

BIM and Conceptual Design Sustainability Analysis: An Information Categorization Framework

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Sustainability in construction has attracted considerable attention from scholars as well as from regulatory bodies. However, early design stage sustainability analysis remains problematic because of the conflicting factors affecting sustainability, the limited and fragmented project data in hand and deficiencies of existing sustainability analysis software for quick evaluation of conceptual design alternatives. Building Information Modelling's (BIM) information management and integration capabilities present opportunities to support early design sustainability analysis. In this paper, early findings of an on-going BIM based early design sustainability analysis application development project are presented. Through literature review and in-depth interviews with a sustainability professional, an information categorization framework for quick evaluation of different conceptual design alternatives from a sustainability point of view is developed. The framework guides further stages of the application development project and also supports BIM Execution Planning for projects where holistic early design sustainability analysis is intended.

Key Words: BIM, Design, Information management, Information technology, Sustainability.

Introduction

A widely accepted definition of sustainability is given by the Brundtland Commission as “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987, p.37). The energy consumption of buildings contributes significantly to global warming which threatens the future of our planet. This fact makes the energy performance of buildings an important issue for their sustainability (Park et al., 2012). However, El-Alfy (2010) states that economical, functionality, durability, aesthetics, ecology, health and sociocultural aspects of a building design are together the factors affecting a building’s sustainability. A building’s sustainability is dependent on several inter-related and inter-dependent factors and these factors are affected by the design decisions made by different stakeholders of a construction project which can be in conflict (Anastas & Zimmermann, 2003). The inter-relations and inter-dependencies that should be considered for a meaningful sustainability analysis require the collective evaluation of the design information created by different stakeholders of the project design team. Therefore, a collaborative and robust building information management system is desirable to support such analysis (Lam et al., 2004).

Building Information Modelling (BIM) can be defined as the process of development and use of a digital model of the facility intended to be built. The resulting product of BIM, the Building Information Model, has the ambition to be the central hub for all information about the facility from its inception onward (BIM Industry Working Group, 2011). The conceptualization and use of the Building Information Model as the central hub for all information requires all stakeholders of the project to contribute to and exploit this building information in an inter-disciplinary collaborative effort during its whole life cycle. Therefore, BIM is increasingly considered as an Information Technology (IT)-enabled approach that allows better management and representation of building information (Fischer, 2004). Consequently, it is argued that information management capabilities of BIM offer new opportunities for sustainability evaluation and decision-making in building design (Bank et al., 2010; Nguyen et al., 2010).

In this paper we present the early findings of a BIM application development project which aims to provide sustainability professionals (SPs) with a BIM based sustainability analysis tool for the quick evaluation of different conceptual design options. This work follows the design science research paradigm under which “knowledge and understanding of a problem domain and its solution are achieved in the building and application of the designed artifact” (Hevner et al., 2004, p.75). Considering the audience that this paper addresses (i.e. built environment professionals), emphasis is on “the importance of the problem and the novelty and effectiveness of the solution approach realized in the artifact” (Hevner et al., 2004, p.90). The research methodology involved a literature review and in-depth interviews with a sustainable design professional which is justified as the starting point for practical artifact generation. The research was undertaken by the first author as part of a secondment to a company funded by the European Union Climate - Knowledge and Innovation Community (Climate-KIC). The work reported here is three-fold: first it explores challenges for quick evaluation of different conceptual design alternatives from sustainability perspective; second it shifts its focus to BIM environment and discusses the implications of these challenges on the development of a BIM based early design sustainability analysis tool; and finally it proposes a framework which categorizes the information needed by SPs for quick evaluation of conceptual design alternatives in a BIM based application. It is argued that categorization of the information following the proposed framework would appropriately define and organize the early design project information from sustainability point of view, thus underpin quick evaluation of conceptual design alternatives in a BIM based application.

