Chapter 32
BIM-Based Sustainability Assessment: Insights for Building Circularity

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Abstract Facing the increased pursuit for sustainable buildings, the construction industry has been adopting new project technologies such as Building Sustainability Assessment (BSA) and Building Information Modelling (BIM), providing new potentialities like continuous data storage, optimised building performance and integrated building design. Facing the opportunity to integrate BSA into BIM, a BIM-based application—SBTool^{BIM}—was developed to automate BSA during the project early stages. Visual Programming Language (VPL) was used to translate 19 criteria requirements from SBTool^{PT}-H and additional BIM connections were identified for the remaining 6 criteria. The applied procedure has established a novel framework to carry out BSA within the BIM environment in a faster reliable way. Such a method can provide valuable insights for a BIM-based application for building circularity assessment by using similar structures and procedures. This research aims to explore SBTool^{BIM} in order to identify possible insights which can be replicated for a BIM-based application to assess buildings circularity potential. Results show the potentialities of SBTool^{BIM} structure for circularity purposes, as different multidisciplinary data can be stored in the BIM model, novel Key Performance Indicators (KPIs) can be easily integrated and the evaluation structure can be adapted according to the analysis requirements.

Keywords Building information modelling (BIM) · Project tool · Buildings circularity

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32.1 Introduction

General society and worldwide authorities are increasingly looking for more sustainable buildings [1]. To turn buildings more efficient, there is a need to act since the early project stages by introducing and analysing different sustainability measures. To support decision-making regarding effective sustainable measures and to monitor the building's sustainable performance, BSA methods have been developed all over the world and adapted to the specific conditions of each location and building [2]. However, carrying out a BSA is currently a time-consuming and complex process, requiring the knowledge of interdisciplinary data and a long manual calculation procedure. Thus, BSA is commonly used in the project later stages after finishing the project design, where modifications are unbearable or too expensive [3]. BSA is also a voluntary approach with an absence of mandatory regulation, establishing a scenario for its reduced adoption [4]. There is a need to develop a more expedited method to perform BSA, with a real-time and dynamic evaluation, able to support project improvements and modifications, instead of the traditional static approach [5]. With the deployment of digitalisation in the construction sector, building requirements are being translated into computer rules, to accelerate and guarantee building compliance in a faster and more reliable way [6]. BSA is based on a set of KPIs, which can also be represented by computer rules. Therefore, the opportunity arises to translate BSA methods into computable rules and effectively integrate them into existing computer software.

BIM has emerged to support designers in managing all the project data and improving project efficiency [7]. BIM creates an excellent opportunity to incorporate sustainable measures throughout the design process, especially during the project early stages, promoting the development of high-performance buildings. It allows the storage of multidisciplinary information and encourages real-time collaboration among stakeholders [3]. BIM potential for automated rule checking has been recognised and together with VPL, several compatible rules have been developed, creating better, faster, and more comprehensive assessment procedures [6].

Facing the absence of a proper connection of BIM with BSA, the authors have established a novel procedure for the automation of the Portuguese residential version of the BSA method SBTool^{PT}. By translating the BSA KPIs into a computer application integrated into the Open BIM environment, a fast and reliable sustainability analysis was achieved for the project early stages by using the SBTool^{BIM} application. Designers are provided with an intuitive tool to analyse their building sustainability performance, allowing them to introduce and compare improvement measures with few resources. VPL was used to translate the BSA requirements into computable rules and the application was hosted in Autodesk Revit to fit into the BIM environment. Taking advantage of the developed procedure and given the interconnection of Circular Economy (CE) and sustainability, the applied theory and methods can be easily replicated for building circularity purposes. Moreover, the implementation of CE principles will also promote the balance between the main dimensions of building sustainability—environment, society and economy. CE can act near local and regional competitiveness by improving resource allocation, utilisation and productivity. Primary resources exploitation is minimised by implementing a novel circular and ecological value chain, which will also create additional job opportunities and economic growth [8]. Thus, this research aims to explore and identify how SBTool^{BIM} can inspire future BIM-based applications to assess buildings circularity potential in the project early stages, to effectively enhance, implement and spread building circularity concepts.

