

Conceptual planning and implementation of an automated workflow in scaled 3D printing with the aim of generating printable models from BIM data

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Abstract: Rapid digitalization in recent decades has driven significant advancements in the construction industry. Additive manufacturing (AM) has emerged as a prominent technology in this field. However, the process of transforming design models into manufacturable objects is often time-consuming and requires specialized expertise due to complex data preparation. This paper aims to develop innovative and practical concepts in the openBIM (Building Information Modeling) environment to streamline the workflow in generating printable models from BIM data. The proposed improvement involves automating the model generation process, enabling quicker application. The implementation takes the form of a user interface (UI) that facilitates the selection of preferred printing settings from the original IFC (Industry Foundation Classes) data, filtering out unnecessary elements. Additionally, it identifies common errors and issues, suggesting improvements to achieve better printable models. The ultimate goal is to bridge the gap between the design and manufacturing through an automated process, allowing precise observation of the printed outcome.

Keywords: BIM, openBIM, 3D Printing, Digital Manufacturing, Visualization



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1 Introduction

In response to the increasing demand for simplification and transparency in information management, also the need to streamline and optimize decentralized and fragmented processes, digitalization becomes a vital catalyst for accelerating production in the construction industry [1].

Among the innovative digital technologies of the 21st century, three-dimensional printing (3DP) or AM stands out as a crucial direction for future industrial development [2]. It not only surpasses design limitations but also provides exceptional flexibility for customized production.

The utilization of scaled AM enables printed models to serve as a bridge between ideas and the physical world. Complex concepts are often easier to communicate through tangible models [3]. This approach reduces the reliance on 3DP expertise and significantly enhances collaboration efficiency among individuals in different roles.

While it is possible to derive printable models from construction-specific BIM data, several challenges arise during the generation process, such as information loss and discrepancies in size between the model and the printer. Manual evaluation from multiple perspectives is required, resulting in time-consuming tasks. Furthermore, the data preparation process is not user-friendly for BIM authors without specific expertise.

Therefore, the purpose of this concept is to evaluate and validate 3D modeling and printing techniques to establish an automated workflow for generating printable data from BIM models within an openBIM environment. The proposed approach includes the development of an interface that simplifies the understanding of the process and provides a preview of the results before printing, allowing for swift modifications and improvements regardless of the BIM author's level of expertise. Ultimately, this will lead to the production of customized models with reduced time and material consumption.

2 Underlying Principle

2.1 Digitalization in construction Industry

BIM is a methodology used in the architecture, engineering and construction Industry (AEC) to digitally represent the physical and functional characteristics of a facility. It serves as a comprehensive knowledge resource for capturing and managing information about a project during its entire life cycle, from conception to operation and maintenance [4].

In today's digital landscape, data and information are valuable assets. To improve the accessibility and usability of this data and avoid information silos, openBIM is employed to facilitate interoperability, ensuring software-independent access and enabling seamless data exchange and collaboration [5]. In contrast, closed BIM relies on manufacturer-specific formats and is primarily efficient within a single company or software ecosystem.

At the core of openBIM lies the IFC data schema, developed by the buildingSMART organization as standard specifically designed to improve interoperability and data exchange. IFC serves as a digital description of the built asset industry and its versatility enables application in various use cases,

providing usable capabilities [6]. By adopting openBIM and utilizing the IFC data schema, the construction industry can overcome the limitations of closed, proprietary formats and enhance collaboration and data accessibility across multiple software platforms.

The AEC plays a vital role in global economic development. However, as a relatively traditional industry, it faces significant barriers and challenges, including low performance and inefficient communication. AM, commonly known as 3D printing, has been increasingly adopted by the AEC industry in recent years, can help to address these issues. AM in this field can be generally defined in two main categories: Fabrication and Visualization in construction, depending mainly on whether they are related to the actual construction process or not.

The first major category is Fabrication for on-site and off-site construction. 3DP technology enables easy implementation of complex forms, while reducing material waste and energy costs. A recent practical example for this is the research project "3DLIGHT_ONSITE" [7], from the STRABAG construction company. The project envisions to create a prototype of a mobile construction site robot that will leverage BIM data to directly print light construction elements on site. Depending on the printing process, the expectation is to reduce the CO₂ emissions of unreinforced walls by up to 50%.

