Semi-automated assessment in fundamental BIM pedagogy for large cohorts

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Abstract: Due to the increasing relevance of Building Information Modeling (BIM) in students' curricula, BIM courses are increasingly in demand. Hence, to advance the quality of teaching and practical application, the Technical University of Munich split BIM teaching into four consecutive parts: BIM.fundamentals, BIM.project, BIM.advanced, and BIM.infra. For the fundamental BIM course, we use graded assignments in the fields of geometric and semantic modeling, model checking, and rendering, which add to voluntary exercise tutorials. However, individual support and evaluation of the assignments cannot be offered for large cohorts exceeding more than 400 students but requires means to streamline feedback provision. We developed a semi-automated workflow for practical assignments using State-of-the-Art digital methods to efficiently evaluate these individually and fairly, even for large numbers of students. To support the objective of geometric and semantic modeling using open BIM technology, we utilize semi-automated, rule-based model-checking approaches. Additionally, based on parametric design generation, we provide individual IFC models to enhance the object of exercising BIM collaboration tasks, such as clash detection and BCF-based communication. To evaluate the use case implementation of model visualization, we aim to use Computer Vision techniques to semi-automatically assess the rendering quality.

Keywords: Building Information Modeling (BIM), Industry Foundation Classes (IFC), Model Checking, Engineering Pedagogy

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1 Introduction

Traditionally, computational methods for the built environment have attracted a few students enrolled in engineering study programs (e.g., civil or environmental engineering). Participants sometimes hesitated to enroll due to the extensive computer science concepts involved in related teaching modules. Nowadays, an increasing number of students use digital methods to design and construct built facilities, particularly with the growing interest in Building Information Modeling (BIM). This has led to a significant rising demand for BIM courses. At the same time, motivation and average performance among participants appear to decrease due to the complex interdisciplinary knowledge and the variety of software applications required. Conventional lectures comprised of theoretical introductions and software exercises lack systematic enhancement methods to effectively guide and motivate participants. Designing suitable learning materials with comprehensive feedback support requires significant curriculum rearrangement, but this is necessary.

Model checking techniques have been extensively studied to facilitate the evaluation of building designs against established building codes [1]. Given the varying levels of complexity [2], a theoretically infinite number of rules can be defined to assess whether a BIM model meets or fails specific requirements. In a similar vein, automated assessment approaches can be integrated to streamline the evaluation of student works in fundamental BIM education. This integration promises to enhance the evaluation efficiency and facilitate the effective implementation of pedagogical strategies for a growing student population. Hence, this study seeks to address the question of how advanced BIM technologies can be leveraged to enhance teaching methods and evaluate performance improvements in fundamental BIM pedagogy for large cohorts.

2 Context

Challenges in offering effective BIM courses by universities hinder the preparation of students for a digital future in the construction sector [3]. Designing the learning material for the rapidly changing field of BIM has proven difficult and requires significant effort. Integrating BIM into higher education necessitates several key components to reach its full potential for training future engineers. For example, participants are supposed to learn relevant industry software and understand various roles in collaborative work. Appropriate teaching methods are essential to offer up-to-date fundamental knowledge and practical exercises, helping students document and communicate their ideas, incorporating elements such as collaborative curricula, industry relevance, and technical skills [4]. Educators typically use tutorials, exercises, assignments, and supporting exercises in such modules [5].

BuildingSMART International standardized a four-level professional certification, differentiating between entry, foundation, management, and practitioner knowledge [6]. The entry level is a self-learning offer, while the foundation level is also suitable for students, and management and practitioner levels with its openBIM management and openBIM coordination offers are available for professionals with industry experience. In German university teaching, the German Association of Computing in Civil Engineering defined BIM-related topics for teaching in Master's degree programs [7]. Besides general motivation and digital modeling of buildings and infrastructure, the main topics are geometry representation, data exchange, data management, digital modeling of processes, and BIM use cases.

3 Methodology

3.1 Overview of BIM teaching at Technical University of Munich

Figure 1 illustrates the modules at TUM. The course *BIM.fundamentals* focuses on the basic principles of BIM. The module aims to equip students with the ability to understand and apply Building Information Modeling (BIM) in the planning process, identify and solve potential issues within BIM processes, and critically evaluate commercial software options for BIM-based planning. Our students learn to appropriately select and utilize digital analysis and simulation tools, analyze BIM technologies through case studies, comprehend BIM data formats, and effectively utilize data exchange mechanisms. The course content covers various aspects, including digital technology introduction, BIM concepts and terminology, use cases, BIM systems, geometric modeling, collaborative workflows, and BIM-GIS integration. Teaching methods include lectures for theoretical understanding and tutorials with software examples and exercises to reinforce practical skills.

