Ph.D. Dissertation

BIM Adoption in Local-based Architecture and Engineering SMEs

Developing an Application-based Method to Pinpoint Objective BIM Uses and Align Them with Business Standards to Facilitate the Execution of BIM Projects in Prospective Architecture and Engineering SMEs

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Contents

Abbreviations:

AECO	Architecture, Engineering, Construction, and Operation
AE	Architecture and Engineering
AHP	Analytical Hierarchy Process
AIM	Asset Information Model
AIR	Asset Information Requirement
BEP	BIM Execution Plan
BIM	Building Information Modeling
BSI	British Standards Institute
BU	BIM Use
CAD	Computer Aided Design
CDE	Common Data Environment
CI	Consistency Index
CIC	Construction Industry Council
COBie	Construction Operations Building Information Exchange
CP	Construction Production
CR	Consistency Ratio
EIR	Exchange Information Requirement
EU	European Union
FM	Facility Management
GDP	Gross Domestic Product
GSA	US General Service Administration
HUF	Hungarian Forints
HVAC	Heating, Ventilation, and Air Conditioning
IC	Information Container
ID	Identification
IFC	Industry Foundation Class
IR	Information Requirement
ISO	The International Organization for Standardization
IT	Information Technology
KSH	Hungarian Central Statistical Office
LOD	Level of Development
LOIn	Level of Information Need
MCDA	Multi-Criteria Decision Analysis
MCDM	Multi-Criteria Decision-Making
MEPF	Mechanical, Electrical Plumbing, and Fire protection
MIDP	Master Information Delivery Plan

MSMEs	Micro, Small and Medium-sized Enterprises
MSZT	Hungarian Institute for Standardization
M€	Million Euros
NACE	Statistical Classification of Economic Activities in the European Community
NBGO	National BIM Guide for Owners
NBS	National Building Specification
NIBS	US National Institute of Building Sciences
OIR	Organizational Information Requirement
PAS	Publicly Available Specification
PCM	Pairwise Comparison Matrix
PIM	Project Information Model
PIR	Project Information Requirement
POR	Program of Requirement
pre-BEP	Pre-appointment and Delivery Team's BIM Execution Plan
PTE MIK	University of Pécs, Faculty of Engineering and Information Technology
QA	Quality Assurance
QTO	Quantity Take-off
RI	Random Consistency Index
SBUs	Set of BIM Uses
SEIRs	Set of Exchange Information Requirements
SICs	Set of Information Containers
SIRs	Set of Information Requirements
SJR	Scimago Journal & Country Rank
SMEs	Small and Medium-sized Enterprises
ST	South Transdanubia
TIDP	Task Information Delivery Plan
VDC	Virtual Design and Construction
2D	Two-Dimensional
3D	Three-Dimensional (base)
4D	Four-Dimensional (time-related)
5D	Five-Dimensional (cost-related)
6D	Six-Dimensional (FM-related)
7D	Seven-Dimensional (sustainability-related)
8D	Eight-Dimensional (health/safety-related)

1. Introduction

1.1. General research introduction

The research is going to introduce several highlighted main topics that are included in this dissertation. The main topics refer to the later on developed chapters for the associated thesis points. This subchapter will provide a comprehensive overview of the included main topics, and later on it will be followed by a specific research introduction that intends to represent arranged specialized insight for the conducted study.

- **Building information modeling:**

Building Information Modeling (BIM) is the method of using digital or virtual model to plan, design, construct, and/or operate building projects [1], by using defined elements that are interactively linked to generate Architecture, Engineering, Construction, and Operation (AECO) information [2]. Meaning that BIM is part of the digitization process in the building industry, and it is a digital-based way that intends to increase quality and decrease errors despite the lack of direct measurements regarding the true implementation of BIM processes [3]. Collaboration between different disciplines within the building industry is essential to deliver or operate built assets, this collaboration was depending on the exchange of Two-Dimensional (2D) information between different disciplines, until the widespread implementation of the revolutionary Computer Aided Design (CAD) and Three-Dimensional (3D) tools, and finally followed by the introduction of BIM processes to replace the traditional methods for information generation and exchange among different project representatives [4]. The potential of BIM arises by its development from intra-discipline to multi-discipline cooperation tool, assisting the tremendous exchange of building data between different project representatives to support the design and construction of projects, and during the operation of the built asset as a life-cycle support tool to assist the operations of the facility during its life span [4], [5].

Based on the National Building Specification (NBS) there are several BIM levels that classify businesses based on their BIM compliancy, including Level 0, 1, 2, and 3 BIM [6]. Level 0 BIM means no collaboration, where 2D CAD drafting is only utilized, the output and distribution is via paper and electronic prints. Level 1 BIM includes a mixture of 3D CAD for concept work, and 2D for drafting of permits, approval documentation, and production information. Level 2 BIM is distinguished by collaborative workflow, which requires an information exchange process which is specific to that project and coordinated between various disciplines and project participants. Any CAD software to be implemented in the project should be capable of exporting to one of the industry's common file formats, e.g., Industry Foundation Class (IFC) and Construction Operations Building Information Exchange (COBie). Finally, Level 3 BIM has not yet been fully defined, but the future vision for this level includes the following key measures: the creation of a new set of "Open Data" standards to facilitate sharing information across the entire industry, establishment of new contractual framework for projects which have been procured with BIM, creation of co-operative cultural environment, training the public sector client in the use of BIM techniques, and driving domestic/international growth in technology and construction [7].

- **The AECO firms in the building industry:**

The AECO industry faces several difficulties and opportunities as it adapts to the continuously changing market trends and technological advancements. As one of the largest industries in the world, accounting for 13% of the global Gross Domestic Product (GDP), the industry witnesses a steady increase in demand for innovative building materials, construction techniques, and digital technologies (e.g., BIM, cloud-based collaboration, and requirement-management tools). On the other hand, the industry grapples with several issues and obstacles that vary from one market to another, including lack of collaboration, poor communication, shortage of skilled labor, rising material costs, increased regulatory requirements, etc. [8].

The AECO firms stand for firms that run the building industry including architectural planning/design, structural/engineering, construction, and operation firms, BIM plays an essential role in the workflow of large AECO businesses, and it is impact is not limited to managers, architects, and engineers, it goes further beyond among clients, investors, contractors, facility managers, professionals, and craft workers, this can be imagined by thinking about the federated BIM model as a collection of different independent models, from which each model refers to a certain stakeholder [9]. However, many built projects are mostly carried out by sub-contracted smaller firms or Small and Medium-sized Enterprises (SMEs), which may also carry out parts of large size projects, so there are frequent calls for smaller firms and SMEs to implement BIM solutions in different sized projects considering affordability, availability, and practicality, since the multidisciplinary nature of the sector applies to smaller and larger markets [10].

In the building industry, SMEs are key components of the industry and considered fundamental to national and international economies. Although the building industry market is divided into two different sections, the first is dominated by global corporations with giant budgets and megaprojects, and the second includes smaller-sized firms that usually work on domestic projects in local regions. Still, smaller-sized firms do not reflect smaller significancy in the market, a published report by UK's Federation for Small Businesses demonstrates that SMEs account for three-fifths of employment and around half the turnover of the private sector, from which the construction industry in particular accounts for 16% of all SMEs that belong to this sector [11]. SMEs are the real driving force in the building industry market, since they occupy the majority of the lower base levels of the industry's size-based pyramid structure, meaning that the stability and development of SMEs will be the driving force for the stability and enhancement of large building industry firms, so that SMEs are the key for the future of the building industry sector including AECO firms [12]. In UK, nearly the fifth of all SMEs play a role in the building industry, hence SMEs are recognized by many professionals as a crucial part of the industry and driving force within it, since SMEs are the source for specialized skills, know-how, technological advancements, and essential share of the workforce required to deliver the built projects [13].

In the EU, the building industry is of vital importance to the European economy, including more than 3 million firms and a total direct workforce of 18 million people, the sector generates about 9% of the EU's GDP. 99.9% of the European construction sector is composed of Micro, Small and Medium-sized Enterprises (MSMEs) with less than 250 employees. In the EU, micro enterprises display the biggest part of the sector with 94.1% [14].

In the Hungarian domestic building industry market, SMEs play a major role in the market shares including the following building industry firms: manufacturing, construction, real estate, and architectural/engineering activities. SMEs in the broad building industry sector employ around 91.7% of the total number of employees in the sector. This highlights the significance of SMEs in the Hungarian broad building industry sectors including all sub-disciplines within the sector [15].

- **BIM adoption and its barriers:**

BIM is an emerging methodology in the building industry and can offer tremendous benefits for the industry's stakeholders. It is clear that BIM adoption rates vary from one country to another, and this turns the light on the field of region-based BIM adoption studies to investigate the reasons behind BIM adoption rates and discover the barriers that inhibit the implementation process [16]. It is almost impossible to write about the adoption of BIM-based workflows without mentioning the barriers against the adoption, the barriers represent obstacles that inhibit the smooth implementation of BIM workflows in daily practice at the building industry firms. These barriers have different themes and relative importance ratios based on the studied region and target discipline within the building industry market. This means that facility management firms may have different BIM barriers compared to architectural design firms, and an architectural design firm that is specialized in early design stages may have different barriers compared to another architectural firm that is more involved in design development and construction detailing. Moreover, size of the firms may also influence the priorities of BIM adoption barriers, a smaller-sized firm may have different perspectives, resources, and scopes compared to a larger-sized firm, and accordingly the relative importance ratios of both firms may vary significantly due to the size difference [17], [18], [19].

Every building industry firm should conduct a strategic planning process to establish BIM objectives and set the orientation to focus future implementation efforts. Strategic planning activities assist building industry firms to set the intended goals and objectives, while directing the means and methods for achieving them. Hence, it is very important to understand that no two firms are alike within the building industry, even within the same subdiscipline, organizations vary based on the objectives and scopes, by keeping this constraint in mind, the BIM strategic planning procedure can be separated into three main steps: assessment, alignment, and advancement [20]. Hence, an essential step is to perform a study and assessment about the current BIM adoption level, and barriers against the adoption in order to define a strategy for approaching the intended implementation.