Challenges of BIM Based Sustainability Analysis at Conceptual Design Stage

A building’s sustainability is dependent on several inter-related and inter-dependent factors and these factors are affected by the design decisions made by different stakeholders in a construction project (Anastas & Zimmermann, 2003). In the traditional, non-BIM design workflow, performance assessments of the design are generally undertaken after the completion of architectural design when the design is almost completed (Soebarto & Williamson, 2001; Schlueter & Thessling, 2009). Such performance assessments consists of several independent (Bank et al., 2010) detailed analyses made by expert software using the detailed design information. Crucially, this detailed information is not available at the early design stages and also involves considerable interpretation by experts (Schlueter & Thessling, 2009). These independent analyses hinder having a holistic understanding of sustainability issues and presenting a holistic sustainable design solution (Bank et al., 2010).

The performance assessments made at late stages of the design may lead to design of buildings that have only limited sustainability e.g. in terms of services but not in architectural aspects (Schlueter & Thessling, 2009). The performance assessments that are undertaken at late stages of design also lead to adoption of bolt-on solutions rather than holistic solutions to fix the unsatisfied target sustainability criteria. This is due to the impossibility of making big design changes at late stages of design development because of the concerns about cost and time. Sustainability and environmental impact issues of a building require to be considered before the conceptual design stage and these considerations should be reflected in the conceptual design alternatives to achieve the sustainability targets (Ding, 2008). It is widely acknowledged that most of the key design decisions affecting the building’s sustainability are made during early design stage and these decisions that are made at early design stage have the greatest impacts on the cost as well (Bank et al., 2010). Therefore, one of the challenges is to find a design evaluation method suitable for early design stage that provides enough understanding of the design for decision making (Brahme et al., 2001). At conceptual design stage, sustainability analysis method and criteria should not rely on detailed design information which will be generated later by the designers (Ding, 2008).

Sustainable building design is a matter of optimization of several different aspects of a building because of the conflicting nature of some of the factors affecting sustainability (Anastas & Zimmermann, 2003). For example, the most environment friendly functional systems configuration for a building, may not always be the most aesthetic and/or cost efficient solution. Optimization requires overall consideration of information provided by different disciplines with different foci against target sustainability criteria. This creates several challenges for early design sustainability analysis. First of all, a sustainability professional (SP) with an overarching focus is required for the translation of client needs and project specific constraints to determine the target sustainability performance criteria.

Second, relevant design information from different disciplines need to be integrated, reachable and exploitable in order to conduct an inclusive sustainability analysis (Nguyen et al., 2010; Wong & Fan, 2013). However exploitability is a relative quality which depends on the intended use of information. Mutis and Issa (2012) stated that users from different backgrounds of an integrated and shared building model may have problems making sense of the information embedded into the model due to semantic gaps between the ways this information is presented to them and the way they need to use it to perform their tasks. This means that, in order to enable SPs to benefit from the information embedded into the model for analysis and interpretation; design information should be presented in a way that can be made sense of it. Once this condition is satisfied, SPs (who are knowledgeable about different aspects of sustainability at systems-level) can interpret results to support decision making.

Finally, although building assessment schemes such as Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM) were not designed to be used as design guidelines, they are increasingly being used as such (Cole, 1999). This is also an important deficiency in sustainability analysis. The credit-weighting approach which compound to the final score of the building being assessed is the heart of building assessment schemes and there is no consensus for the weightings used (Cole, 1998; Lee et al., 2002). Ding (2008, p.457) criticizes that “the overall performance score is obtained by a simple aggregation of all the points awarded to each criterion. All criteria are assumed to be of equal importance and there is no order of importance for criteria”. Mainly due to conflicting nature of some of the factors affecting sustainability, Ding (2008) adds that the criteria should be developed according to each project’s aims and conditions. It can also be argued that, pre-defined criteria (i.e. criteria which are not project specific) of building assessment schemes may hinder some sustainable design avenues, making designers focus on high and relatively easily gained credits provided under some pre-defined headings of the scheme while disfavoring some others.