Following the essential foundations taught in BIM.fundamentals, several additional modules can be selected to gain additional skills in this topic. *BIM.project* is a seminar coursework. In this module, students team up in groups of five and perform joint project work. Besides creating BIM models in dedicated authoring tools, students perform coordination and other simulations across different disciplines.

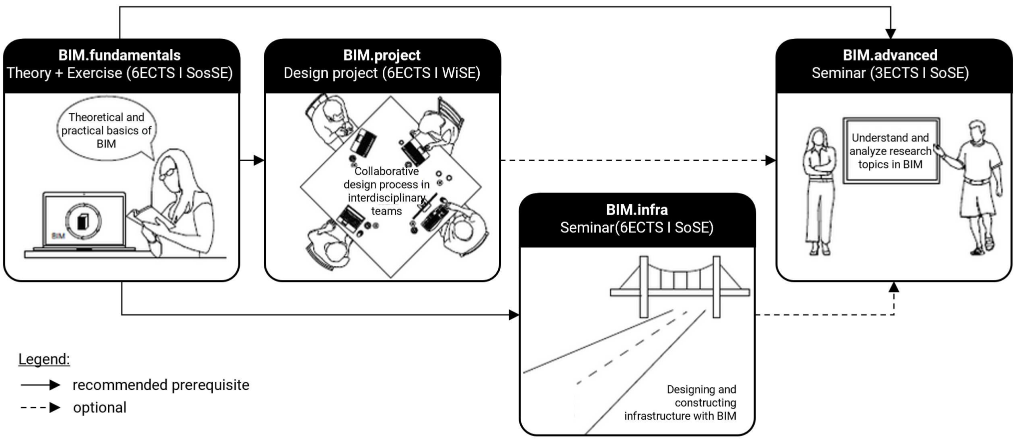

Figure 1: BIM Courses offered at TUM

To deepen the understanding of how BIM is adopted in the industry, the module *BIM.advanced* is a lecture series where practitioners present how they utilize BIM and other digital methods in the design and construction process. In addition to that, the students investigate a technological or scientific topic in-depth and summarize their findings in a written report. Upon completing the *BIM.infra* module, students will possess a comprehensive understanding of creating and evaluating client information requirements and BIM execution plans in transport infrastructure construction projects, along with proficiency in classifying specific discipline requirements within the scope of infrastructure projects. They will also acquire practical knowledge of industry-standard data exchange formats and software products, enabling them to effectively utilize these tools to develop solutions for BIM-based planning tasks in traffic route construction.

3.2 Overall teaching approach for basic BIM knowledge

The *BIM.fundamentals* course is available for Master's students of different study programs, such as architecture, civil and structural engineering, sustainability, and more. As shown in Figure 2, the course is structured in theoretical lectures, covering the topics of geometric and parametric modeling, data management and collaboration, model checking, data exchange and interoperability, project execution, and BIM use cases such as Quantity Take-offs, documentation, sustainability analyses, or BIM and GIS.

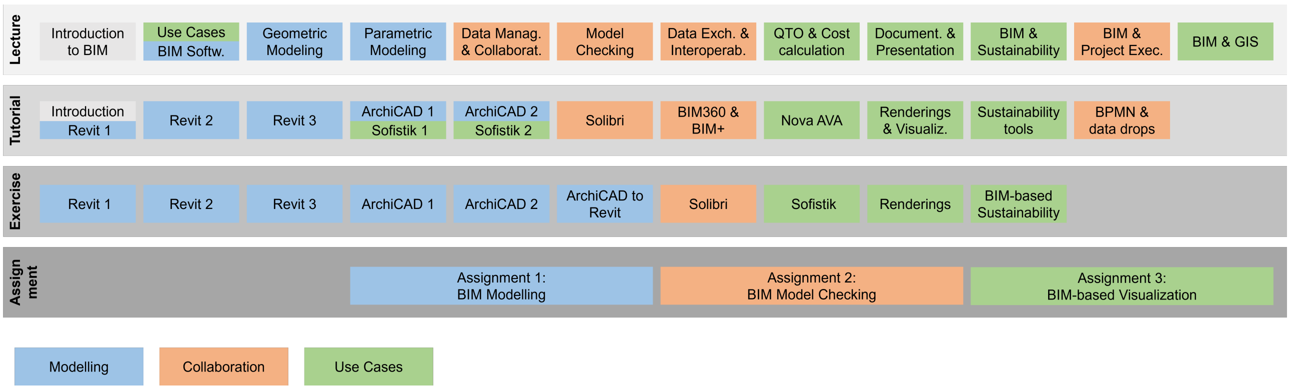

Figure 2: Overview of different blocks and content of the BIM.fundamentals module at Technical University of Munich