- **BIM Uses:**

BIM is being applied at many different processes throughout the lifecycle of built assets, at the initial stages of planning for BIM-based projects, the importance of clear definition for model uses arises. BIM Use (BU) is the method of applying BIM during a facility's lifecycle to achieve one or more specific objectives, [21], [22]. A paper titled "A Model Use Ontology" authored by Ralph Kreider and John Messner has introduced one of the best approaches to accurately classify and define BUs based on the objective and provide comprehensive collection of BUs characteristics. The paper classified BUs primarily based on the purpose of implementing BIM, the developed ontology includes primary and secondary objectives for the related BUs, primary BU objectives include gather, generate, analyze, communicate, and realize, each primary BU objective includes several secondary BU objectives, like (qualify, monitor, capture, and quantify), (prescribe, size, and arrange), (coordinate, forecast, and validate), (visualize, draw, transform, and document), and (fabricate, assemble, control, and regulate), respectively. The primary and secondary objective-based classification of BUs is called the model use purposes, in addition to that, the paper introduced the model use characteristics, including four characteristics that can be also used to further classify the objective BUs based on facility element (the system of the facility on which the BU will be employed), facility phase (the point in the facility's lifecycle at which the BU will be employed), discipline (the party by whom the BU will be implemented), and level of development (the degree of reliability or level of maturity by which the BU will be employed) [21]. Answering the previously introduced aspects regarding BUs for certain BIM-based project will provide a distinct description which can be used in procurement efforts. In addition, the planning team can communicate to all stakeholders about the intended BUs details. Moreover, The introduced model use ontology can be applied in more practice related details like defining exact information requirements and standardizing BIM processes.

In my opinion, the potential of the developed BU ontology by Ralph Kreider and John Messner lies in the essential role of purpose-based classification for BUs in the developed ontology, and this even supports the original idea of BIM-based processes that stands for the process of using digital model to fulfill certain AECO objective, and as shown in the definition the only new thing is the process of using virtual model, but on the other hand the AECO objective is the same. Hence, BIM does not intend to change the objective that AECO firms are conducting in their daily work, but it intends to change the way the accomplishment of these objectives is approached. Here is the brilliancy of the developed objective-based BU ontology that is introduced by Kreider and Messner. Unlike other well-known BUs definition approaches that mainly lean on the facility's lifecycle phase to define BUs (e.g., BUs that are related to the planning, design, construction, and/or operation phases) or the relative importance of the BU according to how common is the intended BU applied in the building industry. I think this kind of BUs definition approach has been introduced in this manner to make it easier for readers and practitioners to understand BIM implementation along the life cycle of the facility, and to highlight most common BUs within the industry, but still this approach may be misleading due to several reasons: a) the difficulty to accurately classify BUs based on the project phase since AECO projects are unique and each one has its own needs and requirements (e.g., based on the project A needs and requirements certain BUs that belong to design stage may be applied in the operation stage for appointment A-7), b) the difficulty to classify BUs based on importance; since AECO projects are unique and each one has its own needs and requirements, some BUs may be highly relevant in A project but may have low relevancy in B project, and c) the lack of consistency among the used terminology, which may lead to misunderstanding and conflict of interests among project parties (e.g., the following BUs refer to the same BU but have different terminologies: capture existing conditions, existing condition model, modeling existing state, record existing situation, capture conditions, record conditions, etc.), missing the consistent terminology that can be used when discussing and defining the employment of BIM in different project appointments may lead to conflict of interests among project stakeholders [21], [23], [24].

It is crucial for any AECO firm that intends to carry out BIM-based projects and appointments to understand the basics of BU, since the first step in developing and executing BIM-based project is to pinpoint the proper BUs based on project's requirements and goals. A huge early challenge is faced by the project management team in the intended firm to identify the appropriate BUs based on the given project's scopes, characteristics, participants' goals/capabilities, and the risk allocation. Prior to BU's definition, the project management team should highlight the project's goals along with the potential relationship with the BIM employment process, these goals should be specific to the project at hand, measurable, and strive to improve success in the planning, design, construction, and operation phases of the facility [23].

Another model use taxonomy has been developed by Bilal Succar and his team by providing two sample practical applications: model use as an implementation task list and model use as a performance assessment module. Since model uses lay the foundations for structured requirements clarification by enabling the translation of project goals into structured requirements, comparison of project requirements with actual deliverables, and performing multi-type interconnected performance assessment. Resulting with knowledge routine or a workflow that connects knowledge blocks into performance-centric approach [24].

- **Business standards:**

The early applicable base guide appeared in 2007 under the title "The CIC Scope of Services Handbook" that was authored by the Construction Industry Council (CIC), the guide presented the CIC scope of services by including numerous examples and illustrations, providing early step toward standardized construction project management. However, it does not have a direct digital source related to digitization or BIM, but usually it is referenced in historical context regarding the business standards that are related to the industry. The guide is recommended for use on major building projects designed by a multi-disciplinary team, regardless of the procurement route. The client can be a developer or end-user client, or a design and build contractor [25].

Then the "BS 1192:2007 collaborative production of architectural, engineering and construction information: code of practice" standard has been published by the British Standards Institute (BSI). The standard is considered one of the first comprehensive BIM-related standards, providing guidance on collaboration, file structures, and information sharing. The standard back then was considered highly relevant since it introduced a standardized key-components for BIM-based processes, including file naming, workflows, and data exchange formats [26].

Followed by the Publicly Available Specification (PAS) 1192 series (2013-2018), PAS are rapidly developed practice-related standards, specifications, codes, or guidelines. A PAS is developed to meet immediate market need and follow guidelines defined by the BSI. After two years duration, developed PAS standards are reviewed to determine if they need revision, should be withdrawn, or become formal British or international standards. The PAS 1192 framework is considered one of the first attempts to develop thorough and comprehensive BIM standard. The framework defines the requirements for the level of model detail (including graphical content), model information (non-graphical content, e.g., specification data), model definition (the meaning), and model information exchange (the swap of information between project's parties). The series currently contains: PAS1192-2:2013 (which deals with the construction or capital delivery phase), PAS 1192-3:2014 (which deals with the operational phase), PAS 1192-4:2014 (which is technically a code of practice rather than a specification standard, regarding COBie), PAS 1192-5: 2015 (which deals with security-minded BIM), and PAS 1192-6: 2018 (which deals with health and safety data for BIM).

Then a great step toward internationalizing BIM processes across the globe, in 2018 the International Organization for Standardization (ISO) published the first part of the so-called ISO 19650 series. ISO is an independent, non-governmental international organization that brings global experts together to agree on the best business practices for several domains. ISO 19650 series "organization and digitization of information about buildings and civil engineering works, including building information modeling (BIM), information management using building information modeling" has 5 published parts, and the 6th part is still under development. The parts include ISO 19650-1:2018 (which deals with BIM-based concepts and principles), ISO 19650-2:2018 (which discusses the delivery phase of the assets), ISO 19650-3:2020 (which deals with the operational phase of the assets), ISO 19650-4:2022 (which deals with the information exchange), ISO 19650-5:2020 (which deals with security-minded approach to information management), and the under development ISO/FDIS 19650-6 (which is going to deal with BIM-based health and safety information) [27], [28], [29], [30], [31], [32], [33].

1.2. Specific research introduction

The research studies the adoption of BIM methodologies in the workflows of professional firms within the building industry. The AECO sector rapidly grows, and this growth is accompanied by plenty of technological developments on several levels to adapt with the market's trends, needs, and requirements. Integrating BIM in the delivery and operation phases of built assets is considered a priority for AECO firms seeking digital transformation and enhanced efficiency.

BIM can be simply described as the method of using digital model to fulfill defined objectives and tasks within building projects supported by the rapid technological development that allows the integration of different methods and tools to enhance the delivery and operation stages of built assets. In response to the increased demand and market trends toward digitization to improve outcomes and efficiency, this research is dedicated to study the adoption of BIM by focusing on the organization and digitization of information on the delivery firms' level, including Architecture and Engineering (AE) firms. The research targets the local Hungarian building industry, and specifically the Small and Medium-sized Enterprises (SMEs) that are based in the South Transdanubia (ST) region, as an attempt to assist domestic smaller-sized AE firms to overcome digitization difficulties and increase their productivity. Moreover, the research may be applicable for other national and international building industry firms that share the same challenges against the adoption of BIM processes.

Several primary and secondary motives shaped the framework of this research and its components. This document will highlight the research drivers, questions, scope, theses, results, summary, and scientific contributions, to provide a brief overview for the conducted research work that is associated with the submitted dissertation.

1.2.1. Research drivers and questions

The research drivers for the conducted study include two main groups: primary and secondary. The primary drivers include research motives discovered at the very beginning of the research journey, during the initial stages of the study. On the other hand, secondary research drivers include research motives derived from later on conducted research stages during the progress of the research study. Primary drivers are considered the main boosters to initiate the study in this specific topic. Later on, secondary drivers appear by the development of the research and deriving initial results and conclusions. By the time the research work evolves, new secondary drivers are derived to point the research toward the right direction of accomplishing the overall objectives, and pave the way for proper research decision making, e.g., research domains, borders, baselines, target groups, etc.

Please note that the classification (primary and secondary) does not reflect the importance of the research drivers, both groups are alike in terms of importance level, this grouping classification only indicates the formulation time of these drivers whether it is during the initial stage or the later on development stages of the research work. Moreover, the secondary drivers do not interfere with primary drivers in principle, the secondary drivers complete the primary ones to form one set of coherent research drivers that will meet the defined research objectives. Hence, the reason that stands behind preventing the clear definition of secondary drivers at the initial stage of the research is due to the difficulty to formulate these drivers without conclusions from a conducted scientific research effort.

