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Employing an Exploratory Research Stage to Evaluate Green Building Technologies for Sustainable Systems

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Abstract- In many industries an exploratory research stage is employed to study new ideas or enabling technologies that may mature into a "system-of-interest". This approach to designing an energy optimizing product and service systems leads to challenging attributes because of the broad range of economic, environmental and social factors that are presented throughout the life-cycle of production. This paper reviews the key decision factors presented during the initial phase of the production of a lifecycle model for an ambitious research and development project (Green 2.0). The Green 2.0 project aims at exploiting advances in (i) Building Information Models (BIM), (ii) Online Social Networks (OSN) and (iii) Big Data technologies, to design and develop an interactive data-driven middleware for socio-technical analysis of *green buildings*. The main technical objective of the paper is to highlight green building technologies featuring advancements in virtual parametric models for creating an integrated technical analysis environment, while at the same time engaging end-users and harnessing their collective knowledge in building design. The paper adheres to a formal system engineering approach in order to identify the scope of the system, investigate alternative system design concepts, explore data collection methods and assess the relevant emerging technologies.

***Keywords*:** BIM, Green Architecture, System Integration, Middleware, Social Networks Analytics

1. Introduction

As the world is experiencing a period of extreme urbanization, professionals and researchers of the AEC (Architectural, Engineering & Construction) industry, as well as, public policy makers are pressed by the increasing complexity and need to improve our understanding of the social, technical and business dimensions of *green building design*. Green building design (a.k.a. *sustainable building design*) refers to the process of designing buildings (or other facilities) that are environmentally responsible and resource-efficient throughout a building's life-cycle. This typically requires close cooperation of the design team, the architects, the engineers, and the rest of the stakeholders (clients, manufacturers, contractors) at all project stages, but most importantly availability of new methods, tools and strategies that are enabled by emerging technologies. Designing and developing better services for the creation of Green buildings, is therefore, a global imperative and defines a number of research challenges and opportunities.

This paper builds around the Green2.0 project at the University of Toronto that tries to leverage advances in Building Information Models (BIM), Online Social Networks (OSN) and Big Data technologies to provide new insights into creating a data-driven approach to building design and planning. In particular, it aims to bring about a fundamental shift in the way we investigate green buildings at the following fronts:

- *Online BIM management*: Deployment of an online BIM management system that enables the efficient storage, indexing, querying and visualization of BIM elements on the Web.
- *Online BIM-enabled communication & collaboration*: Deployment of a service that enables the online communication and collaboration of researchers and professionals of the AEC industry around building elements, in an integrated environment. Data mining and analysis of the collaboration that takes place can further lead to interesting patterns of communication and social networks that can help researchers and professionals to identify, re-design and optimize processes, discover synergies, streamline the workflows of different stakeholders, as well as, to optimize information flow between decision makers.
- *End-user engagement in early stage of building design*: Integration of the system with available online social media will engage end-users in early stage of building design and help researchers build new theories of building design that harness the collective knowledge of participants.
- *Creating an integrated technical analysis environment for green buildings*: Integration of the system with green analysis libraries and platforms will enable researchers and professionals to better study and understand the complexity of energy efficiency of buildings, suggest new tools for faster analysis of design options, and develop new more efficient design codes.

As part of the overall design synthesis this paper aims to identify how social network and energy efficiency analysis methods and tools can be a source of integrating models that can harness creative ideas and enable green building design. The main contributing attributes of the paper is to present and discuss the requirements analysis, functional analysis and design synthesis of such a complex system. This suggests a novel and interesting system engineering process that will contribute to advancing from the project's exploratory research stage into the *design*, *implement* and *operate* phase.

2. Sustainable Systems

Fiksel (2003) recognises that there are several barriers that limit the practical application of sustainable development such as the needs to imply that economic profits should be balanced against environmental and social benefits. Whereas in fact, "sustainability is not an end state that we can reach; rather it is a characteristic of a dynamic, evolving system."