BIM Information Needs for Sustainability in Conceptual Design

Two approaches are identified in the literature for BIM based sustainability analysis applications. Some research concentrates on integration of existing and widely accepted sustainability performance analysis tools (e.g. IES - Integrated Environmental Solutions-Virtual Environment) with other widely accepted collaborative BIM tools (e.g. Stumpf et al., 2009; Azhar et al., 2011) whereas some other research aims to develop new analysis tools that are able to communicate with widely accepted collaborative BIM tools (e.g. Schlueter & Thesseling, 2009; Nguyen et al., 2010). Park et al. (2012) make the point that high development costs, usability and interoperability issues of adapting existing energy analysis software need to be considered when deciding which approach to use. These considerations together with the challenges identified in the previous section led the application development team to create a new early design sustainability analysis application for quick evaluation of different conceptual design options.

Although there is on-going research and development that aims to provide seamless interoperability between collaborative BIM tools (e.g. Autodesk NavisWorks) and widely used sustainability analysis software (e.g. IES), there are still interoperability problems. Transfer of the building model from collaborative BIM tools to proprietary sustainability analysis tools causes loss of information in many instances. Therefore, development of a new application using the Application Programming Interfaces (APIs) to communicate with dominant collaborative BIM tools in the market was preferred.

There are also some other important issues regarding the usability (i.e. exploitability of the information) of existing applications. Firstly, it is revealed from the interviews that a level of understanding of a wide range of technical domains (i.e. building materials, mechanical engineering etc.) is required to benefit from the outputs of the analyses conducted by existing, widely used sustainability analysis tools. This is seen as a deficiency considering the fact that at conceptual design stage the effects of different building sub-system configurations (e.g. type of external fabric, heat generation and distribution systems) and their advantages and disadvantages need to be shared with the client and other stakeholders in a way they can make sense of it. Thus, it is believed by the project team that development of a new early design stage sustainability analysis tool would allow them to present the outputs of analyses in a more meaningful way for client and other design team members and even for other stakeholders of the project.

Tailored outputs that highlight needs and demands of different stakeholders at early design stage would encourage and facilitate discussion around different aspects of sustainable design in construction. This point is even more important when the soft issues (e.g. sociocultural aspects) or qualitative data (e.g. environmental sustainability criteria which are not quantitatively defined yet at early design stage) are to be considered during early design stage sustainability analysis. Although the application development project reported in this paper doesn't aim to integrate the qualitative information and soft aspects of sustainable design into the BIM based application to be developed, it is argued that thoughtfully tailored outputs can be created to support and facilitate the discussion around these qualitative information and soft aspects of sustainable design at early design stage.

Furthermore, it is also revealed from the interviews that the existing sustainability analysis tools don't provide enough flexibility to easily change the building systems' configurations (e.g. type of external fabric, glazing percentage, energy generation and distribution systems) at level required (i.e. systems level) for conceptual design evaluation. Many objects of the model in the sustainability analysis tool need to be selected individually and dropdown menus need to reconfigure the model to evaluate the effects of systems configuration alternatives. It is believed by the project team that development of a new early design stage sustainability analysis tool would be more convenient as it would allow the project team to group the information embedded in the collaborative building model according to their needs and therefore provide a more flexible and suitable working environment for evaluation of different building systems configurations. Finally, because of the deficiencies in their credit-weighting approach and their pre-defined criteria that don't reflect project peculiarities; development of a new information framework that suits early design holistic sustainability analysis is preferred rather than following an existing building assessment scheme (e.g. LEED) for information categorization and sustainability evaluation.

Categorization of Information for Early Design Sustainability Analysis

The application development work is initially concerned with the construction projects in UK. Consequently, in this paper, The RIBA (The Royal Institute of British Architects) Plan of Work 2007 which is the UK model for the organization of building design, construction and operation processes is used to refer to different project stages. The RIBA Plan of Work 2007 consists of eleven key work stages which are: Project Appraisal (Stage A), Design Brief (Stage B), Conceptual Design (Stage C), Design Development (Stage D), Technical Design (Stage E), Production Information (Stage F), Tender Documentation (Stage G), Tender Action (Stage H), Mobilization (Stage I), Construction to Practical Completion (Stage J) and Post Practical Completion (Stage K).