1.2.1.1. Primary research drivers

- Local-based observations regarding the dissatisfaction of employees at the building industry firms (especially employees from ST-based smaller-sized AE firms) including work operability, system processes, workflows, and coordination issues. Complaints arise from local AE professionals in connection with the lack of BIM-based processes in their conducted projects and dominance of traditional methods in daily practice. Moreover, practitioners reveal that lack of coordination between different project disciplines and their representatives results in increased challenge during the delivery of built assets.
- According to the country fact sheet published by the European Commission under the European Construction Sector Observatory in 2020 and 2021 for the Hungarian building industry, local Hungarian firms in the building industry face practical challenges to adopt BIM workflows, including business standards, standardization (of terms, methods, and interfaces), and data security. The report highlights that there are no set laws or binding obligations on public authorities for using BIM processes, so it is highly recommended for contracting authorities to impose BIM on tenderers, as an encouragement for local building industry firms to implement BIM-based processes and workflows.
- According to the country fact sheet published by the European Commission under the European Construction Sector Observatory in 2020 and 2021 for the Hungarian building industry, SMEs in the broad building industry (including building industry-related manufacturing, construction, real estate activities, and architectural/engineering activities) employed around 91.7% of the total number of people employed in the broad building industry, which is higher than the EU-27's average (87.1%) for 2018. This highlights the significance of SMEs in the Hungarian building industry.
- Severe shortage in local-based Hungarian studies and scientific contributions regarding BIM implementation in the building industry on the domestic level. This shortage is clear regarding published scientific contributions in English and Hungarian languages alike, about BIM adoption in domestic building industry firms.
- Lack of statistics regarding the allocation of local building industry firms based on their main activities (main function/scope) and size indicators.
- Lack of statistics regarding the allocation of local BIM-compliant firms within the building industry.
- Local-based observations show the misconception of BIM processes and workflows for many building industry professionals, this may lead to unrealistic claims in connection with BIM-compliance and implementation providing misleading metrics.

1.2.1.2. Secondary research drivers

- Low values of Construction Production (CP) for the building industry firms based in the Hungarian ST region from 2016-2020 and compared to CP values for other small regions in the country and at the same period of time.
- The low values of CP for building industry firms located in the ST region are associated with severe lack in BIM-compliant firms that publicly share their BIM-based services (through business portfolios and references) in the region.
- There is significant dominance for AE firms within the studied region over other types of building industry firms. The dominance of AE (including architectural, structural/civil, and building services engineering) firms is based on the firms' count compared to other specialized building industry firms in the market.

- Size-related observations regarding the collected local-based building industry firms.
- Measuring BIM adoption and its barriers is considered the initial step for region-based BIM-related studies, despite the high dependency of BIM adoption barriers identification on the studied region or country, there is lack of Hungarian-based research regarding the barriers against BIM adoption in the local building industry.
- Defining key BIM adoption barriers by local AE firms assists to pinpoint the scope for the intended BIM adoption mission.
- Publishing the draft regulation (BIM-based planning and implementation) in 2024 by the Hungarian Ministry of Construction and Transport, the regulation sets conditions for adopting BIM to enhance public construction investments by providing high-quality, lifecycle-focused information models, to improve design, construction, and operation of built assets. The regulation technical aspects are derived from the ISO 19650 business processes, highlighting the potential of this standard series for domestic building industry firms that intend to take part in public or private BIM-based projects.
- The published draft regulation (BIM-based planning and implementation, 2024) by the Hungarian Ministry of Construction and Transport clearly states that the designer (architect or engineer) is the responsible party for developing the digital model. In addition, the regulation highlights the importance of BIM Uses identification in alignment with ISO 19650 business processes to ensure high level execution of BIM-based projects.
- Practice-based observations show the lack of common accurate BIM Use (BU) definition among the project's representatives from different disciplines and parties.
- Practice-based observations indicate the lack of a BUs definition method that systematically guides professionals who intend to carry out BIM-based projects and enables them to pinpoint specific BUs based on consistent step-by-step workflow that can be applicable for any appointment.

1.2.1.3. Research questions elicitation

- What is the study region? What is the reason behind nominating the selected study region?
- What is the allocation (discipline, count, and size) of building industry firms in the study region?
- What are the sizes of building industry firms in the study region? What is the market share of SMEs or smaller-sized firms from the total collected firms?
- According to the available collected and analyzed data, what are the potential building industry firms and their disciplines within the study region?
- Among the defined potential firms and their disciplines, what is the allocation of the firms that adopt BIM workflows in their practice?
- According to the potential firms, what are the key barriers against the implementation of BIM processes in their practice?
- What is the BIM adoption mission that intends to overcome defined key BIM barriers?
- What is the proposed method that corresponds with the BIM adoption mission to overcome its key barriers?
- How to validate the leverage of the proposed method with the BIM adoption mission to overcome related key barriers defined by the potential building industry firms?

1.2.2. Research scope

The overall objective of the research study is to assist BIM adoption in local-based prospective building industry SMEs. The study approaches the overall objective through several research steps, including selecting the study region, defining potential local-based building industry SMEs, investigating BIM adoption level and its key barriers at the potential SMEs, setting BIM adoption mission to overcome key barriers, developing a method that corresponds to the mission, automating the developed method, and validating the leverage of the automated method to answer the BIM adoption mission and assist prospective building industry SMEs in BIM implementation.

- Define the potential of AE SMEs in the ST region, through:
  - Select study region.
  - Gather study region-based building industry firms and their related data.
  - Classify building industry firms based on business classes.
  - Size-based nomination of collected SMEs.
  - Define potential business classes among nominated SMEs.
- Define BIM adoption level and its key barriers in local AE SMEs:
  - Collect and analyze BIM barriers.
  - Structure and share surveys.
  - Define level of BIM adoption in local AE SMEs.
  - Define key adoption barriers in local AE SMEs.
  - Derive an objective BIM adoption mission based on the defined key barriers.
- Develop a method to answer the BIM adoption mission (BUs definition method aligned with business standards to facilitate BEP development by the management team):
  - Define academic component (academic comprehensive/particular sources and BUs definition roadmap).
  - Define practice component (infromation requirements, project phases/parties, and information delivery plan).
  - Align the components and introduce the method.
- Develop an application to automate the method and test its leverage for potential AE SMEs:
  - Introduce the significance of automation
  - Develop the application
  - Validate the application
  - Define the leverage of the developed application-based method

1.2.3. Thesis points

There are four thesis points that will be introduced, associated with the submitted dissertation. It is noteworthy to highlight the respective dependencies between the introduced thesis points, meaning that the research work associated with the later thesis points cannot be conducted without accomplishing the research work of the earlier thesis points and derive all of their results and conclusions that will assist in the development of the later upcoming theses. Hence, the arrangement of the thesis points follows the time sequence of the conducted research work during the study duration.

I. Thesis:

The research proves the high potential of *Architecture and Engineering (AE) Small and Medium-sized Enterprises (SMEs)* in the studied *South Transdanubia (ST)* region, with respect to the available primary indicators, and compared to other region-based building industry *SMEs.*

- I performed mass-filtering with 240 search attempts to collect region-based 169 building industry firms, of which 93% are considered *SMEs* according to an introduced size-based nomination method supported by a statistical measure of spread among the set of values for related size indicators.
- I compared all nominated *SME* building industry business classes based on the available primary indicators; the results prove the high potential of region-based *AE SMEs*,

accounting for 62.8%, 38.4%, and 28.6%, including number of firms, number of employees, and net revenues, respectively.

II. Thesis:

The research confirms that the level of BIM adoption and its standards among local-based *Architecture Engineering (AE) Small and Medium-sized Enterprises (SMEs)* is lagging behind, due to the lack of methods and standards definitions.

- I performed systematic literature review, collected 270 barriers, analyzed the barriers by classifying and merging processes, and derived a list of 18 comprehensive barriers to be included in a twin survey round to define the adoption level and its key barriers.
- I revealed the low percentages of BIM-compliant *AE SMEs* on the domestic level accounting for 22% at the ideal scenarios in both survey rounds.
- I revealed the low percentages of ISO 19650 adoption at the BIM-compliant *AE SMEs* on the domestic level, accounting for 9% and 13% for the 1st and 2nd survey rounds, respectively, raising questions about the credibility of related BIM-compliancy claims.
- I proved that 47% of the adoption barriers are processes/uses and legal/management related, including six key barriers, which combined will formulate an objective BIM adoption mission, that aims to assist prospective *AE SMEs* in overcoming almost half of the critical challenge toward carrying out BIM-based projects.

III. Thesis:

The research develops a method to pinpoint specific objective *BIM Uses (BUs)* for BIM-based projects and align them with relevant practice details, to correspond with the intended objective BIM adoption mission.

- I performed an extensive review for related scientific references including 33 articles and 25 textbooks, then introduced a roadmap to define objective specific *BUs* from a collection of over 380 options, introducing the method's academic component.
- I derived essential practice business processes from *ISO 19650-1/2*, including practice *Information Requirements (IRs)* and *BIM Execution Plan (BEP)* details, and aligned them with the defined objective specific BUs, introducing the method's practice component.
- I introduced the method's cornerstone, represented by matching defined specific *BUs* from the academic component with their counterparts *IRs* from the practice component, and grouping them into sets based on their predecessors on the objective roadmap and supported by a developed code syntax for identification and classification purposes.

IV. Thesis:

The research confirms the potential of the introduced method to assist prospective *Architecture and Engineering (AE) Small and Medium-sized Enterprises (SMEs)* in overcoming key adoption barriers and carrying out BIM-based appointments.

- I developed a Windows-based application that automates the method of defining objective specific *BIM Uses (BUs)*, matching them with associated *Information Requirements (IRs)*, and aligning them with essential practice information, to produce a document that includes primary details to kick-off a BIM-based project and develop the *BIM Execution Plan (BEP)* by the management team.