2. 1. System Integration

O. Grady (1994) identified the birth of system engineering as a process whereby complex challenges encourage more intricate combinations of available technology for which in turn require the capacity of open knowledge. DoD (2001a) recognizes that requirements analysis should result from a clear understanding of the function, performance and interface (*environment in which the system will perform*) and other constraints. They outline that the requirement analysis is the baseline for which the function and detail design will follow. Figure 1 illustrates the projects inputs which relate specifically to the "Green 2.0" investigation proposal of designing interactive middleware for analyzing Green buildings.

The requirements analysis involves; enablers such as CANARIE (Canada's Advanced Research and Innovation Network – *projects principal contributor);* control constraints featuring end user comments and specific environmental guidelines such as Social and Socio-economic LifeCycle Analysis (S-LCA – "help stakeholders to effectively and efficiently engage to improve social and socio-economic conditions of production and consumption"), Environmental Life Cycle Assessment (E-LCA – "looks mainly at the impacts on the natural environment of economic activities and, to a minor extent, impacts on human health and natural resources") and Corporate Social Responsibility (CSR – "the responsibility of enterprises to contribute to sustainable development") UNEP (2009) and Benoît et al. (2010) in order to transfer the requirements domain into a system performance outputs (interface elements, feature specification, functional view and process flow maps). Existing open source platforms such as BIMserver and its additional services featuring Building Collaboration Format (BCF - which attaches comments to specific elements of a BIM model via a globally unique identifier, GUID – unique reference number used as an identifier in the computers software) may be used as source to horizontally connect an application featuring Wayfinder ("Peer to Peer file system, Perry et al. (2004) algorithm for unifying publishing, searching and storing stakeholders and community comments on the Green 2.0 centralized heterogeneous network.

