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Integrating Database Management System with Building Information Modeling to Design Green Roofs for Buildings

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Abstract: The construction industry has changed significantly over the last decade. This change has made building design more complex and motivated designers to adopt Building Information Modeling (BIM) and other more advanced designing tools and concepts. Additionally, the demand for sustainable designs has increased tremendously, especially with the global movement toward a healthier environment. Consequently, the need to have full integration between both concepts (BIM and sustainability) during the design phase of new buildings has grown. However, as the concept of sustainable design is still under development, there is a significant lack of sustainable content in BIM tools' built-in databases. These databases lack information about sustainable materials and components, especially those related to green roofs. This shortfall arises particularly when efforts are underway to recognize pre-determined sustainable components (families) and their associated materials. As a result BIM users are often discouraged from designing green roofs because of the tremendous time required to gather information about related material specifications and properties. This paper will propose a methodology that incorporates a database management system and BIM tools in the design of green roofs for sustainable building projects. The methodology will discuss the development and implementation of a model that includes a comprehensive database, one that stores information about green roof products and related sustainable materials. Also, the model will be fully integrated with BIM tools, and will help designers design 3D model green roofs during the conceptual sustainable design stage. To point out the developed model's capability a case project will be presented.

1 Introduction

The construction industry is increasingly recognizing the adverse effects that could arise because of the use of large amounts of energy derived from dwindling natural resources. It is therefore important that designers and engineers start to adopt techniques and principles of sustainable design. One of these techniques involves the utilization of green roofs. Frazer (2005) thinks that in urban areas the percentage of roofs compared to other horizontal surfaces can be as high as 32%. Developed cities like Toronto are beginning to exploit part of these spaces converting them to green surfaces in an effort to address these environmental problems. In May 2009, the City of Toronto issued a bylaw forcing investors and homeowners to design green roofs. Today, modeling a building's design before its actual construction is imperative for owners and designers, especially when sustainability is the main goal. Applying BIM principles can be very helpful in achieving such a goal. It offers an upgrade from the previous two dimensional (2D) modeling that only generates drawings and section views. BIM, which is considered a third dimension (3D) in the space, helps designers visualize objects much better (Hijazei, 2009). What's more, a database built-in and comprised of pre-defined structural and architectural elements in the shape of families is incorporated by Building Information Modeling tools. Designers may use this database to design building projects more efficiently. This database however lacks detailed information about sustainable components and objects such as green roofs. There is a need therefore to enhance the BIM tools built-in database by adding more objects and families. This paper proposes a methodology to design green roofs for building projects that incorporates BIM's tools and a database management system.

2 Literature Review

Green roofs have been identified as vital components in the design of sustainable buildings. Nevertheless, using Building Information Modeling tools to design these types of roofs is a challenging concept. This paper proposes two main concepts, green roofs and BIM. To demonstrate this model value a comprehensive review of literature pertaining to both concepts is discussed.