- I validated the potential of the developed application through response rank analysis and comparative studies after performing another twin survey round with paired samples to the former conducted rounds.
- I proved that the developed application supports accomplishing the objective BIM adoption mission by assisting prospective *AE SMEs* in overcoming the defined key and other adoption barriers with a total of 62.94% and 12.56%, respectively.

2. Potential of AE firms in the ST region

This chapter highlights the points included in the previously listed first thesis, by performing general review for statistical reports regarding the local building industry, defining target region for deep study analysis, conducting mass scan to collect building industry firms based in the region, gathering potential information for each collected firm, classifying collected firms based on sections of businesses, nominating SMEs as target group from the collected building industry firms, and defining potential building industry firms from the nominated target group according to predefined indicators.

The main focus of this chapter is to spot the potential firms (including their business discipline/s) among the collected local building industry firms that are based in the studied region to be carried on for the upcoming research steps as an attempt to minimize the scope of the work and concentrate the research effort on one or more business disciplines that have high potential impact on the local building industry at the region's level. The chapter introduces a sequence of sub-chapters that represent the arrangement of the research development steps, including the answers for major research questions, like the reason of focusing on the ST region and its AE.

2.1. Study region selection

The research work started in 2020 by some observations from the local professional Hungarian market, the author noticed that there is clear unsatisfaction among local professionals who work for local building industry SMEs (mainly AE initiatives) in the city of Pécs, in southern Hungary. The observations are based on unstructured interviews that are not even documented, the main intention behind these interviews is to touch real-life dilemma that professionals face in their daily work. Some of the mentioned problems are lack of coordination between different project participants, inconsistency between different technical drawings, the gap between 3D modeling and drawings production, lack of early project engagement, separated architectural and structural design stages, difficulty in communicating the project's requirements with the contractor and other project parties, inaccuracy in quantity take offs, etc. It is clear that the right application of BIM processes may help in some if not all the issues that have been highlighted, but shockingly many of the participants mentioned lack of BIM processes as potential reason for their issues, even without having knowledge regarding how the employment of BIM processes can assist in their highlighted issue? After pinpointing the main scope of the research (BIM implementation for local building industry SMEs) it was essential to follow a scientific path with defined milestones including recording/publishing the results and re-estimating the status of the research together with the intended direction at each milestone, the first milestone is the study region selection, because studying the entire local Hungarian building industry market is quite challengeable based on the research's capabilities, resources, and time schedule, so that narrowing down the scope to specific region/s is essential to keep the research and its samples workable with.

The first step toward region selection is to study region-based statistics for the local building industry. The research reviewed building industry related statistics for five years (2016-2020) based on reports published by the Hungarian Central Statistical Office (KSH). The study focuses on the behavior of the Hungarian construction market by analyzing and comparing different values of construction production that represent values of net revenues in a region-based manner. The territory of the country is divided into eight planning and statistical regions, six of these being made up of three counties: Western Transdanubia (Győr-Moson-Sopron, Vas, Zala), Central Transdanubia, (Komárom-Esztergom, Fejér, Veszprém), Northern Hungary (Borsod-Abaúj-Zemplén, Heves, Nógrád), the Northern Great Plain (Hajdú-Bihar, Jász-Nagykun-Szolnok, Szabolcs-Szatmár-Bereg), the Southern Great Plain (Bács-Kiskun, Békés, Csongrád), Southern Transdanubia (Baranya, Somogy, Tolna). Pest county as well as Budapest function as independent regions [34]. The eight small regions belong to three main large regions: Central Hungary (Budapest, and Pest), Great Plain and North (Northern Hungary, Norther Great Plain, and Southern Great Plain), and Transdanubia (Central Transdanubia, Western Transdanubia, and Southern Transdanubia). Please see the following Figure 1 that presents the geographical allocation for the Hungarian small regions.

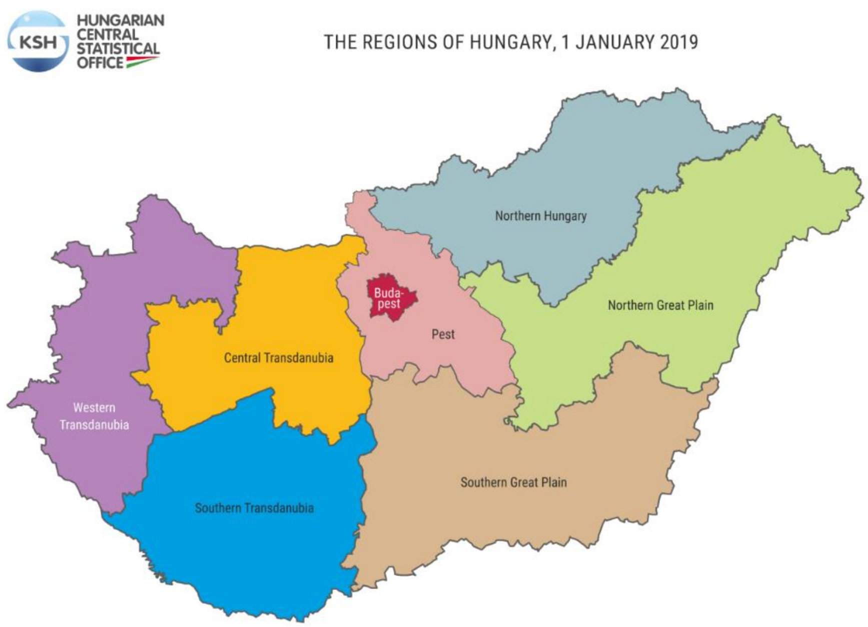


Figure 1: the regions of Hungary, courtesy of the Hungarian Central Statistical Office (KSH)

The research starts with reviewing the values of CP for the Hungarian building industry market, please refer to Figure 41 in the attachments chapter for more details regarding the development of the CP values for the Hungarian building industry market by the location of construction (inside the borders of Hungary), from 2002-2016 the sector witnessed many ups and downs in terms of CP that varied between 1 and 1.5 trillion Hungarian Forints (HUF). On the other hand, from 2016-2020 the sector rapidly developed and doubled its market value reaching up to more than 3 trillion HUF by the end of 2020. The rapid growth during five years duration is result of the growth in the total CP values by the location of construction from all Hungarian small regions, including Budapest, Pest, Central Transdanubia, Western Transdanubia, Southern Transdanubia, Northern Hungary, Norther Great Plain, and Southern Great Plain, accounting for 23%, 13%, 10%, 11%, 8%, 10%, 14%, and 11% from the total CP by the location of construction from 2016-2020, respectively.

Despite the importance of the construction growth indicator provided by comparing the values of CP by the location of construction for Hungarian small regions, and its ability to give an insight regarding the size of construction projects conducted at each small region, the indicator does not reflect the exact CP for building industry firms based in the associated small region, since the provided values are based on the construction project location instead of the firm's location, and due to the fact that participating firms in delivering construction projects are not limited to local building industry firms on the small region level, and firms from other small regions can participate in the delivery process, a need arises for an indicator which is more related to the delivery firms instead of the conducted construction projects.

Hence, the research collects values of CP by the location of the building industry firms, the KSH reports include yearly based data for each region regarding the CP of building industry firms based on that region. The study collects the values of CP per location of the firm for five years (2016-2020) and introduces a region-based comparison (see Table 1) that shows low values of CP (6%) for building industry firms based in the ST region compared to the same values for building industry firms based in other Hungarian small regions and during the same period of time. Bearing in mind, that the values of CP for building industry firms located in Central Transdanubia, Western Transdanubia, Northern Hungary, and Norther Great Plain are almost identical, accounting for 9%, 9%, 9%, and 10%, respectively. For Pest and Southern Great Plain small regions, the proportion of CP values grows up to 13% and 14%, respectively. The highest attribution for CP per building industry firms undoubtedly belongs to the capital (Budapest small region) accounting for 30% out of the total CP allocation by the location of building industry firm. The low values of CP for building industry firms located in the ST region drags back the total value of CP for building industry firms located in the large region of Transdanubia (accounting for 24%) compared to the country's other large regions: Central Hungary, and Great Plain and North (accounting for 43% and 33%, respectively). Please see Figure 42 in the attachments chapter for more details.

Table 1: values and percentages of CP for local Hungarian building industry firms by the location

	Small region	Period	Value of CP (million HUF)	Percentage of CP (%)
1	Budapest	2016-2020	3,480,916	30%
2	Pest	2016-2020	1,467,863	13%
3	Central Transdanubia	2016-2020	1,061,845	9%
4	Western Transdanubia	2016-2020	1,067,995	9%
5	**Southern Transdanubia**	**2016-2020**	**661,788**	**6%**
6	Northern Hungary	2016-2020	1,000,995	9%
7	Norther Great Plain	2016-2020	1,156,389	10%
8	Southern Great Plain	2016-2020	1,647,762	14%

To sum up, this research will focus on the ST region whose building industry firms suffer from severe low values of CP (presented by low values of net revenues) compared to the same values of other building industry firms located in comparable small regions (e.g., Central Transdanubia, Western Transdanubia, Northern Hungary, and Norther Great Plain).

2.2. Region control and selection of building industry firms

On this step the research controls the borderlines of the selected ST Region to collect the building industry enterprises within the region's borders. The region consists of three counties: Baranya, Somogy, and Tolna, and each one includes several administrative cities and smaller towns.

The research collected the AECO firms belonging to each administrative city, with a total of 13, 8, and 6 scanned cities in Baranya, Somogy, and Tolna counties, respectively. The study also contained several AECO companies, which are based within the borders of the region and registered in 9 smaller towns within the counties.