32.2 Methodology

The aim of the enclosed paper is to explore an existing BIM approach to assess building sustainability—SBTool^{BIM}—in order to identify possible and valuable insights for a future circular building assessment. As SBTool^{PT}-H is based on KPIs, which are commonly discussed to be the basis of new circular assessment methods, a new circularity tool can benefit from the existing method to accelerate its development and practical implementation.

With the flexibility of SBTool^{BIM} input requirements and structure, new insights can be provided to inspire the development of new a generation of circular assessment methodologies. By analysing the most identified BIM uses for the circular economy, insights from SBTool^{BIM} will be framed under such applications and process replicability will be further explored to include new criteria and data, according to the circular building components and materials characteristics requirements.

32.3 SBTool^{BIM}

32.3.1 Objectives and Method

SBTool^{BIM} is a BIM-based application to automate sustainability assessment during the project early stages. It provides a simple and intuitive method to promote and encourage BSA implementation by designers, providing real-time feedback about the building sustainability level. The Open BIM concept, allows BSA to be effectively included in the common BIM project workflow. SBTool^{BIM} reflects the Portuguese residential version of SBTool (SBTool^{PT}-H), which is based on KPIs. A total of 19 criteria were fully automated in SBTool^{BIM} and an additional BIM linkage is proposed for the remaining 6 criteria. SBTool^{BIM} application is hosted in Autodesk Revit, as it has the capacity to import and export several file formats (also allowing to frame SBTool^{BIM} into the Open BIM environment) and, to develop personalised interfaces to perform specific tasks through Dynamo. The application has two parts, both based on VPL through Dynamo, which provides a convenient and automated data exchange procedure with the BIM model in Autodesk Revit.

The application algorithm follows an automated code checking procedure method [6]:

- Rule interpretation—SBTool^{PT}-H assessment requirements and calculation procedures are carefully analysed to identify all the necessary inputs and workflow. The collected data is later translated into a computer-processable language;
- Setup the BIM model—The model is created or imported in Autodesk Revit with all the required data for the assessment and a set of modelling guidelines must be followed. A template—the first part of SBTool^{BIM}—is used to host the new required shared parameters for the sustainability assessment;
- Rule execution—All the established "rules" during the interpretation phase and the identified research procedure were programmed in Dynamo. This phase is the core of the SBTool^{BIM} application (second part of SBTool^{BIM}), gathering and processing the required assessment data from the BIM model according to each criterion's needs;
- Rule report and validation—Building sustainability evaluation. The application displays the building results by presenting the individual score of each criterion, as well as the building global score. The analysis results can either be checked in Autodesk Revit environment or a Microsoft Excel spreadsheet can be extracted;
- BIM additional linkage—As Dynamo is not able to automate the assessment of all SBTool^{PT}-H criteria, especially the ones that require performance analysis data, an additional BIM linkage is proposed to collect the remaining assessment information.

32.3.2 Input Requirements and Assessment Model

As SBTool addresses a wide range of criteria categories, different type of data is required for the assessment. The assessment process of some criteria lies only in geometric quantitative data from the model. Other criteria require the knowledge of several specific regional data or even the results of performance simulations. Therefore, the different input types have been grouped into three sections:

- BIM Model—Data intrinsic to the model (identity and geometry data) or data that can be introduced into the model through shared parameters (mainly quantitative data);
- User interface—Specific regional data and qualitative data that the user must provide to SBTool^{BIM} through an interface (as local amenities, transports or recycling conditions);
- BIM tools—Data that requires the use of additional tools (performance simulation tools) for model simulation.

