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BIM-GIS Integration as Dedicated and Independent Course for Geoinformatics Students: Merits, Challenges, and Ways Forward

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Abstract: Information mined from building information models as well as associated geographical data and Geographic Information System (GIS) analyses can increase the success of construction processes and asset management, including buildings, roads, and public facilities. The integration of information from both domains requires high expertise in both spheres. The existing B.Sc and M.Sc. programs linked to the built environment at the Technical University of Munich offer courses for the Building Information Model (BIM) and GIS that are distributed among study programs in Civil Engineering, Architecture, and Geomatics. Students graduating as professionals in one of these domains rarely know how to solve pre-defined technical problems associated with the integration of information from BIM and GIS. Students in such programs seldom practice skills needed for the integration of information from BIM and GIS at a level that is needed in working life. Conversely, the technologies in both domains create artificial boundaries that do not exist in reality—for example, water and electricity would not be of use if the utilities terminated in front of buildings. To bring a change and bridge the gap between BIM and GIS, a change in the teaching methods of BIM/GIS needs to be considered. The Technical University of Munich (TUM) has developed a master's course (M.Sc. course) for students in Geoinformatics which focuses on competencies required to achieve BIM/GIS integration. This paper describes the course development process and provides a unique perspective on the curriculum and subjects. It also presents the course objective, course development, the selection and development of learning materials, and the assessment of the intended learning outcome of the course. The developed course is validated through a questionnaire, and feedback is provided by participants of the BIM/GIS integration workshop representing a panel of experts in the domain.

Keywords: BIM/GIS integration; GIS; CAD; course development

1. Introduction

Growing industry demand requires the integration of data and tools from the Building Information Modelling (BIM) and the 3D Urban Information Model (UIM)/Geospatial domains. BIM and UIM are becoming the new norm in the architectural engineering and construction (AEC), industry, as well as in geospatial research—and they are part of many applications related to design, construction, and urban management [1–10]. Recently, the applications have extended to infrastructure construction and management [11–16] and to political directives, like the "Phased introduction of Building Information Modelling (BIM) until 2020" (https://www.bmvi.de/SharedDocs/EN/PressRelease/2015/152-dobrindt-bim.html) initiative of Germany's Federal Ministry of Transport and Digital Infrastructure, which will contribute to the further adoption of the BIM method in infrastructure construction and management. Executing a project using BIM and UIM technologies/systems and data requires a high level of expertise in the two disciplines—BIM and UIM—with the proficiency typically being distributed among BIM experts from the fields of civil engineering and architecture, and UIM experts from the geospatial domain. This situation is reflected by the status quo in university-level teaching at the Technical University of Munich (TUM) where BIM courses are mainly assigned to study programs in civil engineering and architecture, whereas UIM expertise is taught in study programs related to the geospatial domain, such as geodesy, geomatics, or geoinformatics.

An effective and efficient integration of BIM and UIM requires deep knowledge of at least one of the two disciplines, as well as knowledge on how to interoperate with the other discipline. Consequently, the teaching approach presented here assumes that master's level geoinformatics students are already familiar with the basics of UIM and, therefore, just need to gain enough BIM skills required to integrate both BIM and UIM.

As a result of the above, a significant part of the teaching and learning dilemma is how simple, experimentally-, and conceptually-driven information about BIM can be provided, allowing students to play with the technology at a rate that suits their level of experience and learning needs. Therefore, our aim was to investigate the challenges of BIM resources in a geoinformatics teaching setting—especially regarding ways to develop and utilize appropriate BIM models that best assist the intended learning outcomes (LOs). To this end, this research proposes both a recommended course outline and content of lectures and learning materials, where their instructive and conditional properties may be of assistance when developing a curriculum for geoinformatics students. The early results of this research were introduced by a course offered by the Chair of Geoinformatics at the Technical University of Munich (TUM). This paper presents the course objective, course development, the selection and development of learning materials, and the evaluation of the course. Feedback will be requested from the participants in the BIM/GIS integration workshop through a questionnaire, as they are representing a panel of experts in the domain. The results from this will be used to further develop the course.