The process of collecting the building industry firms based in the region leans on an online public acquainted mapping platform supported by Google (Google Maps), as a public reached source to conduct mass filtering for the AECO enterprises based within the borders of the region, by relying on a free publicly accessed database of addresses and postal codes. The location-based mass filtering process collects building industry firms that have registered addresses within the borders of the studied region. The searching method includes using search keywords as illustrated in Figure 2, the search keyword consists of two main components, including the firm's functional activity (architectural, engineering, construction, or operational firm) and followed by the name of the county or the city where the search is conducted. The ST includes 3 counties with a total of 27 cities, meaning that the total number of search attempts was 240 search attempts, half of the attempts are in Hungarian language and the other half in English language. The following search keywords are examples for the possible variation to search for building industry firms in Pécs city that belongs to Baranya county: (1) architectural firms in Pécs, (2) engineering firms in Pécs, (3) construction firms in Pécs, (4) operation firms in Pécs, (5) architectural firms in Baranya, (6) engineering firms in Baranya, (7) construction firms in Baranya, and (8) operation firms in Baranya, plus 8 search keywords with almost identical context but in the Hungarian language, resulting with 16 different search keywords and attempts.

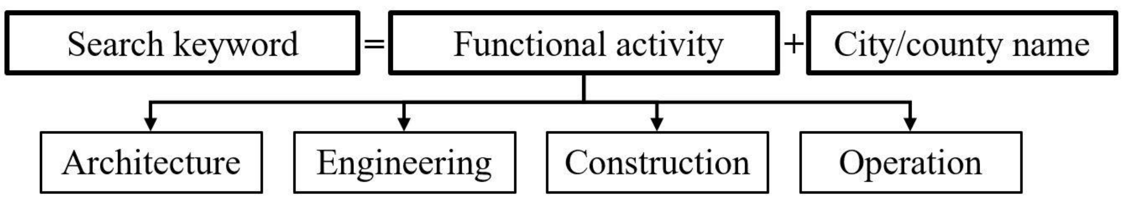


Figure 2: search keyword components

2.3. Data collection for selected building industry firms

By following the previous search method for building industry firms, the research gathers 169 enterprises based in the studied region and have relative main function. After selecting the building industry firms, the research collects inclusive data about these firms, including the official name of the firm, reference county, registered city, address, date of establishment, main activity, subscribed capital, total revenue, number of employees, and number of owners. The data was gathered for each selected firm individually based on the related online initiative profile provided by Hungarian company (Céginformáció.hu Kft.) specialized in services and management of company information [35]. This Hungarian firm (Céginformáció.hu Kft.) is based in Budapest and provides several services including client management, risk management, company information services, and claims management, it is noteworthy that each registered Hungarian initiative has its own profile at the website of "Céginformáció.hu Kft." with all related economical information and metrics derived from the latest processed public databases, hence the website acts as a bank for reliable data to all registered Hungarian firms and it is highly recommended for any researcher who needs to collect local firm related information without getting into the hassle of going and collecting information from the public register offices at each studied county or city.

By focusing on the main factors that play a prominent role in classifying enterprises according to size, the collected data are minimized to more summarized tables of the essential aspects needed for classification and comparison purposes, including net revenue, the number of employees, location of the firm (county and city), and main activity. By arranging and analyzing the summarized datasheets for each county within the ST region, the total number of collected building industry firms is 169 with 2378 registered employees and more than 189 M€ (Million Euros) net revenue, distributed as >79, >13, and >97 M€, and 900, 345, and 1133 registered employees, for 40, 38, and 91 firms, in Tolna, Somogy, and Baranya counties, respectively.

2.4. Size classification of selected building industry firms

According to Eurostat which is an official website of the European Union (EU) [36], and considered the home of high-quality statistics, data, and key indicators of Europe, classification of businesses based on size is an essential economic indicator, mainly when it is about making particular decisions or performing certain comparisons. There are seven main indicators for businesses in the building industry including: number of enterprises, number of employees, net turnover, purchase of goods and services, employee benefit expense, value added, and gross operating surplus [37], [38]. Hence, and due to the previously available collected information for the selected building industry firms in the ST region, this subchapter will focus on the first three main key indicators, including number of enterprises, number of employees, and net revenue.

According to the mandate authorized by the commission of the European communities and published by the official Journal of the EU concerning the definition of micro, small and medium-sized enterprises, SMEs are firms that have less than 250 employees, and have either an annual revenue of less than 50 million EUR or a balance sheet total of less than 43 million EUR [39]. Within the SME population, micro SMEs are enterprises which employ fewer than 10 staff, while small SMEs employ 10 to 49 staff, and medium-sized SMEs employ between 50 and 249 staff [40].

By studying the size indicators (including turnover and headcount) for local and international based enterprises, it is evident that values of Hungary-based enterprises are modest in contrast with values for enterprises based in other countries with more prominent economics whether they are EU or non-EU countries. The research shows obvious incompatibility between the turnover values of Hungarian building industry firms compared to the global and European classification standards due to the unparallel economic sizes, please see the following Table 2 for more details regarding the European firms' size classification criteria.

Table 2: European firm's size classification criteria

	SMEs			Large
Firm size	Micro SMEs	Small SMEs	Medium SMEs	Large firms
# employees	<10	10-49	50-249	>250
Σ revenue	<43M EUR			>43 M EUR

By following the European standard regarding building industry firms size classification for domestic research purposes may result in misleading information, despite the potential of this international firm classification criteria in supporting international research studies and research works that aim to investigate sizes of firms on the global level. On the other hand, on the domestic level, the international classification criteria may be pointless for local observations purposes, therefore, the study finds that the international and European classification criteria for the size of building industry firms has to be tailored to adapt with the Hungarian construction market, by suggesting tailored classification criteria regarding the size of local building industry firms, the nature of this tailored classification criteria may be different from the EU's classification criteria, since following the same formula of classifying firms into brackets with several size categories and different domains regarding net revenues and number of employees requires tremendous database regarding employees and net revenues from all building industry firms on the country level, and then a systematic allocation for the main two size indicators into different size domains and brackets, this research path requires huge efforts and abilities that are considered out of the scope of this dissertation's resources and time schedule. Hence, the research work is going to suggest a tailored classification method that serves the objective of the overall research scope (which is focusing on SMEs or smaller-sized building industry firms), meaning that the main intention is to define the border line between large and small building industry firms, and further classification of the main size categories (large and small) into sub-categories with sub-domains regarding each size indicator is considered out of the research scope and resources.

More research work will be invested in this topic and more aspects will be explained in detail regarding the size classification of the collected building industry firms in the following subchapter 2.6 to serve the overall objective and scope of the research work. Also, and based on the collected information regarding the size indicators (net revenue and number of employees) for each included building industry firm, there are initial points that can be highlighted in this subchapter: (a) the research supports the idea of focusing on smaller size building industry firms due to the fact that the majority of the collected firms in the studied region tend to have low values for the size indicators (meaning that the majority of the firms belong to the small size category), (b) there are several collected firms with relatively high values regarding the size indicators, so it is highly recommended to scientifically determine the target group of building industry firms that belong to the size scope of this research, and (c) the two size indicators (net revenue and number of employees) can be connected with the available number of building industry firm's indicator to pinpoint the potential firms on the local market level. All three points will be studied and explained in detail in the upcoming 2.6 subchapter.

2.5. Building industry firm's allocation based on sections of businesses

Since reliable and comparable business-related international statistics can be only based on common statistical standards, and with the absence of these measure standards the statistical data will be irrelevant or only limited to certain market or region, meanwhile common statistical standard for data allows more room for comparing and deriving results and conclusions to build up strategies and solve problems by the intended user, including private businesses, financial institutions, governments, public institutions, research centers, and international operators. Hence, the Statistical Classification of Economic Activities in the European Community (NACE) was introduced by the European Commission to standardized economic activities and their business sections across the EU, enhancing dealing with statistical data and tracking developments [41]. The introduced NACE is subject of legislation at the EU, imposing the use of the classification uniformly within all the member states, including Hungary.

According to NACE, there are 21 different sections, marked with capital letters from A to U (please see Table 32 at the attachments chapter for more illustration regarding NACE's sections, titles, and divisions). A comprehensive review of NACE's sections has been conducted in this research including carefully going through every NACE section and its title, related divisions, groups, classes, and main activities, in order to identify all possible building industry main activities and their origins and using them as a reference for this research study. According to NACE, there are minimum nine possible sections for building industry business activities, from which seven sections exist in the studied ST region (including: manufacturing, electricity, gas, steam, and air conditioning supply, construction, wholesale and retail trade, real estate activities, professional scientific and technical activities, and administrative and support service activities), indicating the functional diversity of building industry firms among the collected sample.

In NACE classification there are 4 different criteria to define the business main activity, including sections, divisions, groups, and classes. The sections are represented with capital letters and a textual description of the main section for which a certain main activity belongs. On the other hand, divisions, groups, and classes are numerical descriptions that consist of two, three, and four digits, respectively, separated by a point (.) after the first two digits, these numerical descriptions represent the origin of the final business main activity from the divisions, groups, and classes trees. Among the collected building industry firms from the ST region, there are active 7 sections according to NACE classification allocated along the region's 3 counties, the sections include 15, 23, and 25 active divisions, groups, and classes, respectively. The collected main activities include: manufacture of assembled parquet floors, manufacture of concrete products for construction purposes, manufacture of metal structures and parts of structures, manufacture of central heating radiators and boilers, manufacture of other special-purpose machinery, steam and air conditioning supply, development of building projects, constructions of residential and non-residential buildings, constructions of bridges and tunnels, construction of utility projects for fluids, construction of water projects, electrical installation, plumbing, heat and air-conditioning installation, painting and glazing, other specialized construction activities, general construction of buildings and civil engineering works, retail sale of hardware, paints and glass in specialized stores, buying and selling of own real estate, renting and operating of own or leased real estate, real estate agencies, business and other management consultancy activities, architectural activities, engineering activities and related technical consultancy, other professional, scientific and technical activities, and security systems service activities. It is noteworthy that the following 71.12 (engineering activities and related technical consultancy), 41.20 (constructions of residential and non-residential buildings), and 71.11 (architectural activities) business classes and their main activities have the highest company count allocation across the ST region, accounting for 31, 33, and 66 companies, respectively. Please refer to Table 33 at the attachments chapter for more illustrations regarding the allocation of collected ST's building industry firms based on NACE classification, including sections, divisions, groups, classes, and main activities, per county (Baranya, Somogy, and Tolna).