As SBTool^{BIM} is a Dynamo-based application, both the BIM model data and the user interface data are available inside the Autodesk Revit environment. The BIM tools data requires the exportation of the BIM model for additional software to carry

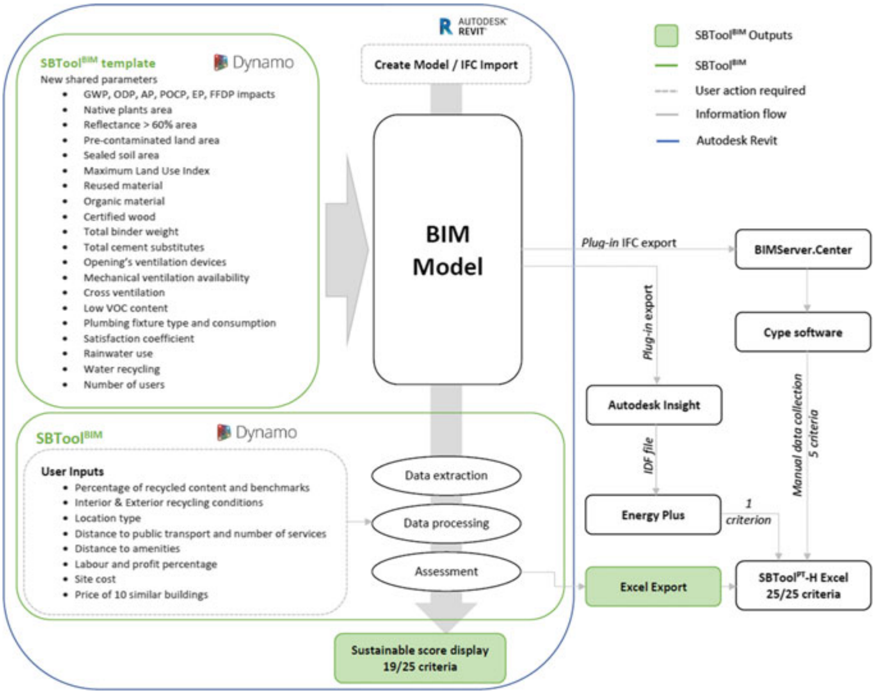

Fig. 32.1 SBTool^{BIM} process map

out performance simulations and data is not directly available in the Autodesk Revit environment.

Based on the adopted software capabilities, the identified input requirements, and the assessment method, the SBTool^{BIM} process map was established, and it is presented in Fig. 32.1.

32.3.3 *Template and Model Characteristics*

Autodesk Revit has a set of base templates with common transversal parameters to characterise the BIM model, such as:

- Elements dimensions;
- Element's cost;
- Material cost, density, class, and function.

This data is usually intrinsic to the model and is shared by all the templates. To introduce sustainability data, Autodesk Revit allows to create and edit templates according to the user's needs. SBTool^{BIM} template was developed to properly describe the BIM model for the sustainability evaluation. It uses Dynamo and the