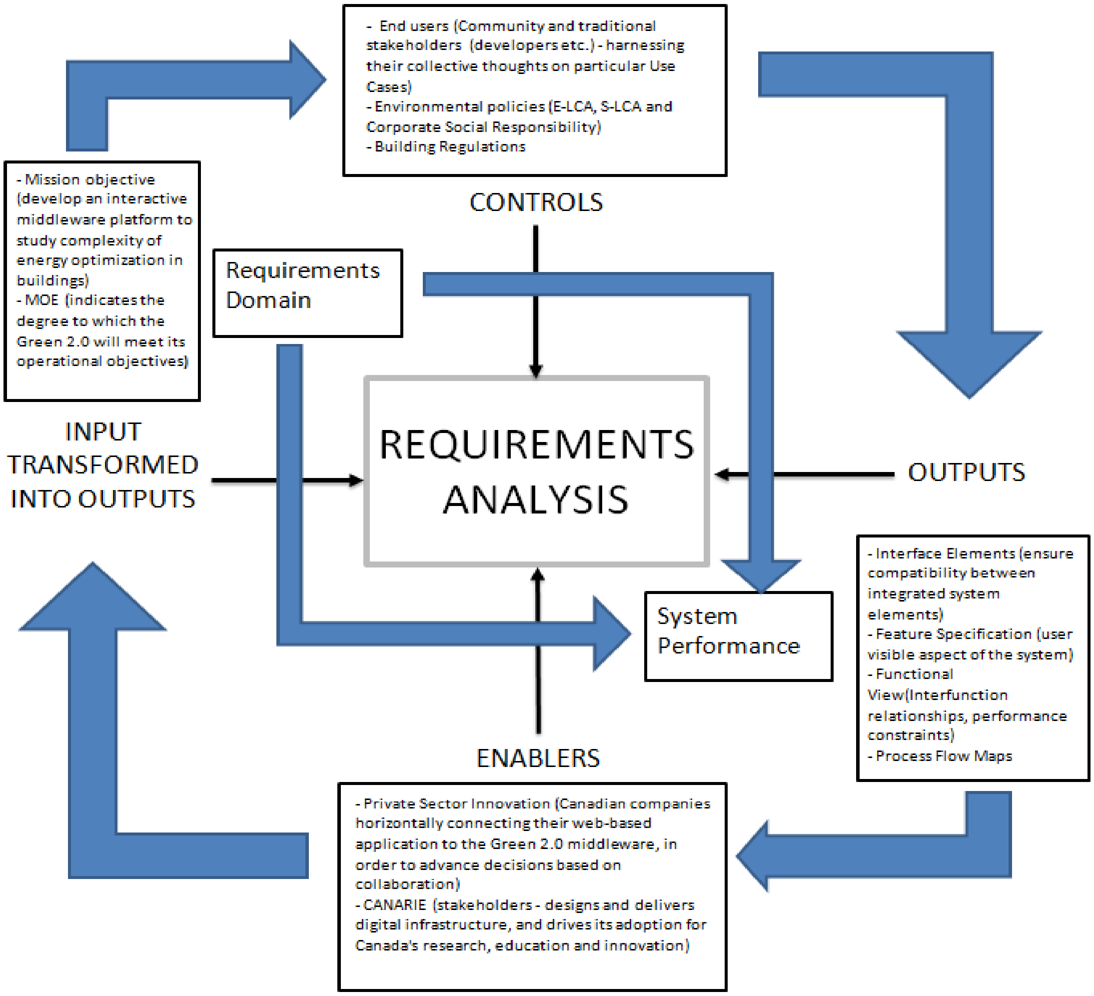

Fig. 1. Converting Requirements Domain to System Features (Authors, 2014) Legend; MOE (Measure of Effectiveness).

2. 2. Proof of Concept

In most cases the "Proof-of-concept" (a naïve realization of an idea or technology to demonstrate its feasibility) would be sufficient. However, the actual system design and development practices which focuses on WHAT the user is attempting to accomplish and select a solution from a set of viable candidates based on decision factors such as *technology, support cost, schedule, and risk*, requires investigation. The Green 2.0 project requires a validation strategy to uncover/clarify the requirements of its services. One such form of validation that will be conducted is prototyping:

INCOSE (2011) "Prototyping is a technique that can significantly enhance the likelihood of providing a system that will meet the user's need. It can facilitate both the awareness and understanding of user needs and stakeholder requirements." INCOSE identifies two types of prototyping rapid (which is a particular type of simulation quickly assembled from a menu of existing physical, graphical, or mathematical elements such as computer simulation shells) and traditional (is a tool that can reduce risk or uncertainty as objectives and quantitative data on performance times and errors rates are obtained from interactive fidelity prototypes).

Through visual modeling it demonstrates assumptions that will identify mismatches between written requirements and the interpretation carried forward in the prototype. It is anticipated that as part of the “programming interface and testing” the prototype will be tested by an external review panel in order to highlight whether the system is suitable and meets the measurements of effectives. In section 3 “Design Synthesis” the authors will outline the techniques used to identify system characteristics that determine requirements for system functions.

2. 3. Online Social Networks

In the future social networking will be regarded as the influential domain for organizing information and knowledge. According to Mislove et al. (2007) sociologists will be able to examine our data in order, to look for new forms of behavior such as sourcing and promoting products and companies. Within a construction context Valdes-Vasquez and Klotz (2013) evaluated 50 social sustainability processes and categorized them into a framework for integrating social consideration at the planning and design phase (“this phase has the greatest potential for influencing project performances”). The results of this study found certain key implications that can relate to the authors research objectives such as “social sustainability focuses on the users, appealing to the needs of those who will utilize the project during its life cycle and that projects will require impact assessment at the user (final and temporary) and community levels, because people are essential to achieving environmental and economic goals.”

Zhang and El-Diraby (2009) highlighted the problems with impending information exchange and knowledge sharing in the construction industry such as, the complexity of capturing a regular pattern of information production and consumption regarding actors and roles because of the diversification involved with these roles from project to project. This challenge prompted them to develop a Social Semantic Web Portal (SSWP) that facilitated people-to-people communication based on using ontologies.