2.1 Green Roofs

Green roofing is a term associated with roofing considered environmentally friendly in general, and in particular the growth of plants or vegetation on roof tops. Sutic (2003) believes that in urban environments, the advantages of green roofing are enhanced where the majority of the land area is covered by surface which is impervious; causing environmental challenges affected by excessive radiant heat, limited green space and storm water runoff. A green roof basically consists of a number of layers stacked over a typical roof structure. Mulvaney (2011) considers that green roof layers can be divided into two categories, major and minor. To be considered green, four major layers should be found on roof tops. They are: thermal insulation, waterproofing membrane, growing medium, and vegetation. The minor layers include: vapor barrier, cover board, drainage layer, filter membrane, water storage and root barrier. On the basis of variables such as: desired activity, plant type and the growing medium depth, green roofs are divided into two categories; intensive or extensive (Stovin et al., 2007). In addition to being a low profile roof, one with an average growing medium depth between two and six inches is referred to as an extensive roof. This amounts to a roof weight of around 10 to 50 pounds per square foot at the point of complete saturation. The extensive green roof consists of a combination of inorganic (75 percent) and organic (25 percent) materials. This helps and facilitates the growth of plants up to a maximum of two feet, or in other words low-growing plants. Extensive roofs only need regular irrigation (Barker and Lubell, 2012). Suitable plants for extensive green roofs could be sedums, alpine plants, and grasses or herbs, since they are highly resistant to heat, drought, wind, and frost (Snodgrass and Snodgrass, 2006). Onmura et al. (2001) think that installation of extensive roofs can be done on slopes to about 30 degrees. However some firms use a grid structure effectively on vertical walls and higher-sloped roofs. Then again, a growing medium which is deeper (seven inches or more) is used by intensive roofs, for the growth of various kinds of plants. In addition, they exemplify green roofs typically by meeting the requirements of recreation like social spaces, ponds and vegetable gardening (Stovin et al., 2007). From an aesthetic perspective, intensive roofs are similar to conventional rooftop gardens without plants in planters, but rather planted in a full-scale garden. The growing medium which is engineered consists of organic materials (45 percent) and minerals (55 percent) (Barker and Lubell, 2012). As a result of larger plants and the growing medium which is deep; intensive roofs are much heavier than extensive roofs and at the point of full saturation they may weigh between 80 to 120 pounds per square foot. Thus, more structural strength is needed by intensive roofs as opposed to extensive roofs. The feasibility of an intensive roof is limited by the weight factor, on the basis of underlying structural integrity and support of an existing roof or architecture (Takakura et al., 2000). At the time of installation, green roofs are more expensive (more than $\$10/ft^2$) than traditional roofs. However, over a period of time, it is an economical alternative to conventional roofing since higher durability and reduction in energy requirements ensure green roofing is a cheaper and smarter alternative (Wong et al., 2008). Also, like typical gardens, green roofs can be useful sources of food and can provide sustainability (Hartig et al., 1991). Shahan (2012) thinks green roofs can be improved further through the use of irrigation methods which are solar powered and a rainwater harvesting system.

2.2 Green Roofs Materials:

A short description of the materials used for green roofing is illustrated in Figure 1 and discussed to give a comprehensive and clear picture of the kind of materials used to construct green roofs:

Figure 1 : A typical Green roof system (City of Toronto, 2012)

- Plants and growing medium: light weight material should be used which maintains a proper balance between the absorption and drainage of water, in addition to sustaining plant roots. If materials like gravel, lava, organic composts, crushed stone or clay are mixed together, they produce high quality as opposed to normal soil growing mean (Dunnett, 2008).
- Filter fabric: This layer is designed to protect the underneath drainage layer from fertilizer particles and soil which can block the drainage system. This layer is derived from semi-permeable poly propylene fabric (Dunnett, 2008).
- Storage/drainage layer: Enormous damage to plants may occur due to non-drained or over-drained systems, hence making it an essential layer. Granular materials like gravel can be used, since there are spaces between particles, allowing plant and vegetation roots to grow. The other type of material is porous mat which is derived from recycled material with great absorption capacity. Another kind of drainage material is polystyrene, which is a lightweight, thin plastic (Dunnet and Kingsbury, 2008).
- Waterproof membrane: A regular waterproofing system could be used, for example shingle, asphalt gravel or tar. The best option has no spaces between its jointed parts. This allows it to serve as a layer of protection between the existing structure and the roots of the growing medium. There are two types of waterproof membranes which are Ethylene propylene dene monomer (EPDM) and thermoplastic polyolefin (TPO). EPDM is a highly durable rubber type with a high density. EPDM is resistant to high temperatures and is also resistant to solvent and organic materials that can be produced by the growing medium or fertilizers. TPO on the other hand provides almost the same advantages as EPDM but the fact that TPO is recyclable while EPDM is not gives it an advantage on the sustainability scale (Delgado et al., 2007).
- Protection board: It protects the layer below it from fertilizers and plant roots. Copper foil, lightweight concrete, or plastic sheets are ideal materials to use for this kind of board (Weiler and Scholz-Barth, 2009).