In the case of visualization, the second major application category, the final product is mostly a scaled model. These models can serve various purposes, such as prototyping to optimize aspects structural and topological aspects, as well as a visual tool [8]. Effective visualization of the construction project is important for communicating complex ideas, facilitating necessary adjustments, and evaluating plans. It allows stakeholders to gain a comprehensive understanding of the project's spatial and visual aspects, aiding decision-making processes [9].

2.2 3D Printing and file formats

AM brings effective and user-friendly communication and production techniques to the realm of construction projects. It involves the creation of 3D objects directly from digital models by adding material layer by layer, eliminating the need for traditional tooling or machining [10].

To generate 3D models, various software tools as Computer-Aided Design (CAD) are utilized. However, these tools often store data in different formats, which may not be optimal for 3DP. Consequently, the 3DP domain has been influenced by open-source file formats that prioritize minimizing additional data [11]. STL (**ST**ereo**L**ithography) is the most used format for 3DP since they can be easily sliced into layers for the printer representing the 3D model as interconnected triangles. STL files can be prone to errors due to non-manifold geometry. The Wavefront OBJ, that stands for object, comes in second place. It uses polygons instead of triangles, creating a smoother geometry texture. 3MF (**3D Manufacturing Format**) is an XML-based standard that enables storage of multiple types of data in a single file while fixing more source model geometry errors. Unlike STL, OBJ and 3MF also encodes color, material, and texture information.

3 Automation for the 3D printing process

3.1 Methodology

This research adopts a systematic approach, referred in Figure 1 below, to investigate and enhance the workflow for AM within the context of BIM. The methodology consists of three main steps: survey research, concept design, and implementation.

In the survey research step, real-world cases are analyzed to understand the challenges and requirements of AM in the construction industry. Existing manual workflows and software solutions are also assessed to identify limitations and areas for improvement.

To address these identified challenges, the second step is concept design, which involves optimizing the 3DP workflow from design to production. This entails defining the input, output, and steps involved in the workflow. Additionally, the potential for automation within the workflow is identified, highlighting areas where efficiency can be achieved. This analysis forms the basis for developing an optimized and automated workflow concept.

The final step focuses on the implementation of the designed concept. A dedicated software module is developed to generate optimized 3D models for AM using the BIM data. This implementation integrates the automated workflow concept into the existing BIM framework, enabling seamless and efficient generation of 3D models specifically tailored for AM.

By following this structured project methodology, the research aims to gain valuable insights into the current workflow for AM, design an automated concept to address its limitations, and develop a practical solution that optimizes the generation of 3D models for AM within the BIM framework.

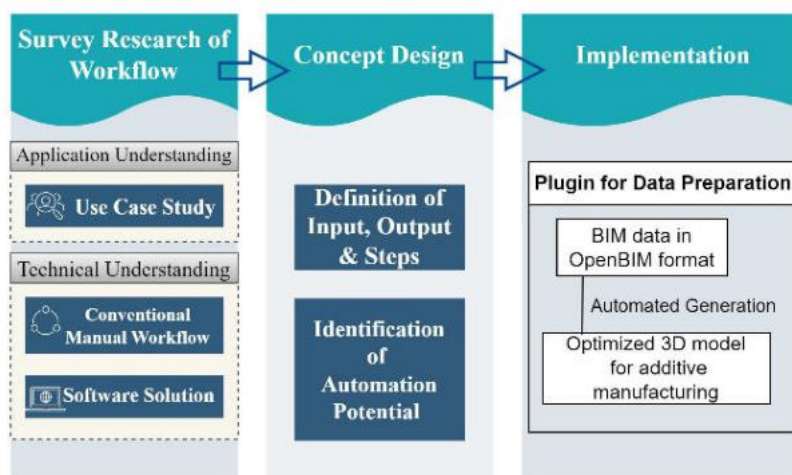


Figure 1: Project Methodology: Conceptual Framework Incorporating Application and Technical Aspects

3.2 3D Printing Workflow

The workflow for 3D Printing BIM models can be divided into two main parts:

- **Modeling:** BIM author software - Computer-Aided Architectural Design (CAAD) -, creates purpose-specific BIM models (architectural, structural, etc.) with geometric and descriptive information. This data is then converted into an exchange file format. To facilitate sharing and compatibility, open-source or neutral file formats are the commonly used for 3D printing.
- **Slicing:** the resulting modeling files are converted to a 3D printer compatible format. This is achieved through slicer software, which may depend on the printer used. The software “slices” the model into 2D layers and generates a series of commands and sometimes additional parameters that instruct the printer in the form of a geometric code, known as G-code [11].