The contribution of this project is to develop a middleware platform upon which researchers can study and develop tools to enhance the handling of the three challenges; i) how to educate, understand, and engage users; ii) how to embed this into a new seamless BIM-based analytical environment; and iii) and how to streamline and integrate the complex information flows of a modern supply chain into the design and operational analysis. It is the intent of this research project that BIMserver will facilitate the needs of providing a BIM infrastructure for developers to connect an external data model hosting University of Toronto’s ‘IFC (Industry Foundation Classes – international open exchange standard) commenting tool and social analytics software’ for providing the user with a range of categorised solutions based on project specific comments

3. Design Synthesis

DoD (2001b) recognises that the ‘The System Engineering Process’ (SEP) is a comprehensive, iterative and recursive problem solving process, applied sequentially top-down by integration. Figure 2 is adapted from U.S. Air Force (2005) and structured to DoD recommended design process. The diagram shows the three main phases associated with the design synthesis for developing services. The requirement analysis phase which is mostly associated with pre-project and pre-conceptual planning stages evolves into the functional analysis which features some aspects of pre-conceptual planning before moving into the conceptual design stage, has a requirement loop as part of the iterative process to constantly review the chosen requirements. The next phase “synthesis” transfers the functional architecture into physical architecture. The pop out section of the diagram illustrates the synthesis phase in detail emphasizing alternative processes and alternating systems that assist in defining external interfaces (section 4 Table 1 shows the proposed interface elements for the Green 2.0 project) before verification that leads to the overall process output. The following sub-sections explain these phases in more detail.

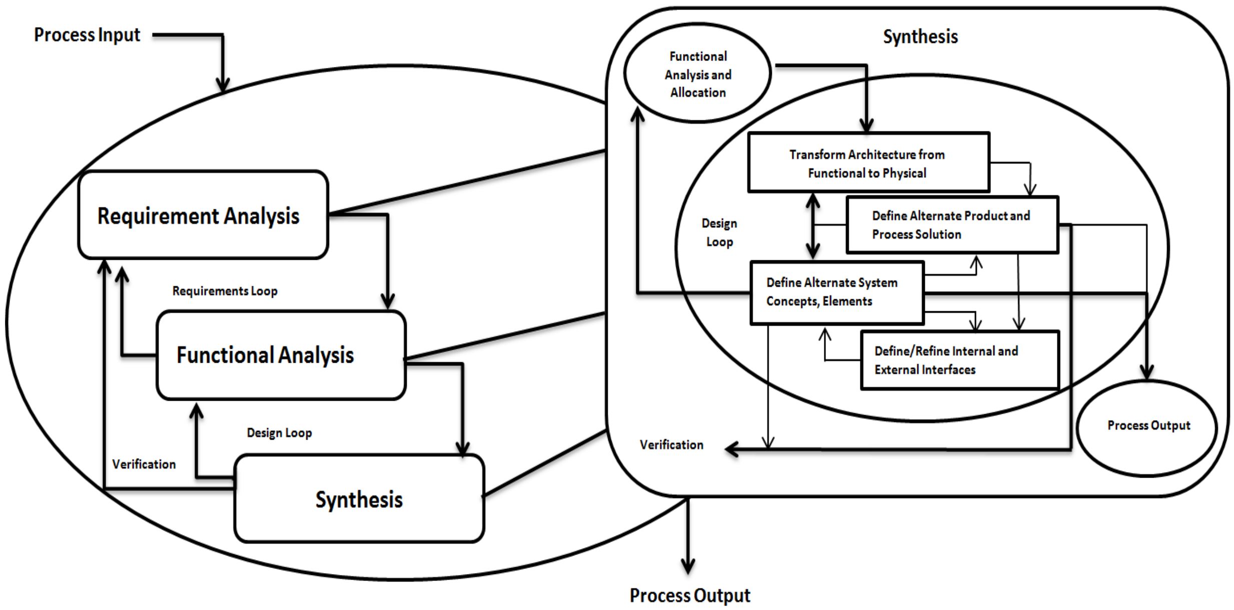

Fig. 2. Green 2.0 Design Synthesis Process (adapted from DoD, 2001b and U.S. Air Force, 2005)

3. 1. Requirement Analysis

The requirements phase involves constantly decomposing functions and constraints of the system elements to lower levels of development. For the Green 2.0 project the requirements engineer has been focusing on scenario analysis based on the properties of the mission statement and the building model from an integration perspective. As part of refining the performance specification the nature and validity of the original proposal of customer needs has been taken into consideration and several alternative design solutions have been investigate via story boards and expert interviews.