2.6. Potential allocation of collected building industry SMEs

In this part of the research the author intends to combine the knowledge derived from NACE regarding the European standard of business classification (including building industry firms) which legally applies in Hungary as member state of the EU, and the previously collected, analyzed, and arranged, information regarding each scanned building industry firm located within the borders of the study region, the result of this combination will be pinpointing the main activity and the size of each collected building industry firm, based on the firm's NACE class (numerical description of 4 digits separated by a point after the first two digits) and size indicators (headcount and net revenue). Thus, by connecting the business class (main activity), size of the business class (including the sum of revenues and headcounts of the included firms), and number of existing firms within the business class, a collective detailed base can be formed to pinpoint the potential of certain business class/es among other business classes within the building industry market. The method includes calculating the sum of the previously highlighted building industry essential key indicators (number of enterprises, number of persons employed, and net revenue), derived from each nominated building industry firm that belongs to certain business class, to identify the potential and exact contribution of the intended business class (main activity) compared to other business classes within the local building industry market.

2.6.1. Size-based nomination of collected building industry SMEs

Please see the attached Figure 43, 44, and 45 in the attachments chapter. The three figures include charts representing the actual values of the essential key indicators of the collected building industry firms, represented by the main activities of these firms within the sector. The values will give an initial (but not accurate) configuration regarding the potential allocation of the business sections within the collected building industry sample (the reason behind the inaccuracy of the configuration is the fact that the included firms do not share the same size category). In the three figures, the main activities are represented with the associated NACE classes, including 16.22, 23.61, 25.11, 25.21, 28.99, 35.30, 41.10, 41.20, 42.13, 42.21, 42.91, 43.21, 43.22, 43.34, 43.99, 45.21, 47.52, 68.10, 68.20, 68.31, 70.22, 71.11, 71.12, 74.90, and 80.20, representing the following main activities: manufacture of assembled parquet floors, manufacture of concrete products for construction purposes, manufacture of metal structures and parts of structures, manufacture of central heating radiators and boilers, manufacture of other special-purpose machinery, steam and air conditioning supply, development of building projects, constructions of residential and non-residential buildings, constructions of bridges and tunnels, construction of utility projects for fluids, construction of water projects, electrical installation, plumbing, heat, and air-conditioning installation, painting and glazing, other specialized construction activities, general construction of buildings and civil engineering works, retail sale of hardware, paints, and glass in specialized stores, buying and selling of own real estate, renting and operating of own or leased real estate, real estate agencies, business and other management consultancy activities, architectural activities, engineering activities and related technical consultancy, other professional, scientific, and technical activities, and security systems service activities, respectively.

Since the focus of the research work is smaller size building industry firms (including SMEs and MSMEs). The research scope excludes large firms in the local building industry market, aiming to study the companies that form the base of the industry's pyramid and represent more than 90% of the firms in the majority of building industry markets. The following points highlight the reasons for focusing on smaller size building industry firms:

- According to the country fact sheet published by the European Commission under the European Construction Sector Observatory in 2020 and 2021 for the Hungarian building industry, SMEs in the broad building industry (including building industry-related manufacturing, construction, real estate activities, and architectural/engineering activities) employed around 91.7% of the total number of people employed in the broad building industry, which is higher than the EU-27's average (87.1%) for 2018. This highlights the significance of SMEs in the Hungarian building industry.
- Local-based observations and complaints: the local-based observations in connection with the satisfaction of professionals with the conducted business processes within their building industry firms are mainly derived from smaller size firms, similar complaints from large firms' professionals were not observed regarding the same topic (including work operability, system processes, workflows, and coordination issues). Complaints arise from local smaller firms' professionals in connection with the lack of BIM-based processes in their daily practice and the dominance of traditional methods and business processes

(which can be described by BIM Level 1 according to the BIM Levels introduced by the NBS). Moreover, practitioners reveal that lack of coordination between different project disciplines and their representatives results in increased obstacles during the delivery of built projects.

- The backbone of the industry: smaller firms represent the backbone of the industry (not only in the studied region, but almost everywhere else), this observation is derived from thorough literature review regarding the topic of "firms' sizes" not only in the building industry, but also in other industries. Meaning that not only large building firms are essential to boost the economy (by increasing the construction production of the related sector, and employing workforce to run the business), smaller firms are also essential to keep the sector running since they form the base majority of any industry [42], and their stability will highly affect the stability of larger players in the industry.
- Available resources: the author believes that the available resources (whether it is financial or human resources) vary dramatically between smaller and large size firms, meaning that a large firm will most probably have the tools to research and develop its workflows and processes aiming for more optimized business outcomes. On the other hand, smaller size firms have limited budgets to investigate business processes, and focus more on "learning by doing", instead of "learning by researching and doing what the research recommends" to have more effective business results.

The nomination of the collected building industry firms will be based on size, and as previously explained, the international and European classification criteria for the size of building industry firms can be misleading when we apply them on the Hungarian construction market, due to the modest values of the size indicators (net revenue and headcount) of the local building industry firms compared to the same values that belong to other international markets that refer to larger economies. Hence, using the European classification criteria for international research scope will be optimal to pinpoint the state of local Hungarian building industry firms based on the global scale, but for local-based research purposes, the global scale may not be optimal to derive useable and workable outcomes that make sense to conclude results. In addition, following the same classification method that is used in the international firm size classification [43], and similarly in the European one [44], which can be represented by having different classification brackets based on the size (e.g., large, medium, small, and micro) with defined ranges for both size indicators (revenue and headcount) may be also challenging to duplicate on the local level, since having defined ranges for each firm size bracket is highly influenced by the total values of the size indicators that are derived from all building industry firms that are based in Hungary, then an accurate range (from-to) can be scientifically pinpointed based on the rigid comprehensive size indicator database derived from all Hungarian building industry companies. Hence, and due to the fact that the existing sample of collected building industry firms exclusively belongs to the ST region, an extensive size classification method (including defined brackets and ranges for size indicators) will be difficult to obtain within the research sources and time schedule, but a scientific border line can be drawn to assist in separating larger firms from smaller firms (the intended target group), based on the existing values derived from the local collected firms and with the help of statistical measure that can assist in the determination of outlier values, to support the research objective in defining the intended target group by excluding the firms that do not belong to the target group (SMEs).

The research will apply a statistical measure to the available number of employees and net revenues to define a standard deviation that belongs to the collected sample of building industry firms from the ST region. The main intent of the calculation is to measure the spread in the net revenue and number of employee values that belong to each collected firm. The measure will define the variation of the data from the average or the spread out of a certain set of data, meaning that measuring the standard deviation for the two main size indicators will allow accurate definition of large firms that can be excluded from the sample (target group) and accordingly from the following results conclusions.

The research work will calculate the standard deviation (that was first used in writing by Karl Pearson in 1894) of the related data set behind each business class by following the variance and standard deviation equations introduced in the published reference work entry "Standard Deviation" in the International Encyclopedia of Statistical Science [45]. There are two types of the sample standard deviation (and accordingly the sample variance): the uncorrected and corrected; the uncorrected sample standard deviation is used in case if the number of observations included in the sample represents the exact real-life number of the objects and their related observations, accordingly, same logic applies on the related uncorrected sample variance. On the other hand, corrected sample standard deviation is the standard deviation calculated by applying the so-called Bessel's correction which is an unbiased estimator of the variance, through using (n-1) instead of (n) to represent the number of observations, this method is used when the observations represent a sample of the related objects (not the entire number of objects, meaning that there is a chance that some existing objects that their observations are not included in the measured sample) [46], [47]. In this research, one observation represents one value associated with one of the listed building industry firms from the studied ST region, this value can be one of the two size indicators (net revenue or number of employee), hence, this study will calculate two sample standard deviations for the two sets of data that indicate size, the aim is to pinpoint all large firms that are included in the list of the collected building industry firms that are based in the studied region. Despite the comprehensive research method that is applied to gather and collect building industry firm by using systematic mass filtering based on research key words and according to predefined procedure as described earlier in this chapter, there is still a chance that the research may not include all of the building industry firms in the region whether its due to human error or simply the initiative is not listed on the used online mapping system, hence, it is preferred to use the corrected sample variance and standard deviation (see Equation 1 and 2) instead of the uncorrected sample variance and standard deviation (see Equation 3 and 4).

Equation 1: corrected sample variance (the squared average distance from the mean)

$$S^2 = \frac{\sum(x_i - \bar{x})^2}{n-1}$$

Equation 2: corrected sample standard deviation (the average distance from the mean)

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

Equation 3: uncorrected sample variance (the squared average distance from the mean)

$$S_N^2 = \frac{\sum(x_i - \bar{x})^2}{n}$$

Equation 4: uncorrected sample standard deviation (average distance from the mean)

$$\sigma_N = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

The symbols used in Equation 1-4 stand for the following:

S^2: corrected sample variance.
x_i: value of one observation.
$\bar{x}$: the mean of the observations' values.
n: number of observations.
σ: corrected sample standard deviation.
S_N^2: uncorrected sample variance.
σ_N: uncorrected sample standard deviation.