The paper is organized into five sections: Following the introduction, Section 2 gives a background on the BIM Industry Foundation Class (IFC) and UIM; Section 3 provides a description of the course development; Section 4 defines course goals and objectives, and the authors provide a brief summary of the course contents and activity organizations; Section 5 summarizes the course evaluation; and the authors present steps and suggestions for future research and implementation.

2. BIM (IFC) and UIM Modeling Paradigms

Prior to the development of the course, the authors conducted a systematic literature review on the topic of BIM/GIS integration [17–19]. The analysis identifies significant contributions and advances in the field of BIM and GIS integration, while highlighting the implication for asset management. These can be divided into two main parts:

1. Integration mechanism: Although different methods have been developed to try and achieve integration between BIM and urban information modeling (UIM), none of them can be described as seamless integration.
2. Applications: Over the past ten years, there have been various successful academic and industrial efforts to simplify BIM models and to integrate them into the geospatial context. The integrations were created with various applications in mind, including indoor navigation, energy assessment, facility management, and utility networks.

Although it would be more appropriate to discuss "BIM/UIM integration" in cases where the authors mean the integration of the two methods, or "computer-aided design (CAD)/GIS integration" in cases where the authors mean the integration of software tools, in most of the literature, the term "BIM/GIS integration" is used. This is problematic, because here a method (BIM) is being compared to a system (GIS). However, in the remainder of this paper, the term "BIM/GIS integration" is used and means the integration on a data model level.

Under the term "urban information modeling" (UIM), us authors have presented a semantic modeling method for representing the relevant entities of urban space cities (such as buildings, roads, rivers, bridges, vegetation, and city fixtures) and the relationships between them, in a way that allows for analysis and simulations on cities or regions. The 3D geometry of objects in urban information models are typically reconstructed from observations of real-world entities using surveying technology, such as total stations, terrestrial/airborne laser scanners, or techniques from photogrammetry.

Figure 1 provides an illustration of the different integration levels. The course intends to provide students with the skills to perform integration on a data model level using IFC as a recognized standard in the AEC industry, the city geography markup language (CityGML), and the open geospatial consortium (OGC) standard for the geospatial domain.

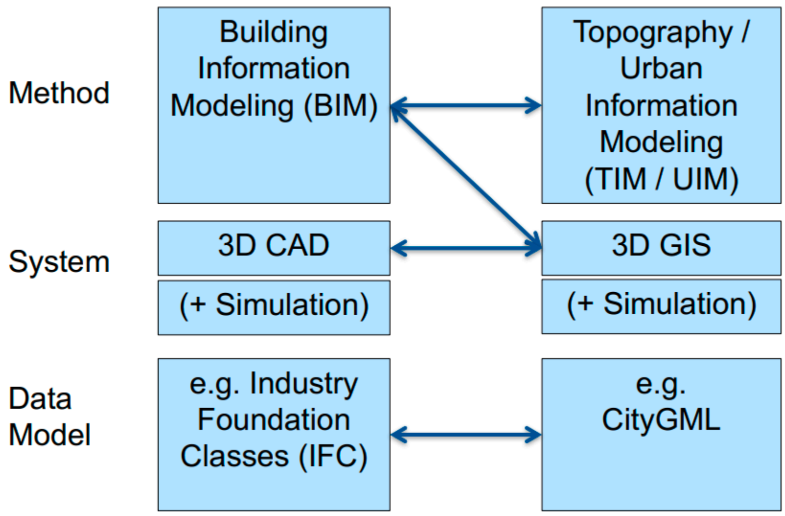

Figure 1. Building information model (BIM)–computer-aided design (CAD) level of integration, the link from BIM to 3D geographic information systems (GIS) referring to implementation of the BIM methods using GIS technology/concepts.