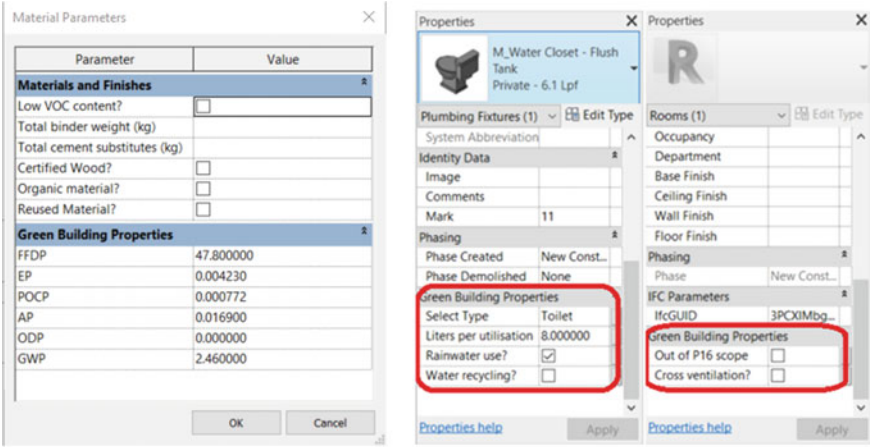

Fig. 32.2 SBTool^{BIM} shared parameters

architectural template as a basis. New shared parameters are automatically created according to the identified input requirements for SBTool^{PT}-H. In total, 28 shared parameters were created to make available the assessment of 13 criteria. Four types of parameters were used: number type, yes/no, text and area. Some examples of SBTool^{BIM} parameters are presented in Fig. 32.2. Most of these characteristics must be provided directly by the user. Although, a material database can also be used, where all the material characteristics are already defined, and it is just necessary to import them for the current model. The template can be saved as an Autodesk Revit template and marked as standard to create and develop models, avoiding the need to run the Dynamo file for every project.

32.3.4 Structure

To extract and process data from the BIM model, the SBTool^{BIM} application was developed through VPL in Dynamo. It automatically assesses the required building data for the sustainability evaluation and provides an interface for the user to complete the analysis information. SBTool^{BIM} code is based on the collection of the BIM model categories data. All elements of each category are assessed and filtered according to each criterion scope. However, SBTool^{BIM} also requires additional information which is not available in the model. Dynamo was used to create user interfaces for the analysis, where the designer can introduce the remaining required data for the assessment. After starting SBTool^{BIM}, a set of pop-up windows will consecutively appear on the Autodesk Revit environment. The aim is to collect external and local data for the analysis. Some examples of the popup windows are presented in Fig. 32.3.

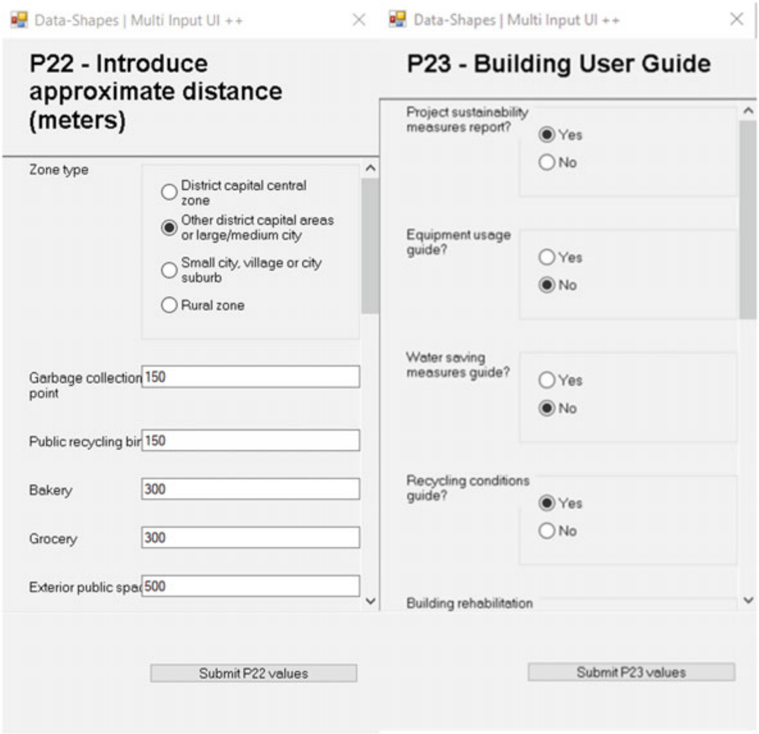

Fig. 32.3 Input forms through user interfaces in Autodesk Revit

After gathering the required data for each criterion, SBTool^{BIM} performs the assessment calculations, normalisations, and qualitative quantification. The building final score is displayed through a pop-up window in the Autodesk Revit (Fig. 32.4). Simultaneously, it produces an Excel spreadsheet with the building quantitative and qualitative scores.