Sustainability issues of a building need to be considered even before the conceptual design stage and these considerations should be reflected in the conceptual design alternatives to effectively achieve the sustainability (Ding, 2008). This view is supported by the interviewed SP who stated that building functionality, site conditions, target building performance criteria, budgetary and time limits should be understood and documented during project appraisal (RIBA Stage A) and design brief (RIBA Stage B) stages to enable an efficient sustainable design starting from conceptual design stage (RIBA Stage C). The in-depth interviews revealed that sustainability professionals divide RIBA Stage C into three consecutive sub-stages. These sub-stages and their aims are presented in Figure 1. The first sub-stage is for selection of the building system. It is stated by the interviewee that spread sheet applications can be used for this sub-stage because at this stage, evaluation of each building system alternative mainly depends on experience as well as insight about the historical data and limited project specific information in hand. Following the building system assessment, a sustainability pre-assessment meeting needs to be organized. This meeting is important to inform design team members about the sustainability criteria established during RIBA Stages A and B and therefore to enable development of comparable and satisfactory conceptual design alternatives.

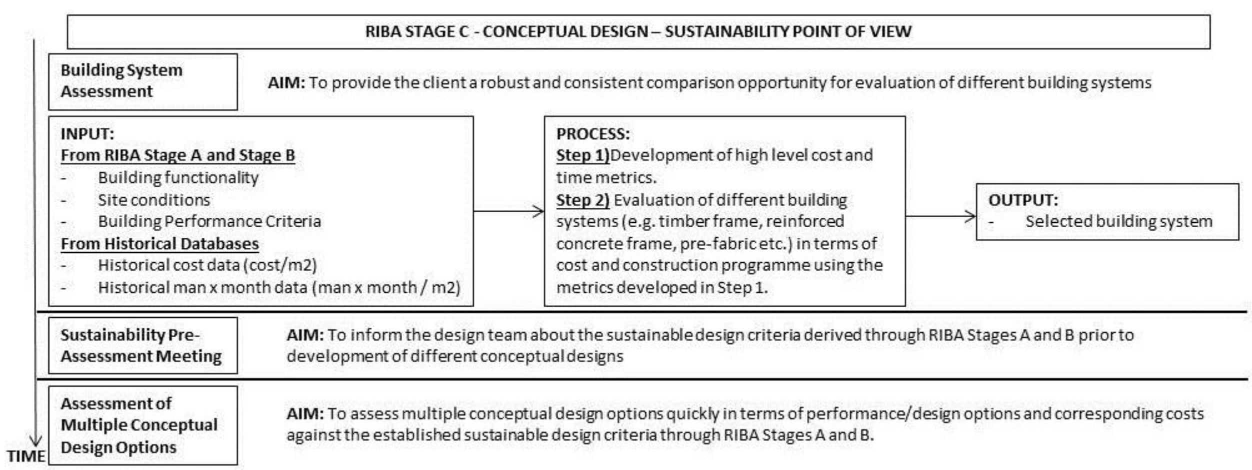

Figure 1: RIBA Stage C (conceptual design stage) from sustainability point of view

The third sub-stage is the evaluation of the conceptual design alternatives. It was decided that this sub-stage can be leveraged by the computer application to be developed. As stated in the previous section, it was decided that the new application would use the information embedded in the building information model created by different contributing parties and merged under a collaborative BIM tool. This means that the model doesn't need to be transferred into the application to conduct sustainability analysis with the application extracting the information needed for sustainability analysis from the collaborative building model. This requires the robust structuring of the information to be entered into the model for later use by SP and other analysis applications to enable quick evaluation of conceptual design alternatives.