BIM (IFC) and UIM (CityGML)

The standards and formats for the representation, storage, and exchange of 3D building and city models are the results of application requirements or purposes of use. Industry foundation classes (IFC) [20] and City Geographic Markup Language (CityGML) [21] are two standards which have been developed independently. Although IFC and CityGML both deal with object geometry, surface materials/appearances, semantics, and their inter-relationships, the information models are different as they are adapted to the specific requirements of the domains from which they originate. An example of a major difference between the models is how the IFC schema is described using the modeling language EXPRESS, which follows the entity relationship modeling paradigm—whereas the CityGML schema is defined using the Unified Modeling Language (UML) and, therefore, follows the object-oriented modeling paradigm. Although both IFC and CityGML are object-oriented, each uses a different formal modeling language. The semantic model of IFC, in its current version "IFC4 Addendum 2", focuses on buildings and alignments as well as the physical elements of the building construction, such as slabs and beams—whereas CityGML models all major observable natural and manmade entities in a city or landscape, including buildings. To represent entities with their geometric and semantic properties in different granularities, CityGML includes five well-defined levels of detail (LOD0–LOD4). Regarding IFC, a building element might have multiple geometric representations. Additionally, a "Level of Development" concept was introduced by Forum B [22] which, according to

Geiger et al. [23], cannot be directly compared with the CityGML's level of detail. Level of development (LoD) is applied in BIM to reflect the progressions of the modelling geographic representation, from the lowest LoD of general 2D, to the highest LoD of BIM involving 3D models and corresponding detailed non-geometric information. The main problem in the integration of BIMs with geospatial information occurs at the point of transferring the geometric information [24]. Building models use representations such as constructive solid geometry (CSG) and sweep geometry mostly in local coordinate reference systems, while geospatial models mainly use boundary representation (BRep) in global coordinate reference systems [24]. The fundamental difference arises from their distinct modeling paradigms, which are due to the way 3D models are acquired in the GIS domain in the field of BIM and computer-aided architectural design (CAAD). Using GIS, 3D objects are derived from surface observations of topographic features based on sensor-specific extraction procedures. Features are then described by their observable surfaces by applying an accumulative modelling principle [25]. Alternatively, BIM models reflect how a 3D object is constructed. They follow a generative modeling approach and focus on the built environment, rather than on topography. Therefore, BIM models are typically composed of volumetric and parametric primitives representing the structural components of buildings [26]. However, the relation between the two semantic models (IFC and CityGML) for BIM (design model) and geospatial models (real-world model) has been researched to develop common unified spatial applications with minimum conversion overhead [24–26].

3. Course Development

The BIM–GIS integration course was first offered by the Chair of Geoinformatics in summer 2016, and is currently being held for the third time. The course is an independent course that has the following prerequisites: Fundamentals in Geoinformatics, as covered by the module "spatial databases and visualization" from the master's program for Geodesy and Geoinformation, as well as the courses "Geoinformatics 1" and "Geoinformatics 2" from the bachelor's program in Geodesy and Geoinformation. Knowledge in object-oriented modelling with Unified Modeling Language (UML) is helpful but not required. The development of the BIM and GIS integration course has been a rigorous, intensive, and ongoing process. To help guide and clarify the discussion of this process, the course development framework has been outlined in Table 1, compiled from Graves [27], which lists the primary components of course design as well as the questions that teachers must consider in relation to each component.

Table 1. Course design components and questions in relation to each component, compiled from Graves [27].

Component	Corresponding Questions
Needs assessment	What are my student's needs? How can I assess those needs so that I can address them?
Determining goals and objectives	What are the purposes and intended outcomes of the course What will my students need to do or learn to achieve these goals
Conceptualizing content	What will be the backbone of what I teach? What will I include in my syllabus?
Selecting and developing materials and activities	How and with what will I teach the course? What is my role? What are my students' roles?
Organizing of content and activities	How will I organize the content and activities? What system will I develop?
Evaluation	How will I assess what students have learned? How will I assess the effectiveness of the course?
Consideration of resources and constraints	What are the givens of my situations?