2.3 Benefits of Green Roofs

There are many benefits to be derived from the use of green roofs over conventional roofing. Its positive impacts can be seen and felt on the environment, economy and society. Moreover, it also provides a return on investment to the owners of the particular building. Clark et al. (2008) consider the most important positive economic effects of green roofing technology are: Saving on cost of energy, protecting the structure of the roof and thereby increasing its longevity, downsizing HVAC systems & saving on the initial cost of investment and enhancing the value of real estate. Whereas Saiz et al. (2006) think green roofs' positive environmental effects include: Improving in air quality due to plants' filtration effect, reducing the effect of heat islands, reducing Carbon Dioxide (CO_2) gas emissions, earning Leadership in Energy and Environmental Design (LEED) points and bringing improvement in tenants' health.

3 Building Information Modeling BIM

The construction industry is fragmented by nature due to the uniqueness of each project and the number of stakeholders involved. As a result, a high level of collaboration between different parties is required to have efficient project delivery. As defined by Penttila (2006) BIM is a set of processes creating a desired methodology to manage the project data in digital format throughout the whole project life cycle. Having the mentioned technology would increase the effectiveness and efficiency of project design and management (Froese, 2010). BIM is not just using design technologies to display building components in a 3D virtual environment. It can be considered as a transformation of the traditional design delivery process to a more integrated one (Eastman et al., 2008). BIM makes it possible to have one depository to store all the design components' data and each component should be described once. Consequently, changes to the model are instantly updated on all drawings (Hardin, 2009). In earlier Computer-Aided Design (CAD) systems, the building components are geometric while BIM-based CAD systems are object-oriented in that building elements are basic components of drawings (Hijazi, 2009). Another difference is that in traditional 2D and 3D CAD systems, space is not defined. However, in BIM, space is a fundamental part of the BIM model that can define the relationships between walls, ceiling, and floors. Therefore, we can do several types of analysis relevant to the space by using BIM which is not possible with the use of traditional approaches (Khemlani, 2004).

4 Methodology

The model requirements established are based on an extended literature review along with the characteristics considered in a practical model. The process of introducing a valuable methodology is to enhance the benefits of the model under its categorized requirements and development constraints. The methodology is divided into two phases. The first consists of collecting information about all the required materials and their associated properties and storing them in a database that will be developed for this purpose. The second comprises customizing BIM's tool (e.g. Revit Architecture) by creating three dimensional 3D intensive and extensive green roof families. The proposed model is intended to enhance the objects' families. Green roof components will be added to the library where they can be easily accessed when designing sustainable building projects. After a comprehensive literature review related to green roofs and BIM, collection of data to build the green roof materials and properties database is fulfilled. This is done by contacting local subcontractors and by adopting the results of previous research published projects. Next, 3D green roof families are drawn and added to the database of BIM's tool. Following this stage, is the integrating of both databases "material & properties and drawings" to come up with a unique model that generates multi green roof models.

4.1 Phase One

The main objective of this phase is to have a comprehensive database of green roof systems and materials. The database should give the user easy access to the needed data in order to crystallize the idea. This model is managed by a database management system. The functions performed within each of the model components and their local developments are illustrated in Figure 2.

