in the educational building sector, represented the highest responses with 56% followed by residential with 54%, while other building types ranging from mixed use to cultural and healthcare represented15%. Also, those who work on medium scale projects (1000-5000 square feet) represented the highest responses with 48% followed by X-large scale projects (more than 10000 Square Feet) with 42%.
- The majority of the participants (81%) had previous experience with building material reuse either in new construction or renovation projects. Also the majority of respondents (73%) had previous experience with BMR but the reason was not to fulfill the RR section of the LEED certification, but for other various reasons ranged from client desire to good practice.
- Local and environmental impacts represented the greatest benefits from using salvaged materials with 72% response rate, followed by Green Certification (LEED or Cradle to Cradle) with 59%. The lowest impact was community development with 38%. The responses regarding the reason for not using BMR were highest in the “other reasons” category with 63% (for example “client bias” and “lack of commitment from upper management” followed by 38% for “lack of procedural knowledge”. 57% of respondents agreed that lack of knowledge and information on reused building materials is the biggest constraint for designers to consider reuse.
- 82% of respondents said that they would be likely to consider BMR if there were more incentives or tools in place. The lowest responses with 3% were undecided and very unlikely. Material availability was considered to be the number one incentive to consider reuse with 83% response rate, followed by reduced cost with 80% response rate. The majority of respondents 73% indicated that they didn’t use any tools for making the decision on BMR, while 27% indicated that they did use a tool like” online reuse vendor” or cost analysis software.
- The majority of responses indicated that the Design-Bid-Build (DBB) project delivery method remains the most implemented method in their practice followed by other methods. The highest number of respondents 47% indicated that the Design Development phase (DD) would be the best phase to make a decision about BMR followed by the Schematic Design phase (SD) with 43% response rate. The lowest responses were for Demolition and Bidding-and-Negotiation phases with 3%.

3. Discussions

Knecht’s article, *Designing for Disassembly and Deconstruction*, suggested that architects are reluctant to use salvaged building materials in new projects due to several uncertainties, liability issues and lack of information on BMR. In contrast to our expectations that architects and designers would be the least interested individuals of all building stakeholders in our questionnaire, results from the preliminary survey showed that the majority of participants were architects and designers, especially from EPA Region 9, where states like California supports eco-design and resource reuse initiatives.[13] Contractors were the least interested in participation, and that is perhaps due to the many uncertainties in the process and liability issues. Small-size architecture firms (1-20 employees) and medium scale projects (1000-5000 square feet) are the perfect combination where BMR can be highly implemented. Design principals in small-size practice most likely have the biggest influence on clients, and medium project size allows for greater opportunities to incorporate reuse. Surprisingly, achieving a green certified building such as LEED was not the main reason for incorporating BMR, but good practice and client desire were the main drivers behind achieving local and environmental impacts. The traditional Design-Bid-Build project delivery method remained the most used method in practice; however, most of the participants indicated that BMR must be incorporated in early stages of the design to achieve greater success. That being said, the Integrated Project Delivery method (IPD) appealed to the majority of participants as a potential fit for BMR.[14] A decision on incorporating building material reuse is not necessarily taken by a specific stakeholder and differs from one case to the other but architects and building owners have the most influence on initiating the idea. The lack of supporting tools, a structured system and knowledge and information available for salvaged building materials were the biggest constraints for the design team in order to consider reuse. Findings from the Delphi in-depth preceding interviews confirmed that the decision on BMR should occur as early as possible in the design process and the issues of sourcing, quantities, qualities and liability should be addressed in the materials' specification. Stakeholders from the deconstruction services and the reuse vendors indicated that their industry is lacking a system of information exchange that connect them well with other design and building stakeholders and the dynamic nature of the salvaged materials inventories should be studied carefully to allow for streamlining the design process. These findings emphasized the need for going forward with the knowledge capturing process through multiple Delphi rounds in order to build the knowledgebase for reuse.[15] The second round of open-ended questions were successfully distributed to the Delphi Focus Group of 17 individuals who represented a cross section of all building stakeholders. Face-to-face interviews with experts were also conducted. Results of this round will be presented in future publications. Preliminary results of the interviews suggested a need for a new stakeholder to collaborate with the design team. Some participants explained the usefulness of having a building material reuse consultant or 'material broker' in the design team early in the process to identify, source and document opportunities for reuse.