3.1. Needs Assessments

The BIM/GIS integration course goals and objectives are determined based on a literature review for different use cases of BIM/UIM integration, reported in a published paper by the author [17]. Additionally, other literature review papers on BIM/GIS integration were considered [18,19]. The following are some of the major findings:

- Different problems in Geoinformatics domain can be better resolved by BIM integration, such as navigation analysis, utilities infrastructure analysis, and emergency response.
- Different GIS functions can be of great benefit to the BIM domain.
- Cases related to energy, project management, indoor navigation, design, emergency response, flood management, and cadastre are reported in the literature.
- Different integration mechanisms are developed to achieve interoperability between the two domains.
- IFC and CityGML are the most commonly used 3D semantic models and exchange formats in the BIM and UIM domains.

The above list represents some of the issues which geoinformatics students need to understand to conduct projects that include information from both the BIM and the UIM domains. It drives the course objectives and goals and determines the learning materials that are required for the course.

3.2. Determining Goals and Objectives

The course introduces students to the concept and practice of BIM and UIM. Its major goals are to equip students with knowledge of BIM and the 3D urban models theory, as well as the skills needed for conducting their own projects. The course provides an overview of the latest advancements in building information modelling (BIM) technology, which is rapidly transforming the way building and infrastructure projects are designed, estimated, and constructed. Additionally, building information models can effectively represent complex built environments with high granularity, which is an essential data source for the recently matured 3D geospatial technologies. The objective of this course is to give students a thorough understanding of the capabilities and information structure of BIM. Students will learn to fuse information from BIM and use it in their geo-studies, and to integrate BIM data in geodatabases. Students will also gain an appreciation for the importance of accuracy, organization, and attention to detail. More specific objectives are:

- To recognize the importance of BIM and its linkage to Geospatial Information Sciences (GIS).
- To recognize the major differences between the BIM and UIM modelling paradigms.
- To develop the ability to create and modify BIM models using BIM editors, such as Revit Architecture.
- To identify various BIM/GIS integration mechanisms, i.e. the pros and cons associated with each mechanism.
- To develop the ability to browse the BIM files and extract required information.
- To develop the ability to integrate BIM models in GIS accurately and quickly, and to analyze BIM models in a geospatial context.
- To think critically about specific needs of the BIM community that can be supported by geoinformatics methods and techniques.

Indeed, these learning goals and objectives align with the mission of the Technical University of Munich, which emphasizes whole-person development and encourages students to assume greater responsibility for their own learning processes [28].

3.3. Conceptualizing Content

The course content is conceptualized into two parts: (1) The theory, applications, and skills of BIM/GIS; and (2) the theory and skills needed for BIM/GIS integration. The former conceptualization includes the history of CAD and the maturing of BIM concepts in the AEC industry, the importance of BIM for geoinformatics through use cases, GIS functionalities that are important for the AEC community, BIM and GIS integration mechanisms, and the difference between the two domains with respect to geometry, coordinate reference systems, standards, and semantics related to each domain. The latter refers to the knowledge and skills required for students to implement and undertake projects that include BIM information, such as practical exercises that provide students with the ability to differentiate between 2D CAD, 3D CAD, and BIM. Additionally, hands-on experience on BIM editors are provided to gain knowledge on how to create, edit, and modify BIM models. Moreover, exercises are provided to enable students to understand the BIM exchange format, such as IFC. In addition to theory and skills, students undertake real examples for integrating BIM and GIS, by using the mechanism for BIM and GIS integration and considering different use cases related to applications in computer-aided facility management (CAFM), energy, indoor/outdoor navigation, and utilities. The course allows students to proceed through online course rooms using the eLearning platform Moodle (https://moodle.org/), and Moodle serves as the main repository of the course regarding learning materials, as well as for different activities around communication, collaboration, and self-learning provided by the teacher. The course concepts are introduced in the following order:

The course commences with a highlight on the motivation and contemporary problems for CAD–BIM/GIS integration. Following the introduction, the most prominent standard in the AEC industry—IFC—is introduced. Secondly, an overview of the standards and a detailed analysis of the building object relationships, as well as semantic representations of 3D features in a built environment within this model are explained.