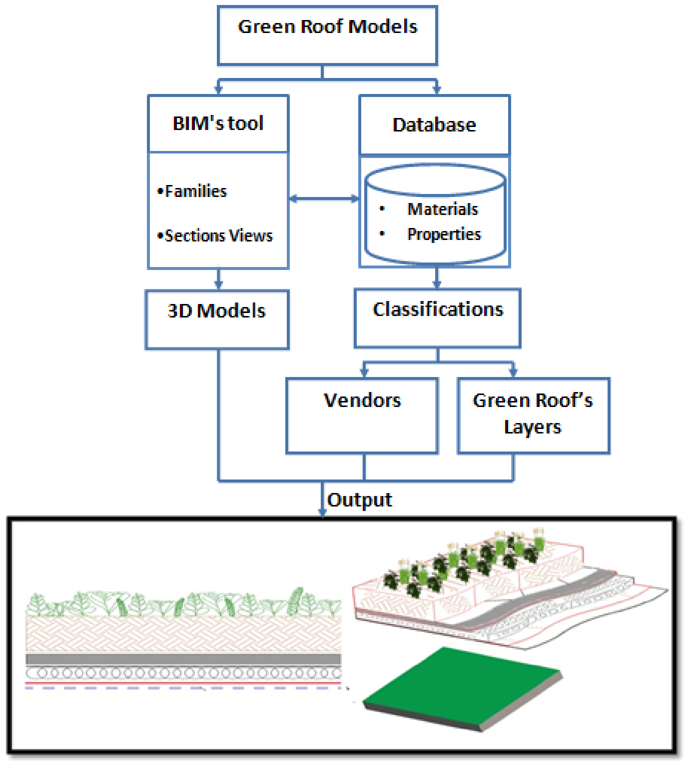

Figure 2: Green Roof's Model's Components

The development of the green roofs' materials and properties database is done using Microsoft Excel. The data is collected from twenty seven companies. Each of these companies' products is stored in a different database. The main database is linked to all these databases. As discussed earlier at this paper, the green roofs consist of 4 main layers above the structural support. These four layers are 1) Plants and Growing medium, 2) FILTER FABRIC - Growing Medium Retention, Root Barrier, 3) DRAIN CORE - Drainage, Water Storage, Aeration and 4) PROTECTION FABRIC-Waterproofing Protection. For each of these layers, different materials are to be considered, consequently different properties. Also, each layer's properties of interest are different. Table 1 points to some of the main properties that will be considered for each layer.

Table 1 : Main green roof layers and their associated properties

Layer	Material	Properties				
Plants & Growing medium	Material	Thickness	Weight	Water flow rate	Porosity	Saturation water content
FILTER FABRIC	Material	Thickness	Weight	Water flow rate	Tensile Strength	UV Resistance
DRAIN CORE	Material	Thickness	Weight	Water flow rate	Compressive Strength	Water Storage Capacity
PROTECTION FABRIC	Material	Thickness	Weight	Water flow rate	Tensile Strength	UV Resistance

Defining the material's properties is the initial part of the integration process. Through these tools the green roofs are identified as objects rather than just drawings.

4.2 Phase two

This phase focuses on customizing BIM's tool (e,g. Revit 2013) by creating and adding new 3D green roof families. The focus of this phase is to enhance BIM's tools database by adding new families and components, which consist of different elements that can be used later in the model to determine cost and energy consumption. The creation of green roof families has to follow certain steps. First an initial 3D design for each material should be sketched. The design should reflect the real life measures of the components and it is features. Figure 3 shows a 3D example of water retention and the drainage layer or GR32 (Green Innovations, 2012).

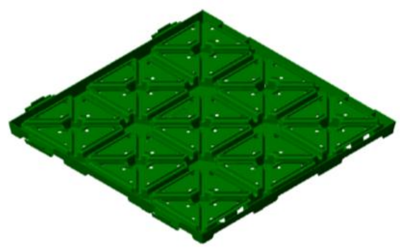

Figure 3: 3D water retention and drainage layer (Green Innovations, 2012)

Then the design of a typical 3D green roof family for all companies and their different systems is developed. This is done by taking space and interaction between the selected materials into consideration while designing as shown in Figure 4.