The main actors currently identified as part of the scenarios are; project owner, facility user, government agency and supplier. The six characteristics associated with the Green 2.0 project (Estimate HVAC cost for design, evaluate projected LEED score, evaluate cost and environmental benefits of a design alterative, check if design complies with environmental codes, evaluate benefits of green technology, and estimate building lifecycle costs and emissions) are the current key scenarios that will eventually be measured as part of requirements analysis phase.

3. 2. Functional Analysis

The functional interface analysis has been structured to bridge the gap between the high level set of system requirements (commenting tool, BIMserver, BIMsurfer (open source visualization of a BIM model), green in and out technology and requirements) and constraints (simplification of IFC files) and the detailed set required in the synthesis (design codes, environmental analysis ratings, social and economical lifecycle analysis, sustainability lifecycle analysis, life cycle costing, open source BIM energy analysis applications etc.) to develop and implement the program.

The three separate architectures (illustrated by three large squares filled with columns and rows) are connected in a diagonal flow shown by the bold highlighted squares. The squares located on the left represent input whereas the squares positioned on the right of the associated diagonal square denote output. The large bold lines show how a column from one N2 square can be connected to a row of another representing input if the line is connected from the under-layer of the N2 square or output if the line is stemming from the right connecting to the top of the subsequent N2 square. The following sub-sections will explain the relationships between the N2 squares (architectures) shown in Figure 3.

Figure 3 shows 3 x N2 diagram (a systematic approach that is used to develop (sub) system interfaces). The system functions are placed on the chart diagonally; "the remainder of the squares in the N x N matrix represents the interface inputs and outputs" (NASA, 2007).