Although BIM software solutions for modeling have strong information integration capabilities, there are still gaps that need to be addressed by BIM authors with some knowledge of 3DP. This often comes to reviews and modifications. Some of the discussed issues include the occurrence of dropping parts, distortion, loss of detail, or even loss of entire elements due to the limitations of the printing equipment conditions, which are not accounted for in the planning software. These unexpected problems often end up requiring multiple reprints, resulting in wasted time and materials.

Furthermore, the direct conversion of BIM models to printable data lacks the flexibility to automatically identify architectural element features. This requires extensive manual screening settings to achieve the desired custom fabrication.

To address these challenges, we propose to introduce a new step in the above-mentioned workflow by developing a module that automates the identification and filtering of architectural elements. It also performs the necessary analysis for the model with the aim of improving the quality of the final printed product.

3.3 Implementation

The module was created as a PlugIn for the KITModelViewer application, the successor of FZKViewer created and offered by the Karlsruhe Institute of Technology [12]. The software is an open-source viewer for semantic data models. It displays properties and relationships between objects and make analysis of the data. The KITModelViewer besides that has a completely revised visualization and an open PlugIn Interface, where our module will be found.

Once the IFC data is imported into the KITModelViewer, the user can access the PlugIn and start working on the print model, visualizing the changes in the Viewer after each new step.

In the beginning of the process, some typical model types are disposed for choice in the main Dialog displaced on the far left of Figure 2. Each one is pre-filtered to match different types of visualizations

for different use cases, such as the filtering for external elements, ideal to represent building facades. Users have the ability to modify and expand settings according to their preferences through the dialog in Figure 2 middle top. After choosing the model, it is possible work further on the filtering from components in the dialog disposed in Figure 2 middle bottom.

Subsequently, comes the details segment. The level of intricacy for windows and doors can be chosen between “simplified” and “detailed”; and the visualization changed. Between the changes are the options to visualize the model in the default colors or in a single color; and to toggle between selected and unselected elements.

The last parameter section follows the selection of scale and the desired printer. After the printer is chosen, the maximum length, height and the minimum thickness from the printer's configurations are set. Its information plays a crucial role in the subsequent scale checking process, by comparing the resulting size of the scaled model and its components with the printer capability. In the dialog from Figure 2 far right, users have the option to input or modify the printers being used.

Lastly, with all the parameters chosen, a checking tool is available. Some of the analyses (e.g., such as edges, face and solid checks) are already offered by the KITModelViewer and are here repurposed.

Once the verification process is completed and the results are satisfactory, the model is ready to be exported. If desired, users have the choice to save each storey in a separate file. The export functionality supports the STL, binary STL, OBJ and 3MF file formats.