Practical tutorials follow the lectures to apply the theoretical concepts in class using different software products introduced by tutors. Afterward, the students are encouraged to do self-studying blocks using exercise sheets for deepening the learned content in the field of BIM model authoring, IFC export, BIM-based structural analyses, or several BIM-based sustainability assessments, such as solar radiation studies, daylight and complete building energy simulation, and life cycle assessment. To increase the students' motivation for practice and to check the learning outcome of the tutorials and exercise sheets, we introduced three voluntary assignments, which were corrected and included in the grading process. The assignments cover the topics of model authoring, model checking and the use case of visualization, which will be introduced in the following sections.

3.2.1 BIM modeling with authoring tools

The model authoring assignment focuses on BIM-based modeling, enabling participants to produce OpenBIM models that adhere to specified semantic, geometric, and exchange requirements. Participants are free to choose their preferred authoring software, including but not limited to Autodesk Revit, Graphisoft ArchiCAD, and Allplan, to develop a model representing either a residential or office building.

The building outline shapes, geometric parameters, and dimensional specifications are individually generated for each participant by the organizers. Essential building objects such as walls, windows, columns, doors, beams, roofs, slabs, and stairs must be included, with a sufficient variety of object types. Specific emphasis must be spent on the semantics of load-bearing building elements, as well as the accurate designation of internal and external walls and doors. Furthermore, the assignment mandates space objects with descriptive names and realistically sized areas for their intended use. The final deliverable must adhere to the IFC 4 Reference View standards to enhance participants' understanding of the collaborative design process. The model authoring assignment aims to help participants enhance their BIM and IFC proficiency and develop skills to integrate architectural and structural considerations into a functional model.

3.2.2 Model Checking

The model checking assignment involves examining an IFC model of a three-story office building to identify and communicate design issues in accordance with specified requirements with the Solibri Office model checker. This assignment includes several space-related architectural checks, such as window-to-space area ratios, minimum room areas, and space accessibility. It also involves checking door clearance for clashes with furniture and detecting incorrectly assigned properties, like internal walls mistakenly marked as external.

To communicate the model checking results for each task, participants must briefly describe the detected issues, provide a textual proposal for resolution, and attach a highlighted view that includes the affected building parts. Additional information, such as coordination and responsibilities, is optional but recommended. The final deliverable is a bcfzip file adhering to the BCF Report v2.0 format. This assignment aims to familiarize participants with the OpenBIM workflow including models and issue communication means to enhance their skills in model quality control.

3.2.3 Visualization

To perform a thorough downstream application without required domain-specific knowledge, the scope of the third assignment is the creation of BIM-based renderings. Therefore, two visualizations are requested from the students, one each from the interior and exterior of the student's model of the first assignment. Several requirements are set for the renderings and used for grading, such as clear and consistent lighting, materials settings including intended textures and reflection, surroundings and people, and realistic sky and weather conditions.

4 Implementation

Students hand in their solutions via a Moodle platform hosted by TUM. The course instructors then use Moodle's batch download options to import all submissions into the checking platform. Due to the specific demands and the variety of data of the three different assignments, a dedicated checking platform has been implemented to streamline the evaluation process of all three assignments. The platform itself is developed in Python and offers a web-based user interface. It further utilizes additional software packages described in the following paragraphs.

4.1 Automated model quality checking

To effectively evaluate the large number of assignments submitted for the first assignment, we automated the process of checking the IFC models. Tasks in the assignment outline the concrete requirements that have to be reached in a model by students. Each requirement is graded with specific points depending on the delivered quality. Hence, the threshold of these criteria played an important role in the fair assessment of the models. Figure 3 represents the workflow performed from the parametrization of assignment tasks up to the grading process using the model checking Solibri software. The ruleset, as well as information take-off (ITO) templates, were created to retrieve the relevant parameters of the model. To address the number of submitted models, the Solibri Autorun extension tool is utilized to be able to process them in a batch. Later, the results are fed into the checking platform, where previously set thresholds are applied to grade the students accordingly.