4. Mapping the Building Materials Reuse Workflows using BPMN

We initially mapped all phases of the traditional DBB process using Unified Modeling Language (UML) activity diagrams standards and used these maps to help our research participants understand where decisions occur.[16] Later we found that UML is limited in its ability to represents more details about the process, therefore we switched to the Business Process Modeling and Notations (BPMN) mapping standards and created three stages of maps from general to detailed. We will present here only the first stage of our mapping process. We adopted the BPMN mapping repertoire (Figure 3), which described the elements of the process boxes in more details.[17] *Project Phase* refers to phases of the DBB delivery method (P: Programing, SD: Schematic Design, DD: Design Development, CD: Construction Document, BN: Bidding and Negotiation, CA: Construction Administration), *Process Name* refers to a short and brief description of the activity (usually in the form of an order), *Responsible Party* refers to the project stakeholders (Owner, Architect, Design Team, Engineering Consultant, Landscape Architect, Contractor, BMR Consultant, All Stakeholders), and finally the *Detailed Map* refers to the process maps in the blueprint set (P1a, P1b, SD2a, SD2b, SD2c, DD3a, DD3b, DD3c, CD4a, etc.).

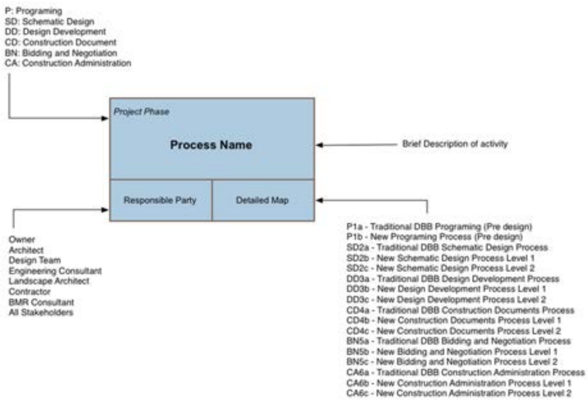

Fig. 3. BPMN Process Activity Box Legend [8]

4.1. Stage One: BMR Overview Process Map

The BMR overview map represents the highest level of information exchange of the whole project life cycle from programming to landfill. The map addresses the relationship between the nine phases of the DBB traditional process and the proposed BMR workflow scenario in light of several revisions and feedback from the research focus group. To capture an overview process map for BMR, a number of steps needed to be taken accordingly. First, identification of a proper project delivery method (in this study, the DBB is selected), then a dissection of the project life cycle phases needs to be addressed. The following steps were essential to create the BMR overview map: 1) Include all related DBB phases in the overview map. 2) Arrange DBB phases into the project sequence. 3) Include new activities related to BMR integration. 4) Identify responsible stakeholders in each activity. 5) Determine information exchange required for each activity. The captured BMR overview map shown in (Figure 4) is a result of converging and updating two UML maps that were presented to the Delphi focus group, the overall DBB design process and the proposed BMR scenario. The two maps were used to solicit the industry expert opinions. A number of processes (activities) were added to the overall workflow, distinguished in the map with green color boxes. The majority of the added processes fall between programming, Schematic Design and Design Development phases. This early planning is consistent with our findings in most of the case studies and our literature review. The map is divided into two swimlanes, the upper one contains the traditional DBB phases and the BMR proposed scenario. The lower swimlane contains mostly the new BMR processes and the two major decisions to incorporate BMR. One of the concerns presented during the Knowledge Capturing Process is that materials and components outside the BIM virtual repository (the proposed standardized online knowledgebase and marketplace) will be inaccessible to this system. Therefore, to enhance access to reusable materials, the system should either expand the list of information sources, or to include a local database that includes reuse stores. The proposed overview process could help architects and designers to specify reclaimed materials and mitigate the difficulty in sourcing. It also helps to identify the necessary steps to obtain information and define opportunities for reuse earlier in the design process. Each box of activity in the BMR overview map represented a phase in the DBB process and therefore the need to develop more detailed workflow for each phase was critical. As explained, we developed a blueprint set of maps that can be easily integrated with the BIM Execution Planning Guide, which was developed by Penn State.