Thirdly, the course discusses the different semantics of harmonization approaches to achieve interoperability between BIM and UIM, such as by using IFC and CityGML for things like formal mapping, unified models, semantic web technologies, and BIM and GIS query languages.

Finally, the course ends with a presentation of use cases and lab work with four prototypes for indoor/outdoor analysis, based on the harmonization between the BIM/GIS indoor network for pedestrian navigation, utility network, thermal design, and CityGML model creation from IFC models.

Students receive hands-on training with cutting-edge BIM products, including BIM editors (like Autodesk Revit), the BIM server, IFC parsers, and 3D GIS-analysis products (like FME and ArcGIS).

3.4. Selecting and Developing Materials and Activities

A number of lectures, labs, and agency visits were developed by the instructors to provide students with the required knowledge and skills. Table 2 summarizes the teaching and learning activities for the course.

Table 2. Teaching and learning activities.

Activity	Frequency	Description
Lectures	Weekly	Knowledge and theory of BIM; history of CAD; BIM; BIM/GIS integration approaches are introduced and discussed; use cases; IFC standard; BIM versus GIS data modeling.
Agency visit	Once—Munich Airport	The visit familiarizes students with the CAFM tasks and operation which is based on BIM/GIS integration.
Labs	Weekly	Hands-on experience on BIM and GIS tools using project-based exercises.
Guest lecturers from the industry	Once	Familiarizing students with the experience of people involved in BIM–GIS projects.

As the teaching and learning activities listed in the table reveal, the theoretical and technical aspects of BIM/GIS integration are encapsulated to provide the knowledge and skills required to manage BIM in GIS.

3.5. Organizing the Content and Activities

The course is organized cyclically, and the entire course follows the experimental learning cycle on the macro level. Looking at the micro level (of a unit or part of the content), students learn and revisit certain content in various ways, such as by lectures, labs, or reflection activities. Course materials and activities are arranged in such a way that the related knowledge and skills are covered in lectures before they are applied to the lab in learning projects. Table 3 provides a chronological overview of the content covered in lectures and service learning-related activities.

Table 3. Organization of content and activities.

Week	Content of Lectures	Labs
1–2	Fundamentals and CAD history up to BIM—Current trends and future direction of CAD	2D CAD, 3D CAD, BIM—BIM editors (Revit Architectural and MEP)
3	Why BIM is important for GIS	
4	What the current capabilities in GIS are that could be useful for BIM people (brainstorming and discussion)	
5–7	IFC as standard for BIM	
	Getting to understand the IFC structure	BIM Server, FME, 3D GIS functionalities
	My wall, my house, my structure	
7	Integrating and analyzing BIM in GIS approaches and challenges	Generate 3D City Models from BIM
8–10		CAFM applications: Extract indoor network for pedestrian navigation
		CAFM applications: Extract network utilities for stream flow analysis
		Extract information for thermal design

4. Assessment of Learning Outcomes

The expected learning outcomes (Section 3.1) are verified in the form of a written examination (60 min). The purpose of the written examination is to provide evidence that students are able to analyze problems from CAFM by means of coupling the BIM and GIS methods. Therefore, the students have to analyze problems within a limited time, and need to find and implement solutions based on the intended learning outcomes of the course. The answers partly consist of personal formulations and drawings, and also partly consist of a choice from multiple options for answers. The students are not allowed to use any assistive material. The test is divided into three parts: The first part consists of three theoretical questions; the second part includes three small examples; and the third part consists of a larger practical example. The questions and examples of the tests cover all the topics in the subject.

- Three theoretical questions—these short questions have the form of a brief question that requires a written answer no longer than a few sentences or a paragraph. The students have to describe or explain things like the basic definitions, the history of CAD/BIM, or current integration approaches. The maximum score for each question is 10 points. An example of these questions is presented in Figure 2.
- Practical example (essay)—this part of the test has the form of a case-study/scenario question which is used to show that students can understand and integrate key concepts of the course, apply theories in a practical context, and demonstrate the ability to analyze and evaluate the obtained results. Students are asked to describe how BIM/GIS integration would be useful for the use cases, such as flood management, building evacuation, 3D cadaster, or traffic analysis (Figure 3).