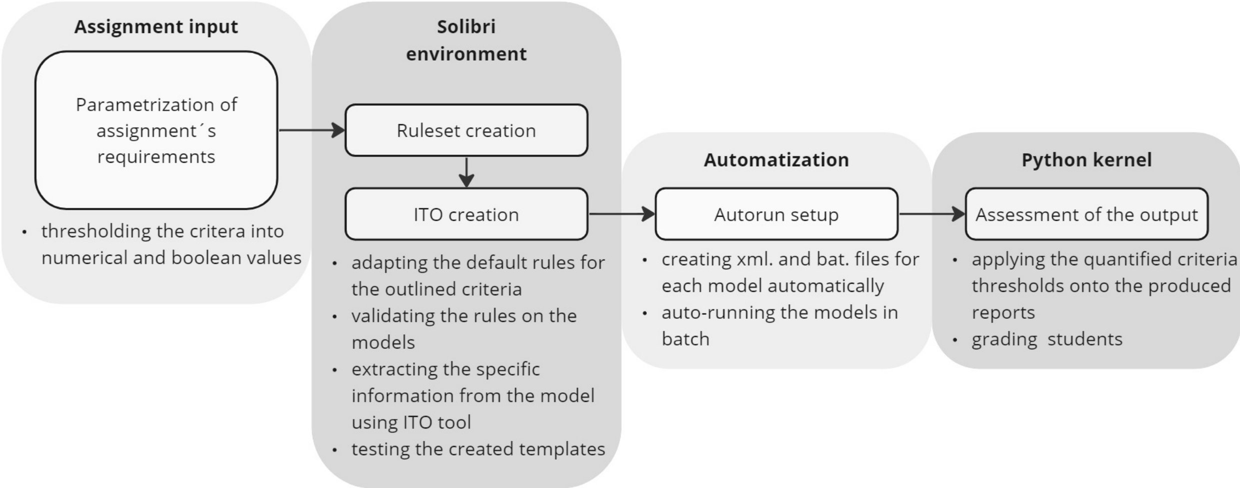

Figure 3: Automated model quality checking workflow

4.2 BCF parsing of model checking

To ensure robust evaluation, we use parametric modeling to create unique models with different issues for each participant. For example, space accessibility errors are introduced by randomly removing doors from internal spaces, while internal and external property errors are created by mislabeling internal walls as external. By varying a basic model of a three-story office building and refreshing all IFC GUIDs, we provide unique IFC files for each participant to complete the model checking assignment. This approach offers different architectural issues and enables an automated assessment process based on parametrically pre-defined design errors each participant must identify.
Based on these custom models, each student performs model checking and submits a bcfzip file containing the identified deficiencies. Each issue must include the task title, descriptions, authorship details, and snapshots. The instructors evaluate the textual description and resolution proposal of the detected issues manually. Additionally, the referenced elements in the snapshot are extracted from viewpoint files. We automatically check if the identified components carry the correct IFC GUIDs and comply with the expected values originating from the parametric model generation. The approach taken facilitates the evaluation process and efficiently helps prevent plagiarism in large cohorts.

4.3 Visual quality checking of Renderings

Figure 4 exemplarily shows the platform for manually grading the rendering quality of the exterior in the third assignment. In total, 10 points can be achieved for both interior and exterior rendering. For every criterion, the grading step is 0.5 points with one point maximum each for exterior and interior light conditions, people, aesthetics, and perspectives for the exterior and interior renderings, and half a point for exterior and interior materials, exterior ground, and sky conditions.
A practical study was conducted to find a means of semi-automating the visual quality checking of the renderings submitted by students. The goal was to find a ready-made deep-learning model to semantically understand the renderings and output individual scores in all ten categories. This output can then aid the examiners by providing a rough grading preview. Deep-learning models of the types "Visual Question Answering" and "Image Text to Text" provide the most promising results out of the