Detailed structuring (i.e. identification of parameters and attributes to be assigned to objects and/or systems/sub-systems in the model) of the information is not in the scope of this paper and will be undertaken at later stages of the application development project. Moreover, the detailed structuring of the information to be entered into the model will change according to the collaborative BIM software that the application would be integrated with. However, a general framework which would underpin the detailed structuring of the information has been developed and presented in Figure 2. This framework categorizes the information required for quick evaluation of conceptual design alternatives from sustainability perspective considering and connecting SP's and analysis application's needs.

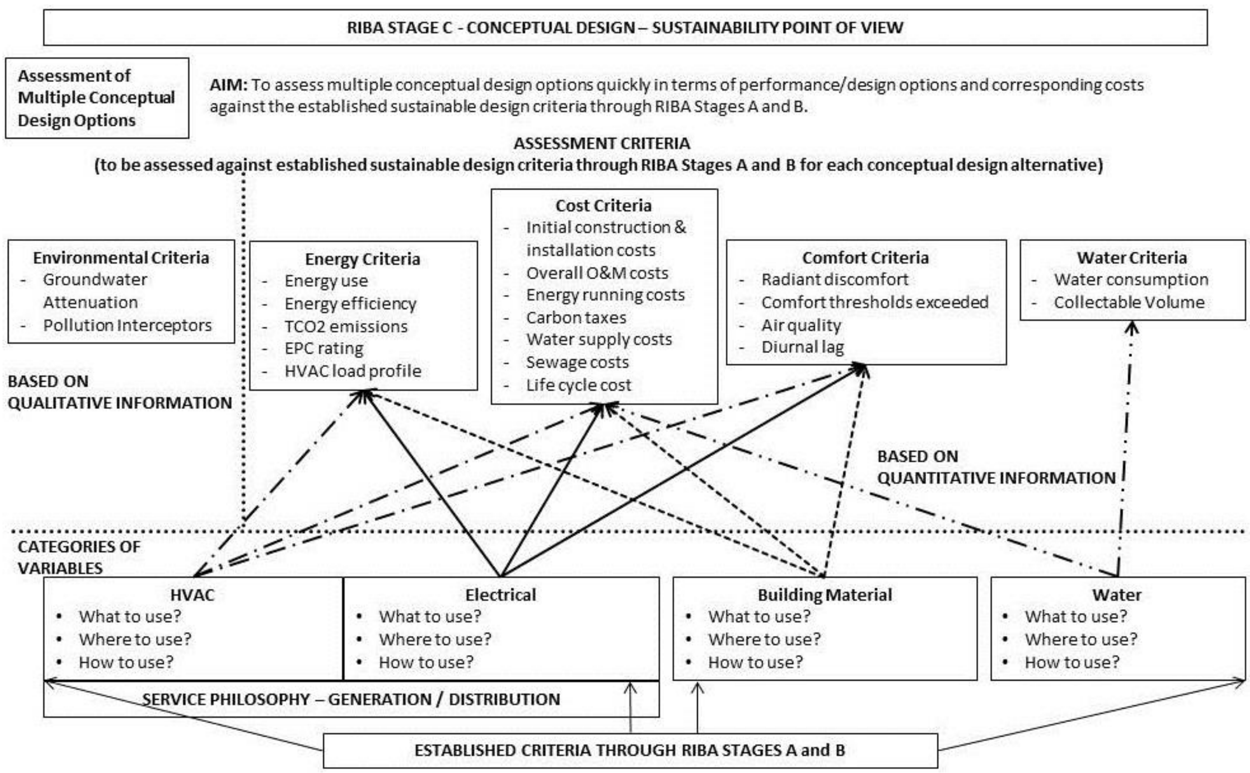

Figure 2: Categorization of the required information for sustainability analysis

The assessment criteria categories identified through the interviews represent the different aspects of sustainable building design which are needed to be evaluated for each conceptual design alternative at RIBA Stage C. Among them, the "Environmental Criteria" category is mainly based on qualitative information at RIBA Stage C; therefore, it was decided that it would be kept out of the analysis application. The arrows drawn between variable categories and assessment criteria categories show the contributions of each variable category to different criteria categories.