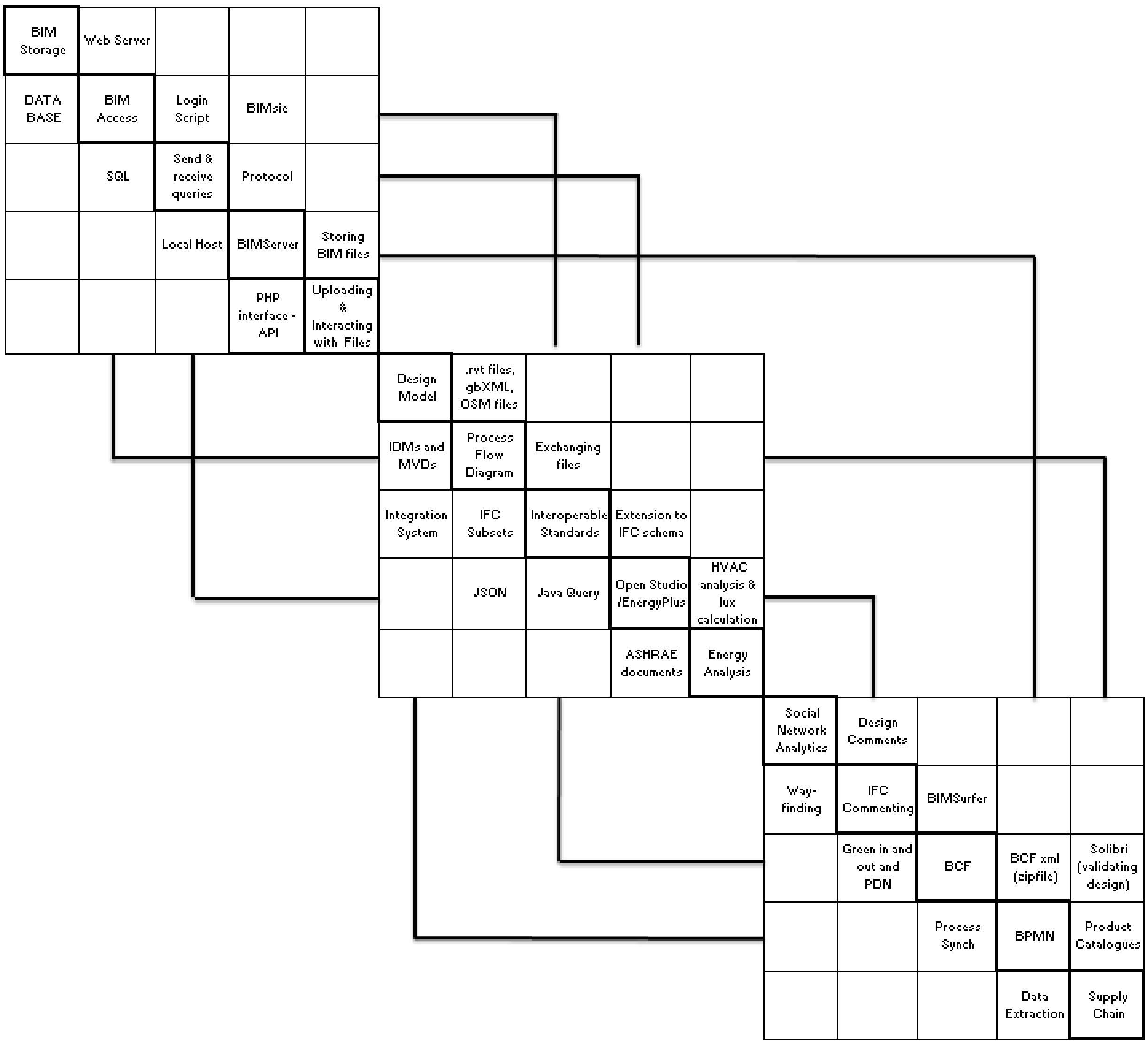

Fig. 3. Green 2.0 N2 Diagram (Authors, 2014) Legend; BCF (Building Collaboration Forum), SNA (Social Network Analytics), PDN (Professional Discussion Networks), BPMN (Business Process Management Notation)

First N2: The first N2 diagram has five diagonal boxes; 1) BIM storage and 2) BIM access management - refers to the database and its relational database management system (RDBMS) that interacts with BIMserver (open platform for storing and viewing IFC files), the output of login scripts and BIMsie (Building Information Modeling Service Interface Exchange) to interface with BIMserver and connect to other applications, 3) Send and Receive messages – this box relies on the input of SQL (Structured Query Language – used to manage the data held in the BIM storage (RDBMS) and the output is the connecting calls based on the specific queries, 4) BIMserver – this local host will be stored within the project on premise server but will have public user domain features to access the BIM files, and 5) Uploading and Interacting with Files – the Application Performance Interface (API) will enable access through Simple Object Access Protocol (SOAP – specification for exchanging web service information) developed by PHP server script.

Second N2: The second N2 diagram is formatted in the same manner as the previous; 1) Design Model – this is the actual virtual model that contributes to output files such as .rvt (if using Revit application), Green Building XML (gbXML) and OpenStudio Model (OSM), 2) Process Flow Diagram and 3) Interoperable Standards – feature the interoperable challenges that exist with using different files and a common issue in relation to IFC is the actual file size, as a means to reduce the file size, BuildingSmart Alliance have recommended a standard process flow; Information Delivery Manuals (IDMs – swim lanes representing the exchange process) and Module View Definition (MVDs – specifications based on IDMs that assist in developing sub-sets of IFCs) in order to exchange files that represent the process needed i.e. the mechanical engineer only requires the information extracted from the model based on specifics such as HVAC etc., 4) OpenStudio/EnergyPlus – OpenStudio is a cross-platform (Windows, Mac, and Linux) collection of software tools to support whole building energy modeling) https://openstudio.nrel.gov/) it can conduct energy analysis using EnergyPlus and advanced daylight analysis using Radiance, however due to different formatting issues JSON format (JavaScriptObjectNotation: a lightweight data-interchange format) is required for accomplishing the transformation, and 5) Energy Analysis – at this stage (preliminary design) the main output been considered is radiance and HVAC.