- Three examples—these are computational questions which have to be solved by interpretation of the IFC code, the results of which have to be interpreted. The maximum score of each example was 15 points, but the scoring was changed last year and, nowadays, the maximum score for each example is 10, see Figures 4 and 5.

There are differences that exist between BIM / 2D CAD/ 3D CAD. Please describe these differences with respect to the following aspects:

	2D CAD	3D CAD	BIM
Automatic Update			
Geometry			
5D			
Architecture elements			

Figure 2. Example of a theoretical question.

Describe how BIM/GIS integration would be useful for the following use cases

•Flood management

•Building evacuation/ Fire fighting

• 3D Cadastra

•Traffic analysis

Figure 3. Practical example—essay question.

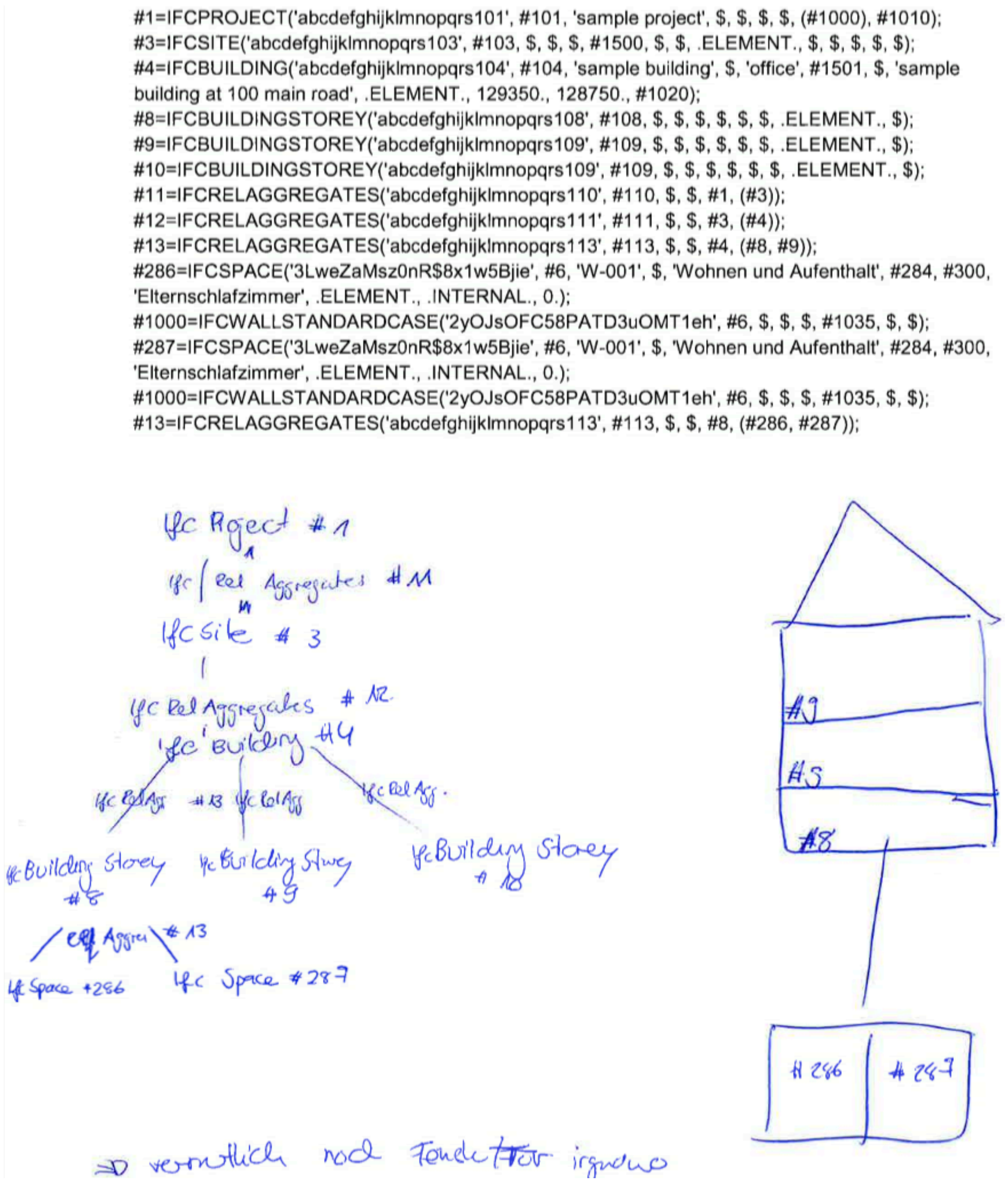

Figure 4. Example for a code interpretation question—building hierarchy.

```
#240=IFCFLOWSEGMENT('ABCDEFGHIJKLMNOPQ00040',#9,'C','',$,$,$,$);
#242=IFCDISTRIBUTIONPORT('ABCDEFGHIJKLMNOPQ00042',#9,'C0','',$,$,$,.SOURCE.);
#243=IFCRELCONNECTSPORTTOELEMENT('ABCDEFGHIJKLMNOPQ00043',#9,$,$,#242,#240);
#244=IFCDISTRIBUTIONPORT('ABCDEFGHIJKLMNOPQ00044',#9,'C1','',$,$,$,.SINK.);
#245=IFCRELCONNECTSPORTTOELEMENT('ABCDEFGHIJKLMNOPQ00045',#9,$,$,#244,#240);
#246=IFCRELDEFINESBYPROPERTIES('ABCDEFGHIJKLMNOPQ00046',#9,$,$,(#240),#247);
#310=IFCFLOWFITTING('ABCDEFGHIJKLMNOPQ00073',#9,'T','',$,$,$,$);
#312=IFCDISTRIBUTIONPORT('ABCDEFGHIJKLMNOPQ00075',#9,'T0','',$,$,$,.SOURCE.);
#313=IFCRELCONNECTSPORTTOELEMENT('ABCDEFGHIJKLMNOPQ00076',#9,$,$,#312,#310);
#315=IFCRELCONNECTSPORTTOELEMENT('ABCDEFGHIJKLMNOPQ00078',#9,$,$,#314,#310);
#317=IFCRELCONNECTSPORTTOELEMENT('ABCDEFGHIJKLMNOPQ00080',#9,$,$,#316,#310);
#405=IFCRELCONNECTSPORTS('ABCDEFGHIJKLMNOPQ00086',#9,$,$,#312,#224,$);
```