The answers to the questions under each variable category determines the required level of detail (i.e. what question) and contextual information (i.e. where and how questions) in order to satisfy application's computational needs and SP's application usability needs. It is argued that a BIM application which allows quick and easy reconfiguration of these variables would allow SPs to quickly and efficiently evaluate different configurations of systems/sub-systems of conceptual designs through meaningful presentation of their implications on sustainability.

The interviews revealed that SP wants to be able to evaluate different systems/sub-systems under four variable categories at conceptual design stage: HVAC, electrical, building material and water fittings. A critical task here is to identify the level of detail and perspective of information that would be addressed asking "what", "where", and "how" questions for each variable category. It is very likely that more than one answer representing a different perspective for each variable under each category would be used for holistic evaluation. For example in the HVAC category, the "what" question should distinguish whether the whole system or distribution and heat generation systems should be addressed (i.e. different level of details)? At the same time, the HVAC system can also be described as an energy conversion system (i.e. representation of a different perspective). The same situation applies to "where" and "how" questions. For example, again for the HVAC category, the answer to "where" question would address both different heating/cooling zones in the building and the positions of the spaces in relation to building orientation. Again for the HVAC category, the "how" question should identify the performance information needed for each element identified under the "what" question. The performance here can be energy performance but it can also be thermal performance. It is argued that, answers to these questions would give a clear understanding of expectations of SPs from the application to be developed.

Due to the different stakeholders' contribution to a single final product (i.e. a building), organization of the information has always been a concern in contemporary construction industry. This concern is further increased in BIM enabled projects where there is a strong emphasis on information interoperability. Similarly, in order to answer the questions in the framework without causing any confusion between different stakeholders, using a predefined structure for the organization of the information is beneficial. There are several different built environment information classification systems in use around the world (e.g. OmniClass, Uniclass). Among these information classification systems, Uniclass is the UK implementation of the international standard ISO 12006-2 (Building construction - Organization of information about construction works - Part 2: Framework for classification of information).