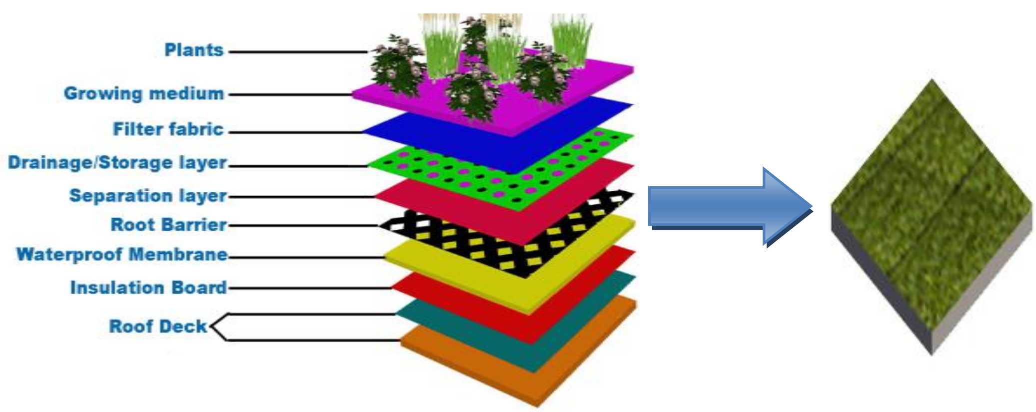

Figure 4: 3D family design for green roof system

After developing the material and properties' databases using Microsoft Excel the data should be transferred to the BIM tool. Each material linked to it is an associated design. Afterwards, the new families will be saved in the Revit material database under new Library Files (*.adsklib). The different layers of the green roof drawings can now be easily identified by linking each layer to a specific material as shown in Figure 5.

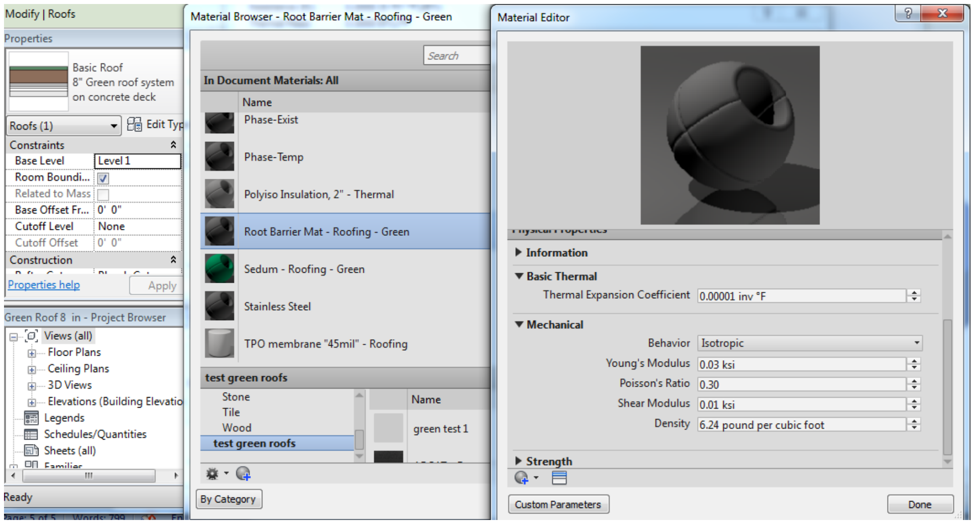

Figure 5: Defining material properties for green roof root barrier mat in Revit 2013

5 Case Example:

To present its validity, an existing project was chosen for re-design using the green roof model. The project is the Brown & Jones Architects' office building in Raleigh, North Carolina. Figure 6 shows a photo of the project from a) Front view and b) top view using Google Maps (2013). According to Brown & Jones Architects (2003), the existing 2,660 ft^2 one floor building was originally built as a gas/service station around 1920.

Figure 6: Brown & Jones Architects Office Building (front and top view).