32.4 Discussion

Estimating the performance of a complete building is a complex procedure and depends on several external factors. SBTool^{BIM} application reflects the KPIs of SBTool^{PT}-H and provides instant feedback for designers, making it a cutting-edge tool to support decision-making towards the practical implementation of the sustainable building concept. With this tool, project designs can be easily analysed and compared with fewer resources, creating the opportunity to integrate new sustainability measures and improve building efficiency. SBTool^{BIM} was found very reliable and can reduce the sustainability assessment time from a week to a couple of days

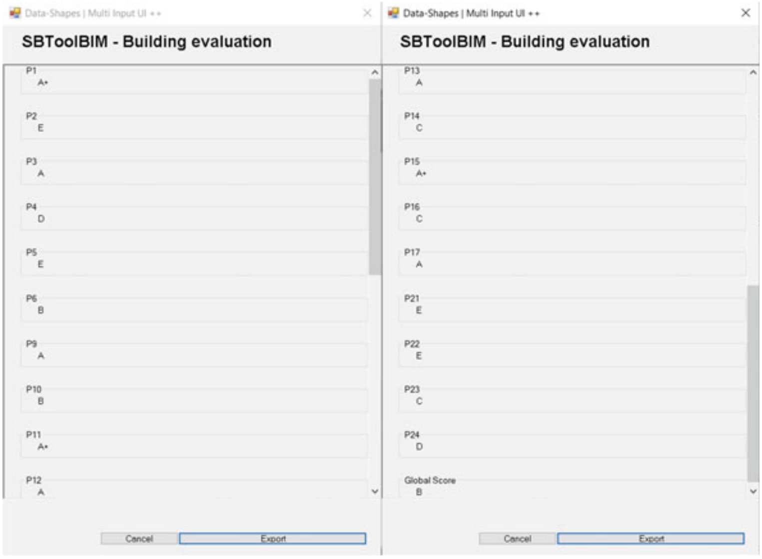

Fig. 32.4 SBtool^{BIM} results in Autodesk Revit

when performing the first project analysis. When integrated into the BIM environment, the prior existence of a BIM model can further reduce the assessment time and enhance the coordination of building sustainability with other project disciplines.

SBTool^{BIM} process replicability was found very accessible for other building types or locations, as Dynamo allows to adapt and/or introduced new criteria with similar established procedures. The replication for other BSA schemes is also feasible, as long as they are based on KPIs. Therefore, this approach can also be replicable for other kinds of building assessments, such as circular building assessments, pre-demolition audits or building deconstruction assessments, making SBTool^{BIM} a valuable bank of contributions for cutting-edge assessment models.

Within the frame of CE, BIM has been recognised as a key feature to enhance the building circularity potential. The BIM method simplifies and automates the integration of CE strategies during the design process, as well as integrates them with traditional assessment procedures, such as BSA or Life Cycle Analysis (LCA). Given BIM applicability throughout the building life cycle, it offers three main features that make it suitable for CE assessment [9]:

- Parametric modelling which regulates building design form and functionalities using established parameters and rules;
- Bi-directional associativity which provides support and real-time updates;
- Intelligent modelling ensures that supplementary data is provided in addition to 3D geometric data, such as building local data, cost information, energy analysis details, waste management plan, etc. This data can also be stored in the BIM

model during the building lifecycle, making it a data storage, which is available for all the stakeholders in any life cycle stage.

Although, BIM can also be applied according to the building life cycle stage [10]. During the project early stages, it can be used for automatic data extraction and can be coupled with material passports, BSA and LCA to provide the environmental, sustainability and recyclability potential of building materials and components. In the operation phase, BIM can act as a management tool to aid in maintenance planning and provide more efficient management of the applied resources. At the end of life, it can support waste management, especially in quantifying waste and in the evaluation of the building and materials recycling, deconstruction or disassembly potential.

Moreover, Charef and Emmitt [11] have identified seven BIM uses for supporting CE: (1) digital model for building end-of-life evaluation, (2) material passport development, (3) project database, (4) data checking, (5) circularity assessment, (6) materials' recovery processes and (7) materials' bank.

Facing the common application of BIM for CE purposes and the need for establishing a new assessment framework to assess buildings circularity potential, SBTool^{BIM} method replicability can provide valuable insights which can be framed under the majority of BIM uses for CE.