Third N2: The final diagram representing the third architecture includes two of the main components of the project as outlined in the introduction section (Social Network and Supply Chain); 1) Social Network Analytics – the output stemming from the PDNs focusing on guidelines such as E-LCA and S-LCA (as shown in Figure 2) and regulations will form the specific design comments, 2) IFC Commenting – this tool will be connected to the files hosted in BIMserver and a possible means of using Wayfinder to store and categorize the important comments, the BIMsurfer output attribute is to view the associated elements of the model within BIMserver, 3) BCF – BIMServer has created BCF as a means to exchange comments based on the associated IFC files, it is the authors anticipation that BCF should be advanced (via extension to the existing script) to analyze a more depth meaning to comments with the concept of interacting with the IFC Commenting application or advancing it, the output of the file can be loaded in Solibri where automated reviews can be undertaken (Khemlani, 2010), 4) BPMN – is a specification for which its primary objective is to eradicate productivity bottlenecks in writing software code, by using a simple set of flow chart symbols, business managers can describe a process flow and the software developer can implement these workflows into an executable code (White, 2004), the process flow diagram for the IDMs identified in the second N2 architecture will feed into the BPMs overall supply chain management such as guiding users through decisions, leveraging existing systems and data (synchronization), and real-time visibility and process control.

4. Green 2.0 Work Breakdown Structure

The Green 2.0 project defines a complex system that provides several interfaces for interacting with input and output of data. With regards, to the development of the middleware, a Work Breakdown Structure (WBS) method has been employed for assisting in the decomposition of the project into smaller components. Moreover, the WBS provides a common framework for the natural development of the overall planning and allows for schedule, cost, and labor hour reporting to be established. Meredith and Mantel (2012) identify that the preparation of WBS is to determine the increments (tasks) required to complete each of the project components. For the needs of the Green 2.0 project, four modules have been identified and designed. Table 1, defines the four components and the increments (tasks) associated with each of them towards an integrated system.

Table 1. Green 2.0 Work Package Modules (Authors, 2014)

BIM Community	Green In & Out	Social Network Analytics	Alert/Notification
• Authorization	• Provide Input for Analysis Software	• SNA Metrics	• In-depth monitoring
• Account Management	• Manipulate IFC Model for Analysis	• User Engagement	• Real-Time Performance Charts
• Profile Management	• Perform Energy Analysis	• Reaction Time	• Management Repository
• Activity Dashboard	• Save Analysis Results	• Influence Analysis	• Email Notification
• Browse Projects	• Perform Life-cycle Cost Analysis	• Sentiment Analysis	
• Browse Users			
• View User Profile			
• Project Management			

Component 1 "BIM Community" – this module enables the creation of a Community of Practice (Lave and Wenger [1991]) around Building Information Models (BIM). It consists of methods for efficient storage, indexing and querying of BIM documents and methods that provide means of online collaboration and communication of the various stakeholder around building design elements.

Component 2 "Green In and Out" – this module enables the integration of Building Information Models and third-party open source Energy efficiency simulation software (such as, OpenStudio for providing radiant and HVAC analysis) and can enable real-time energy-efficiency analysis.

Component 3 "Social Network Analytics" – this module enables socio-technical analytics of buildings. Analysis of discussion networks formed around BIM elements can reveal interesting patterns and trends of collaboration and communication. Moreover, it can enable engagement of community in early stages of building design and can guide the decision making process.

Component 4 "Alert/notification" – this module enables real-time monitoring of key performance indicators (or metrics) of the system that provides a means of delivering messages to a set of recipients (notifications or alerts) when some pre-defined limits have been reached, thus enabling prompt awareness and reaction.

5. Conclusion

This paper was based on the conceptual design phases of a systems lifecycle. In referring to "design stages", the conceive stage within an overall design synthesis represents requirements analysis of a system integration. The main objective of the project is to exploit advances in emerging technologies in order to design and develop an interactive data-driven middleware for socio-technical analysis of green buildings ("system integration"). The paper outlined both why ("to empower researchers from diverse backgrounds to create analysis protocols to study the complexity of energy optimization in buildings") and how ("to engage end-users and harness their collective knowledge"). The project's overall rationale features aspects of social analytics, building information models, and supply chain management. Various methods of Systems Engineering were presented throughout this paper, such as; N2 diagram - N x N matrix representing the interface inputs and outputs; work package structure - illustrating a preliminary breakdown of the modules in relation to Table 1 proposed Green 2.0 system BIM communication, BIM SNA, Green technology and alert/notification. The associated challenges and limitations have also been expressed and due to the fact that the project is only entering the design stage many more constraints will be defined, before selecting the most appreciate process for advancing the design synthesis of a sustainable system.

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