In order to calculate the corrected sample standard deviation (σ), first we have to calculate the corrected sample variance (S^2) which is the squared average distance from the mean, followed by the standard deviation which is the squared root of the variance (the average distance from the mean). The following Table 3 demonstrates a sample of the total 169 observations of the collected building industry firms and their associated NACE business classes, each business class is aligned to two measure sections, the first is associated with the net revenue size indicator, meanwhile the second is related to the number of employees size indicator, the results of the calculations show that (σ) for the net revenue and number of employee observations regarding the collected companies is 3750319.69 € and 40.64 employees, respectively. According to the scope of the research work of targeting smaller-sized building industry firms, then all collected building industry firms from the ST region that have net revenue or number of employees more than the measured related (σ) values are excluded. On the other hand, all building industry firms that have lower values than the measured related (σ) values are nominated and considered smaller-sized building industry firms.

Table 3: sample of the collected building industry firms and their corrected sample variance and standard deviation calculations for the two main size indicators

Measure the corrected sample standard deviation of the two main firm size indicators:						
B.C.	**S^2 and σ for Σ revenue**			**S^2 and σ for # of employees**		
	x_i	$\bar{x}$	$(x_i - \bar{x})^2$	x_i	$\bar{x}$	$(x_i - \bar{x})^2$
16.22	2186591	1069822	1247173012577	158	13	20925.59
23.61	36114068	1069822	1228099178123240	301	13	82746.44
25.11	1843404	1069822	598429119878	29	13	245.14
25.21	25332514	1069822	588678223373996	382	13	135907.84
28.99	514477	1069822	308408062452	14	13	0.43
35.30	1354011	1069822	80763391084	22	13	74.94
41.10	1038819	1069822	961185642	4	13	87.30
41.20	442160	1069822	393959578816	7	13	40.24
42.13	1994084	1069822	854260255582	25	13	135.88
42.21	3523551	1069822	6020786034479	48	13	1201.09

42.91	1218837	1069822	22205471988	21	13	58.63
43.21	1066042	1069822	14288355	12	13	1.80
43.22	2030384	1069822	922679367211	77	13	4052.19
43.34	1379487	1069822	95892415889	24	13	113.57
43.99	165355	1069822	818060543385	8	13	28.55
45.21	125004	1069822	892681041942	9	13	18.86
47.52	3327681	1069822	5097927290601	25	13	135.88
68.10	221	1069822	1144046286543	1	13	152.35
68.20	6737	1069822	1130149704644	3	13	106.98
68.31	69038	1069822	1001568602812	3	13	106.98
71.11	459023	1069822	373075411172	2	13	128.67
71.12	97573	1069822	945268106495	8	13	28.55
74.90	75757	1069822	988165212460	3	13	106.98
80.20	237217	1069822	693231076171	11	13	5.49
Please note that this is only a sample of the total 169 observations for demonstration!						
S^2	**14064897806064.2**			**1651.54**		
σ	**3750319.69 (€)**			**40.64 (employees)**		

2.6.2. Define potential business classes among nominated SMEs

The second section of this sub-chapter focuses on the last two steps of the research work in the related chapter. First, the research work defines the target group (building industry SMEs), by excluding large firms from the total examined building industry firms' sample. Second, the research work defines the potential group (potential group of firms from the defined building industry SMEs), by pinpointing potential business classes for which the potential SMEs belong, according to their available key essential factors. The potential SMEs will later represent a group of potential business classes that will take part in upcoming steps and further research work in the following chapters.

The first step is to define large firms among the collected building industry firms from the ST region. Based on the first section of this sub-chapter, nomination of smaller-sized building industry firms is based on the calculated (σ) values for the related size indicators, the calculated (σ) values are measures of spread referring to data variation from the average, the values can be used to identify data that is significantly above the mean. In this particular research step, the work is going to draw a border line from which we can define two size groups (large and small size firms), meaning that only firms with data lower than the calculated related (σ) values will be included in the target group, meanwhile firms with data higher than the calculated related (σ) values will be classified large firms and excluded from the target group. The following two points express the importance of defining the size group (whether it is large or SME) of each collected building industry firm:

- Ensure size consistency among the collected firms and their belongness to the research scope, by confirming that included building industry firms are smaller-size building industry firms, in order to match the scope of the research which targets SMEs including.
- Increase the creditability and reliability of the derived values and accordingly the concluded results, since the results may affect the upcoming steps of the research steps; by properly nominating the right size of target group (SMEs) from which the potential

building industry firms will be defined and carried on take part in future research work at the upcoming chapters.

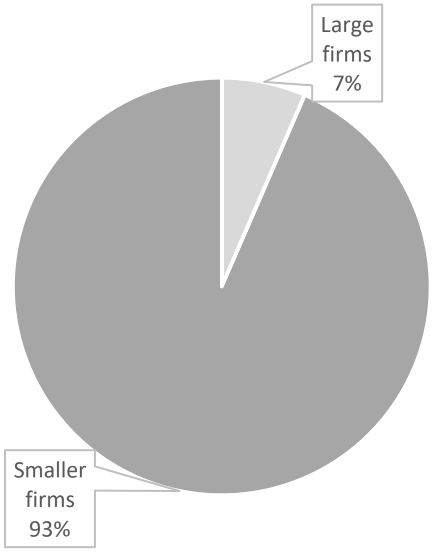
The following Table 4 illustrates the included business classes (for which the collected building industry firms belong) aligned with the related net revenues, number of employees, and number of firms with two value sets, the first set includes values before excluding large building industry firms (including values from the region's building industry firms from all sizes), meanwhile the second set includes the values after excluding large firms (including values from the target group which is the region's smaller-sized building industry firms or SMEs).

Table 4: potential indicators' values (including net revenue, number of employees, and number of firms) for the region's business classes before and after excluding large building industry firms

	Before			***After***		
B. C.	**Σ revenue €**	**# emp.**	**# fir.**	**Σ revenue €**	**# emp.**	**# fir.**
16.22	2186591	158	1			
23.61	36114068	301	1			
25.11	1843404	29	1	1843404	29	1
25.21	25332514	382	1			
28.99	514477	14	1	514477	14	1
35.30	1354011	22	1	1354011	22	1
41.10	1842073	4	4	1842073	4	4
41.20	47617388	519	33	19100434	270	28
42.13	1994084	25	1	1994084	25	1
42.21	22106814	200	4	3129455	60	2
42.91	1218837	21	1	1218837	21	1
43.21	1066042	12	1	1066042	12	1
43.22	3491360	86	2	1460976	9	1
43.34	1379487	24	1	1379487	24	1
43.99	165355	8	1	165355	8	1
45.21	165018	11	2	165018	11	2
47.52	3963781	30	2	3963781	30	2
68.10	161824	2	4	161824	2	4
68.20	49431	4	2	49431	4	2
68.31	562238	6	2	562238	6	2
70.22	N/A	N/A	1	N/A	N/A	1
71.11	13499814	195	66	8287013	181	65
71.12	13858332	188	34	7822235	171	33
74.90	75757	3	1	75757	3	1
80.20	237217	11	1	237217	11	1
Σ	**180799917**	**2255**	**169**	**56393149**	**917**	**156**

In total there are 13 large firms, accounting for only 7%, these large firms are going to be excluded from the total 169 collected building industry firms, including the following NACE business classes 16.22, 23.61, 25.21, 5x41.20, 2x42.21, 43.22, 71.11, and 71.12 representing the following main activities: manufacture of assembled parquet floors, manufacture of concrete products for construction purposes, manufacture of central heating radiators and boilers, constructions of residential and non-residential buildings, construction of utility projects for fluids, and plumbing, heat, air-conditioning installation, architectural activities, and engineering activities and related technical consultancy, respectively. On the other hand, there are 158 firms that are considered smaller-sized building industry firms, and represent the SMEs target group, accounting for 93% of the total 169 collected building industry firms, including the following NACE business classes 25.11, 28.99, 35.30, 41.10, 41.20, 42.13, 42.21, 42.91, 43.21, 43.22, 43.34, 43.99, 45.21, 47.52, 68.10, 68.20, 68.31, 70.22, 71.11, 71.12, 74.90, and 80.20, representing the following main activities: manufacture of metal structures and parts of structures, manufacture of other special-purpose machinery, steam and air conditioning supply, development of building projects, constructions of residential and non-residential buildings, constructions of bridges and tunnels, construction of utility projects for fluids, construction of water projects, electrical installation, plumbing, heat, and air-conditioning installation, painting and glazing, other specialized construction activities, general construction of buildings and civil engineering works, retail sale of hardware, paints, and glass in specialized stores, buying and selling of own real estate, renting and operating of own or leased real estate, real estate agencies, business and other management consultancy activities, architectural activities, engineering activities and related technical consultancy, other professional, scientific, and technical activities, and security systems service activities, respectively. Please see the following Figure 3 that illustrates the allocation of large firms in comparison with the allocation for the target group (SMEs).

By defining the intended target group (building industry SMEs) that account for 93% of the total examined firms, the following task is to define the potential firms from the target group. Potential firms are firms from the defined target group with certain business classes, nominated based on the values of their essential key indicators defined by the EU [48], [49]. There are three essential key indicators for firms in the building industry, including main indicators, share in business economy (%), and derived indicators. In this research the focus will be on the key essential main indicators, since the available observations all belong to the main indicators' section. The main indicators include a sequence of frequency, size, and economic indicators, the first three most important indicators are 1) number of enterprises (number), 2) number of people employed (number), and 3) net revenue (value in relative currency, e.g., €). Hence, and based on the values of the given indicators for the target group companies, it is clear that architecture, engineering, and construction firms presented with 71.11, 71.12, and 41.20 business classes that refer to architectural activities, engineering activities and related technical consultancy, and constructions of residential and non-residential buildings, respectively, have the highest values of the main three indicators from the essential key indicators of firms from the building industry. Therefore, the research will make a head-to-head comparison between the NACE divisions for which the mentioned business classes belong, and the nominated division (and its included business classes) will be the one with the highest total scores from all three main indicators, please see Figure 4, 5, and 6 that illustrate the allocation of NACE divisions for which business classes (with the highest values of the three main indicators) belong.