Figure 5. Another example for a code interpretation question—indoor utility network.

5. The Way Forward

Future developments will include considering new topics such as BIM for infrastructure, including the newly introduced IFC Alignment concepts and future extensions for IFC, such as concepts for representing tunnels and bridges [15,16], and their corresponding object classes in geospatial domains, like tunnels and bridges in CityGML, as well as InfraGML [29] for alignments.

Moreover, during the BIM–GIS integration workshop that took place during the 3D Geoinfo 2017 conference in Melbourne (focus group), a questionnaire was conducted, and feedback collected for future topics. The focus group interviews provided a direction to organize the sequences of the topics covered in the course, as well as to ascertain the effects of the related knowledge, covered topics, problem solving skills, and research skills required. The feedback provided information on ways to enhance the course. Additionally, the workshop participants were asked to provide specific points that could be considered as strengths and weaknesses of the course. The participants considered teaching the IFC schema as the most important part of the course, and no specific weaknesses were highlighted. The workshop participants ranked the teaching of the different integration mechanisms as the most important topic to teach in the course, and teaching the benefits of BIM for geoinformatics came second. Finally, the participants proposed other topics to be covered in the course, such as the legal aspects of BIM/GIS/IFC, highlighting the added value of BIM and GIS integration, and more use cases related to disaster management, asset management, and the energy performance of buildings.

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