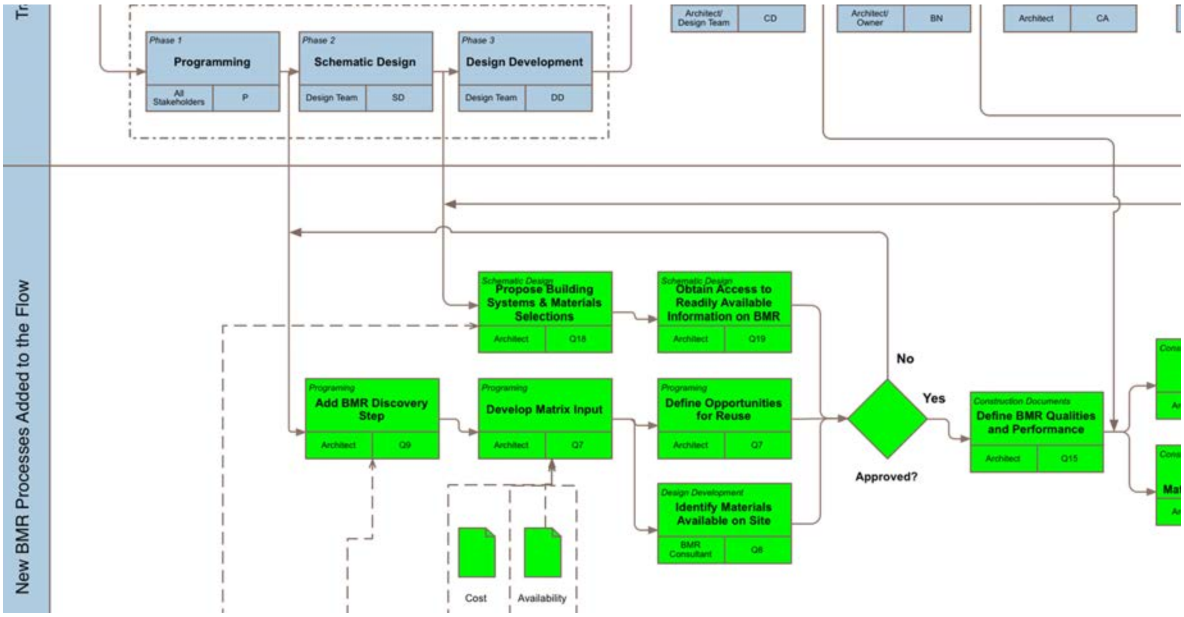

Figure 4: OM-00 Building Materials Reuse Proposed Overview Process Map (Partial View)

5. Conclusion

Major findings to our initial inquiry were incorporated into our BPMN mapping process. For example; we found that the importance of mapping the programming phase in the new BMR workflow is a result of the extensive multiple knowledge capturing phases, feedback from the industry experts and the research Delphi focus group inputs. We performed consistency checking to our findings through three sources of data (literature, case studies and surveys) by triangulation. The project team should be assembled in the early stages of a project and should include the owner, designers, contractors, engineers, major specialty contractors, facility managers, and a materials broker. It is very important for the owner as well as all primary team members to fully support the BMR process. For the initial goal setting meetings, key decision-makers should be represented from each of the organizations so that the overall goals and vision for implementation on the project are clearly defined for further planning initiatives. The decision on incorporating BMR into a project has to occur before any finalized designs or decisions are made. The key information needed is: available materials, the processing necessary for these materials to be used on the project, and what their final cost would be. The most important information that can be provided to the decision makers is the following: What is the impact on the project schedule (i.e. when will the materials be available)? What will the materials look like (confirm material quality)? Will there be enough material (confirm material quantity). Early in the process the information needed for reused materials are general. Later, they are specific and detailed.

In our proposed BMR scenario, Building Information Modeling (BIM) was found to be a critical component to the workflow. The proposed design scenario is the process that was found to be lacking in the current architecture and design industry, and its implementation is necessary for a viable reuse industry. Part of the process would be what is being referred to as the “Virtual Repository”, because it seems that many architects and designers do not specify reclaimed materials because of the difficulty in sourcing them, and that they need to be identified earlier in the design process. Another important BMR key factor is to make contingent design decisions based on the availability of materials. The project team including the owner should have high tolerance for uncertainty, and willingness to do something that would lay claim to a paradigm shift in sustainability of the built environment. Although process mapping found to be a foreign language to architects, it is critical to provide a clear understanding of such dynamic process such as integrating BMR in new construction. Our proposed BMR workflow if combined with BIM execution planning could highly result into sustainable building design that promote a circular economy.

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