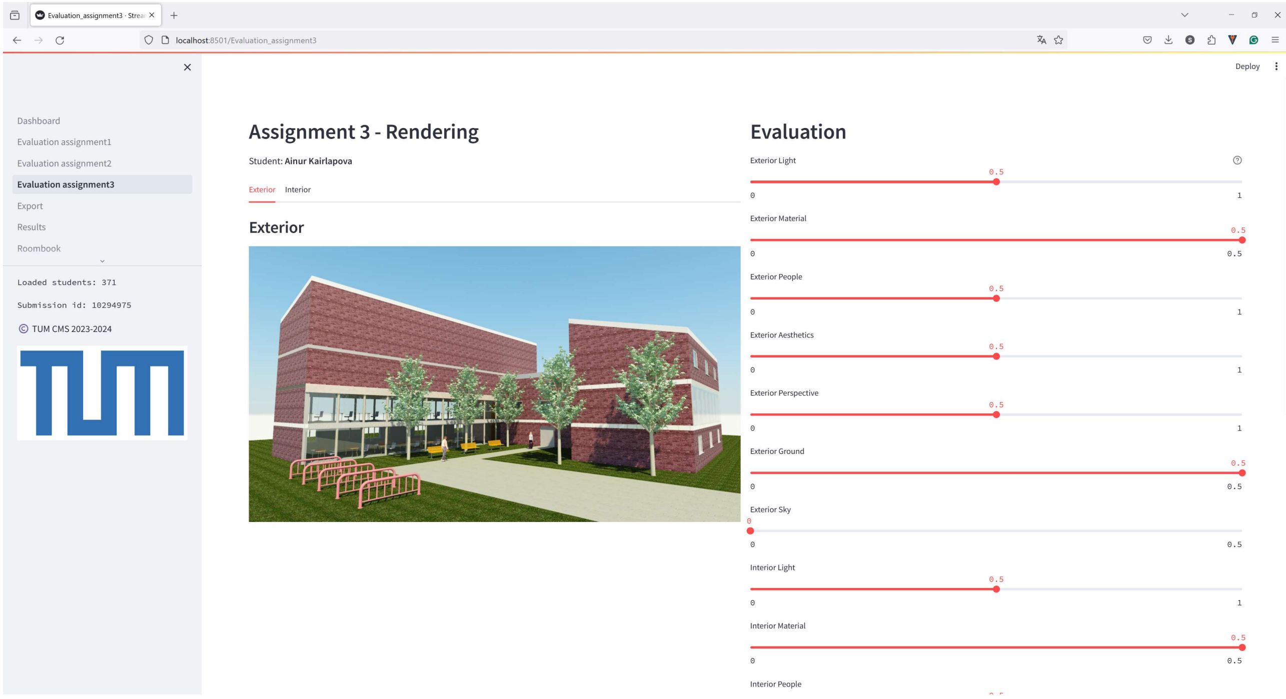

Figure 4: Manual grading of exterior rendering as the third assignment

box. The best model tested is Google's PaliGemma 3B Mix 224 [8], an open vision-language model. While not able to output structured data representations, it can output "yes" or "no" when specific questions for the respective categories are prompted. The accuracy, computed as the number of correct predictions divided by the number of all predictions, of the model's predictions was asserted by comparing the model predictions to the ground truth grading for all images and all categories from a previous semester. The category "Exterior Sky" shows the lowest accuracy of 71.68%. The highest accuracy is achieved for the category "Interior Material", with a value of 95.33%. This binary prediction does not yet allow for the more fine-grained grading of the categories that can receive a score of 0, 0.5, or 1. Further testing and possibly transfer learning must be done for the model to be used for fully automated quality checking of the renderings.

5 Conclusion and Outlook

The semi-automated assessment method presented in this paper enables efficient evaluation of large cohorts of students. This method checks the quality of OpenBIM models and extracts the core elements in design issue communication files in an automated manner, significantly reducing the time and effort required in manual evaluation. It also facilitates the visual quality assessment of renderings and has the potential to leverage machine learning for more efficient evaluations. This automated evaluation allows course participants to receive more timely and consistent feedback, enhancing their theoretical BIM knowledge and supporting systematic practices of BIM-related skills.

We envision this system as a continuous support mechanism where participants can upload their assignments and receive instant feedback. Furthermore, the current checking kernel could be improved to accommodate larger IFC files, enabling the evaluation of more complex exercises. Furthermore, we envision incorporating the checking system into the Moodle platform to enable students to check their models already during the assignment preparation. Such an integration would allow even more direct individual feedback to the students.

Besides this, further investigations are planned to enhance the quality checking of submitted renderings. Given the visual grading of architectural renderings is more subjective than the technical grading of an IFC model, predicting the renderings' scores roughly as an aid to the examiners may be sufficient. This is already possible with the above-mentioned accuracy achieved with the pre-trained model. We will report on this matter in future publications.

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