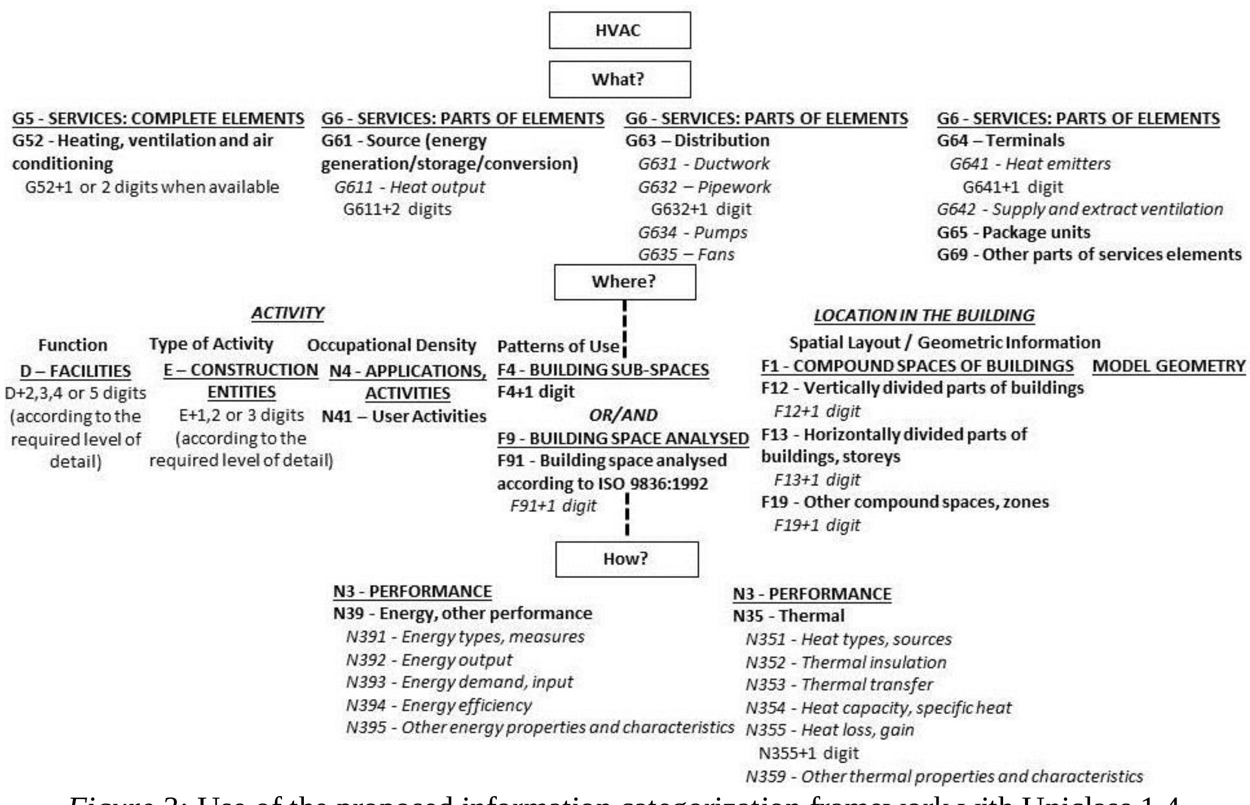

Figure 3: Use of the proposed information categorization framework with Uniclass 1.4.

Uniclass provides a robust information classification structure for the built environment. Furthermore, Uniclass provides the flexibility to identify different levels of detail and perspectives of information necessary for the proposed framework. For example, in Uniclass 1.4, the information about the user activities in a building can be classified under the Table N4 – Applications & Activities - N41 – User Activites (i.e. a particular perspective for answering the "where" question for the HVAC category considering the occupational density). At the same time, the information about building sub-spaces (e.g. working space, activity space etc.) can be classified under the Table F4 – Building Sub-spaces (i.e. another particular perspective for answering again the "where" question for the HVAC category this time considering the patterns of use). Additionally, the breakdown structure of each table in Uniclass allows its users to choose the level of detail they are concerned with. A demonstration of how Uniclass can be used to structure the information acquired answering the questions in the framework are presented in Figure 3 using Uniclass 1.4.

Consequently, it is argued that Uniclass is a beneficial classification system that can be used for the organization of the information addressed by the questions asked in the developed framework. Therefore, using Uniclass, or another information classification system with similar features, would help to avoid information organization problems such as overlap, confusion and misinterpretation in the application of the developed framework (e.g. development of BIM based early design sustainability analysis application; BIM Execution planning for the projects where a holistic early design sustainability analysis is intended).

Conclusions

Sustainability in construction has attracted considerable attention from scholars as well as from regulatory bodies. However, early design stage sustainability analysis remains problematic because of the conflicting factors affecting sustainability, the limited and fragmented project data in hand at early design stage and deficiencies of existing sustainability analysis software for quick evaluation of conceptual design alternatives from sustainability perspective. BIM's building information management and integration capabilities present opportunities to support early design sustainability analysis. However, in order to benefit from BIM's capabilities, the requirements of early design sustainability analysis need to be well understood.

This paper developed an information categorization framework to enable SPs to quickly evaluate multiple conceptual design alternatives in BIM environment. The framework allows the identification and connection of the building aspects necessary for optimization in the early design. This categorization also guides the future stages of the application development project when the detailed information needs will be refined. Furthermore, this categorization can be used as a support tool for BIM Execution Planning for the projects where a holistic early design sustainability analysis is intended to be conducted. The limited results used in this paper may imply that the conclusions are not generalizable and so will be validated further through more interviews, workshops and software testing. Such future research to validate the categorization presented in this paper will lead to a better understanding of early design sustainability analysis and better applications supporting it.

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