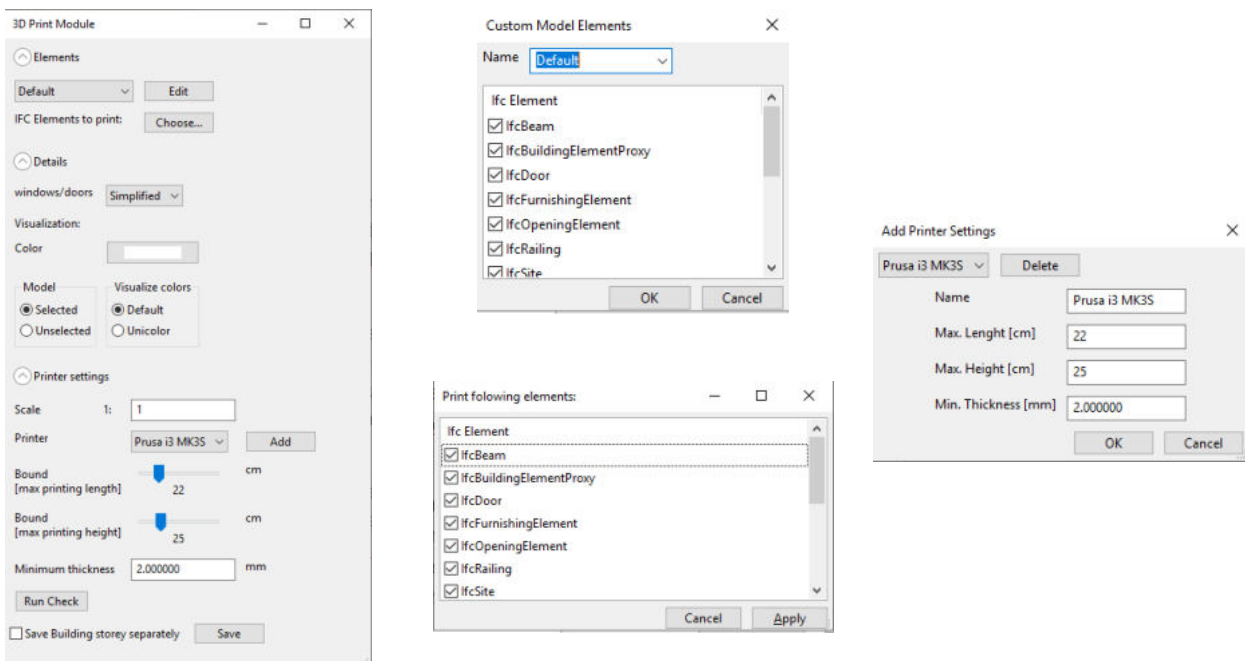


Figure 2: PlugIn Dialogs: Main(left), Model Types (middle top), IFC Choice (middle bottom), Printer Settings (right)

The implementations are in the programming language C++. The interface dialogues were constructed with the help of wxFormBuilder, a tool utilized in conjunction with the wxWidgets library to create GUI. Both the elements and the printers, along with their respective configuration, are saved in JSON files. This allows for convenient storage and retrieval of the data in a structured format that can be easily accessed and manipulated. The information from the IFC data is explored through the module parameters to make targeted changes. In the option for external elements, the data is analyzed to identify the exterior components using the Common Propertyset with the "isExternal" property, so it can be immediately seen after activation.

These features aim to minimize the additional effort required for remodeling, thereby saving valuable time and making the whole process easy to follow. The test results can be seen in the Figure 3 below, where all the changes were made in less than a couple of minutes.

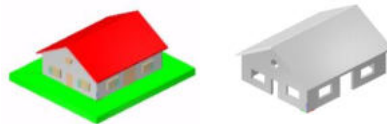


Figure 3: Model before and after PlugIn modification

4 Conclusion and Outlook

In summary, this paper, based on the traditional workflow and use case study of 3DP from BIM models, identified that due to the limitations of the printing equipment and certain specificity of the construction project, manual adjustments need to be made and challenges arise. To overcome these problems, this paper proposes an automated solution and implements it through a UI that clearly displays settings related to AM prior to printing facilitates rapid modifications and optimizations, enabling customized models to be achieved in less time and with less material, regardless of the skill level of the BIM author. This will streamline the process and ensure that the final product meets the desired specifications.

The presented workflow is more suitable for visualization use cases of producing visualized models and small size formworks or replacements but to fabrication use cases of the large-scale printing is not fully applicable, which differ in some aspects such as material and mechanical.

The next step will be to develop appropriate workflows for more complex "use cases of Fabrication" where the output is used for actual construction. For example, when building a one-to-one house with 3DP technology, the plan data should first be roughly analyzed to distinguish the components to be printed, and then to classify off-site prefabricated, on-site temporary and permanent construction elements. Finally, the specific construction plan is obtained.

One of the practical implications of the development of 3DP is how it can incorporate other innovative technologies, such as robotics, to streamline and automate its counterpart and truly participate fully in the production process of a construction project. Currently, 3D printed construction objects require time-consuming and costly case-by-case analysis. However, there is great potential to discover their commonalities to improve the standardization of the particularities of new construction methods. In this way, the efficiency and applicability of this innovative technology can be improved. Finally, the goal is to maximize the automatic matching of the project production chain from a data perspective.

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