To make it more sustainable the new owner undertook a major rehabilitation and re-design of the building, making half of the roof cool and the other half green. Using the traditional method, the designer provided the owner with 2D Cad drawings for the green roof and a specification sheet. A green roof product named AMERGREEN 50 by American Wick Drain Company was chosen. (This method's main disadvantage is the long time required to finalize drawings, especially if the designer has no experience designing green roofs. On the other hand, using the proposed model to design green roofs saves considerable time.) When using the model, the steps taken to arrive at the specified green roof design are the following:

- The development of a database of materials and properties for American Wick Drain via the collection of information about all their green roofs and systems as illustrated in Table 3.

Table 2: Main properties for AMERGREEN 50

	Material	Thickness (mm)	Water flow rate (Lpm/m^2)	Grab Tensile Strength "N"	UV Resistance (%/500Hrs)	Water Storage Capacity (L/m^2)
FILTER FABRIC	Polypropylene		3,260	645	70	
DRAIN CORE	High Impact Polystyrene	11	200			2.4
PROTECTINO FABRIC	Polypropylene		2,260	645	70	

- Desiging the 3D green roof system's “AMERGREEN 50” using BIM tool “Revit 2013”. (This design's geometry is then saved as a new family design.)
- Updating the above mentioned properties to the family design and storage within Revit's materials library.

In the subsequent phase and in future project construction the designer chooses the product from the Revit material's library and applies it to his project's roof design as shown in Figure 7. This ease of use encourages the designer to suggest to the owner the adoption of more sustainable designs, especially green roof products provided through the proposed model.

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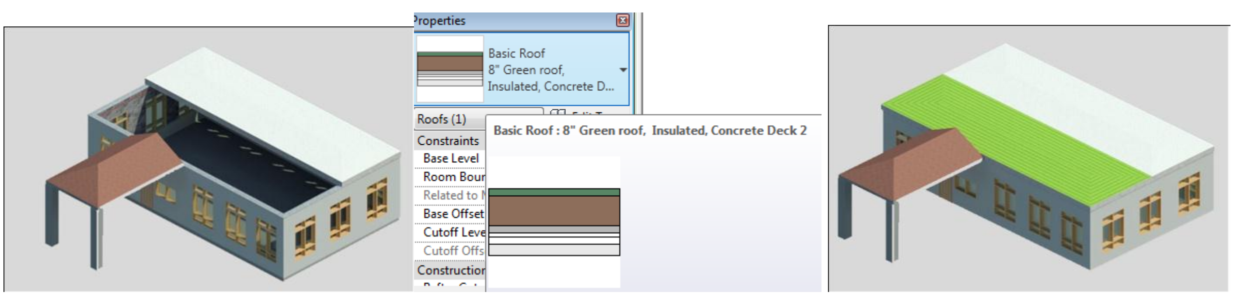

Figure 7: Example of selecting green roof family for the project Revit 2013

6 Conclusion and Future Work

This paper has discussed the development of a model that integrates a database management system with BIM for the design of green roofs. The integration of green roof databases and BIM is useful because individual components and their associated stored data can be selected when needed by linking product specification information. Using predefined families that meet the needs and requirements in the design process leads to the establishment of sustainable green roof design for proposed projects. In this research, a comprehensive database of green roof families has been developed for architectural components and elements. BIM's tool have been customized to fit the needs of users when they design for such roofs. The aforementioend case study demonstrated the effectiveness of the model in producing green roofs for proposed projects. The model is simple, user-friendly and user input and error are minimized. One of the advantages of using BIM is the time saved. This occurs through the capacbility to select material which is pre-defined in the BIM tools database. The proposed methodology enhanced the BIM tools database with green roof materials. Hence, it provides the decision maker with more sustainable options to select from while designing buildings. After storing all materials in the BIM database, products can be retrieved easily. Also, they can be easily modified to meet user needs. Ongoing research is underway to enhance the workability, capabilities and dependability of the model by increasing the number of materials and their properties.

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