BIM models have enough flexibility for being used for different purposes. In SBTool^{BIM}, a properly characterised BIM model is required. Such a model can also be used to extend the building analysis, as it was already developed through parametric and intelligent modelling, acting as a data storage tool. To proceed with further CE analysis, new parameters can be integrated into the BIM model to reflect the circularity assessment, by using a similar procedure as SBTool^{BIM}. The personalised BIM model characterisation made in SBTool^{BIM}—by creating new shared parameters—can be replicated to new assessment methodologies such as circularity or deconstruction assessment of buildings. Different types of data are allowed to be used, in order to identify key building and material features, such as specifications of reusable/recyclable materials, use of nut/bolt joints, use of prefabricated assemblies, minimisation of building components, materials toxic content and/or material maintenance/deconstruction data. According to the type of data, Autodesk Revit and Dynamo flexibility allows to create and adapt new parameters according to those characteristics for building components and/or materials. Quantitative data can be easily introduced by creating new shared parameters for the BIM model components or materials, while other specific data such as analysis results, landfill locations, transportation requirements or recyclable procedures can be added as supplementary information through pop-up windows, by using similar procedures as SBTool^{BIM}. Overall, a template for circularity assessment can also be developed, where all the new shared parameters are already defined and all the supplementary data is listed to be integrated into the BIM model. Such a template can reduce the required time to carry out the circularity assessment, minimise model characterisation errors and enhance the proper development of the BIM model according to the life cycle circular requirements. Moreover, to support model characterisation, a circular material and components database can be developed, where all the materials can already have pre-defined circular characteristics, as well as other building components, such as walls, windows or roofs (for example, the type of joints and connections between element layers).

For a KPIs-based circularity scheme, each indicator assessment procedure can be coded into Dynamo—as made in SBTool^{BIM}—and all the new circularity data, as well as the intrinsic model data, can be collected and processed according to the circular indicator requirements. The building circular performance is provided in real-time during early project stages, allowing designers to compare different strategies and enhance the building circular performance.

Furthermore, all this data can either be used to define material passports or stored as a project database, where the building materials and components characteristics can be listed during any life cycle stage, making it an important tool for building operation and maintenance. Besides the BIM model usability as a life cycle storage, if proper characterised, it can also be used to predict the end-of-life scenarios, from construction and demolition waste management to the building deconstruction and recyclable potential.

32.5 Conclusions

The circular design has a lot to gain by integrating BIM-based workflows in the process. SBTool^{BIM} has proved its applicability and functionality in improving buildings sustainability performance during the project early stages. Its replicability potential allows gathering valuable insights for future researchers to increase investigation on new BIM-based procedures, such as building circularity assessment, providing a broader and detailed assessment of buildings and, consequently, developing high-performance constructions. A new framework for a circular assessment can be developed by using the same host platforms as SBTool^{BIM}—Autodesk Revit and Dynamo—to automate circular assessment data collection and calculations. The BIM model can store different types of building circular data during its life cycle, making it a support tool for building maintenance and operation. Local complementary data can also be introduced into the analysis through specific popup windows. SBTool^{BIM} method still has a set of features which can be improved, such as the minimisation of user interference (there is still a need to manually collect specific regional data), optimisation of the dynamo script to minimise the analysis time and software requirements, as well as the development of new user-friendly interfaces to extend the application usability. Regarding the insights for CE, future research should include a detailed definition and structure of those insights, together with the development of a process map for future BIM-based applications for CE. Overall, the SBTool^{BIM} framework has enough flexibility to be adapted for circularity purposes, only by modifying the KPIs and the BIM model requirements according to the assessment scheme. This framework marks a new era of BIM-based assessments for decision support in the project early stages, allowing to achieve more sustainable buildings and meeting decarbonisation and climate targets. Moreover, the corresponding fully detailed BIM model can be integrated into local or national databases, creating an effective national buildings database, which can enhance the concept of buildings as material banks.

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