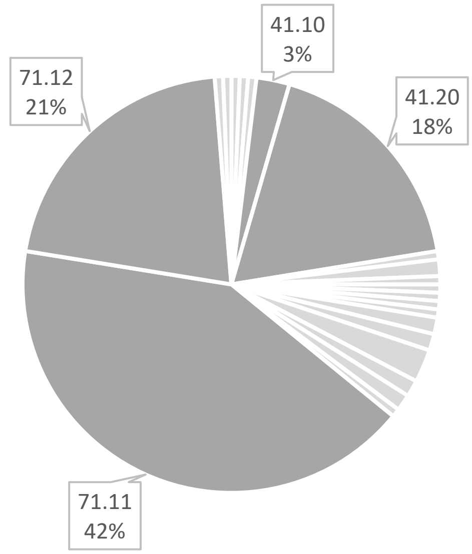
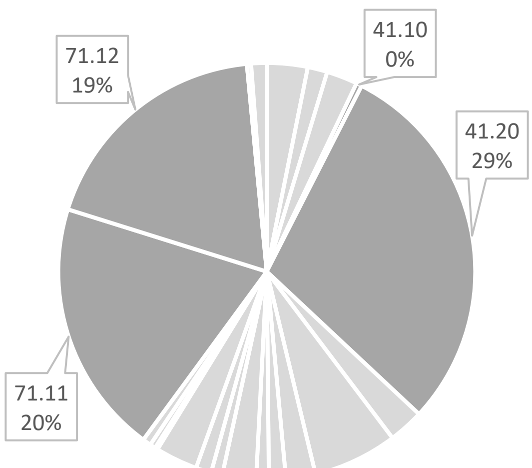


Figure 3: (to the left) the allocation of collected building industry firms from the ST region, target group 93% (including smaller-sized firms) and large firms 7%.

Figure 4: (to the right) the allocation of the main indicator (number of enterprises) among the target group for the two NACE divisions (71 and 41)



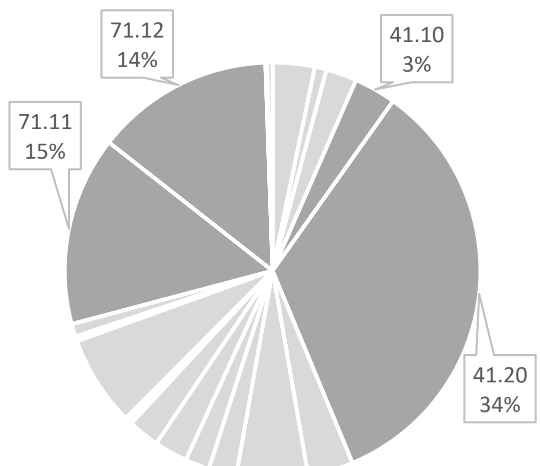


Figure 5: (to the left) the allocation of the main indicator (number of people employed) among the target group for the two NACE divisions (71 and 41)

Figure 6: (to the right) the allocation of the main indicator (net revenue) among the target group for the two NACE divisions (71 and 41)

The following Table 5 demonstrates the comparison between all NACE divisions for which the target group's business classes belong and the share of their three main indicators, each division is aligned with its classes which are aligned with the percentages of their three main indicators (number of firms, number of employees, and net revenues) and their totals on the division level. Based on the values, there are two dominant competitors among the target group's divisions, including building construction and architectural/engineering activities represented by 41. and 71.

divisions, that belong to 4 (construction) and 7 (professional, scientific, and technical activities) NACE sections, respectively. The study conducts a head-to-head comparison between the two dominant divisions, and the results show that the 71. division has more plus points compared to the 41. division regarding the total percentages of the three main indicators. Hence, the 71. division (including its 71.11 and 71.12 classes) is considered the potential division, and consequently all firms that belong to the target group and have the following NACE classes: 71.11 and 71.12 (architectural activities and engineering activities and related technical consultancy) are considered potential firms; these potential firms will take part in the upcoming research steps in the following chapters. The potential AE firms account for 98 firms, 352 employees, and 16109248 € from the total target group's number of firms (156), number of employees (917), and net revenue (56393149 €).

Table 5: potential firms' definition by comparing the share of the three main indicators

Target group		**Potential firms' definition by comparing the three main indicators**								
Div.	**Class**	**# fir. %**	**Σ%**	**Ev.**	**# emp. %**	**Σ%**	**Ev.**	**rev. %**	**Σ%**	**Ev.**
25.	**25.11**	0.64	0.64		3.16	3.16		3.27	3.27	
28.	**28.99**	0.64	0.64		1.53	1.53		0.91	0.91	
35.	**35.30**	0.64	0.64		2.40	2.40		2.40	2.40	
41.	**41.10**	2.56	20.51	-	0.44	29.88	-	3.27	37.14	+
	41.20	17.95			29.44			33.87		
42.	**42.13**	0.64	2.56		2.73	11.56		3.54	11.25	
	42.21	1.28			6.54			5.55		
	42.91	0.64			2.29			2.16		
43.	**43.21**	0.64	2.56		1.31	5.78		1.89	7.22	
	43.22	0.64			0.98			2.59		
	43.34	0.64			2.62			2.45		
	43.99	0.64			0.87			0.29		
45.	**45.21**	1.28	1.28		1.20	1.20		0.29	0.29	
47.	**47.52**	1.28	1.28		3.27	3.27		7.03	7.03	
68.	**68.10**	2.56	5.12		0.22	1.31		0.29	1.38	
	68.20	1.28			0.44			0.09		
	68.31	1.28			0.65			1.00		
70.	**70.22**	0.64	0.64		0.00	0.00		0.00	0.00	
71.	**71.11**	41.67	62.82	+	19.74	38.39	+	14.70	28.57	-
	71.12	21.15			18.65			13.87		
74.	**74.90**	0.64	0.64		0.33	0.33		0.13	0.13	
80.	**80.20**	0.64	0.64		1.20	1.20		0.42	0.42	
Potential division per indicator:				**71.**			**71.**			**41.**
Potential firms' division/classes:				**Division 71. including 71.11 and 71.12 classes.**						

3. BIM implementation level and its barriers for local AE SMEs

This research chapter proceeds to serve the overall objective of the research work in defining BIM implementation level and BIM barriers, the previously concluded results from the second chapter including the definition of study region and potential firms will be included in the upcoming research steps as a base for this chapter. The main objective of this chapter is to define BIM implementation level and key barriers against BIM implementation, and by embedding the results from the previous chapter, the objective can be described more accurately through defining the current BIM adoption status and key BIM adoption barriers of the potential AE SMEs in the studied ST region, meaning that we have a clear study region (the ST region) and potential group of firms AE (smaller-sized firms or SMEs). Defining a study region and potential group of firms makes the research more focused and disciplined. Also, it facilitates later research processes and procedures. In addition, it supports the accuracy, usefulness, and practicality of the later derived results and conclusions.

The scale that is followed to measure BIM implementation will be the NBS BIM Levels, including Level 0, 1, 2, and 3, the research will examine the implementation of BIM in the AE firms based on the minimum defined Level 2 BIM, which is distinguished by collaborative working, and requires "an information exchange process which is specific to that project and coordinated between various systems and project participants" [6]. Similarly, the introduced model by Bew & Richards in the Construct IT Autumn 2008 members' meeting, in Brighton, UK, has the same logic for classifying BIM levels, it was later included in the prepared strategic report by the BIM Industry Working Group for the Government Construction Client Group [50]. Hence, the research will consider the NBS BIM Levels when questioning the participants about the implementation level of BIM in their AE organizations at the intended survey study.

On the other hand, and in connection with BIM barriers, and based on thorough study and review of this large research topic, it is obvious that the majority of the collected BIM barriers are quite similar in terms of theme and content, bearing in mind that there are some outdated and relatively new BIM barriers, but still the main factor that influences the definition of BIM barriers is the associated studied market. Almost every upcoming citation regarding BIM barriers is exclusive market, country, or region-based, there are studies that investigate BIM barriers in building industry firms on a multi-markets, countries, or regions level. Hence, it is very clear that the included BIM barriers in academia are more or less identical through studies from different parts of the world, the only difference is the potential of these barriers in one research compared to another and with respect to the studied markets. Consequently, this research suggests collecting and analyzing BIM barriers from academia and including the analyzed barriers in a structured survey study to define key BIM adoption barriers among AE SMEs in the local market.

3.1. Collect and analyze BIM adoption barriers

This subchapter collects listed BIM barriers at the reviewed academic sources, then performs several sorting and merging analysis to derive a final list of BIM barriers that will be included in the planned survey study. BIM barriers are similar across the entire industry, but the difference is regarding the relative importance of one BIM barrier over another in a certain market, e.g., BIM barrier 01 that stands for lack of ICT infrastructure in (x) market may have high relative importance index compared to the same value from (y) market. Here comes the potential of market-based or region-based studies for BIM adoption and its barriers to support local building industry firms according to their priorities and preferences, and to provide a case study example for other markets and regions. The case study's content may be useful for other markets that share similar barriers and their relative importance, meaning that methods to overcome these barriers may also be useful, or at least the research sequence, materials, and methods may be inspirational for other markets to investigate their own BIM barriers and their relative importance, in addition to their associated strategies, methods, and recommendations to overcome these barriers.

In this subchapter there will be two sections, the first will collect BIM barriers from the academic sources, and the second will analyze the collected BIM barriers to make it suitable for inclusion in a market-based survey study to investigate BIM adoption and its key barriers for AE SMEs. The following Figure 7 demonstrates the workflow of the selection and analysis procedures, including searching for scientific articles with defined search keywords by using Google Scholar and then checking the nominated articles' reliability by testing their compliance to the Scimago Journal & Country Rank (SJR) database; if the articles' publishers are SJR distinguished then the research process continues with searching for included BIM barriers within the selected articles and listing them. After that, the research proceeds with analyzing the listed barriers including classifying, filtering, and merging, and finally introduces the final list of BIM barriers that will be included in the following research steps.

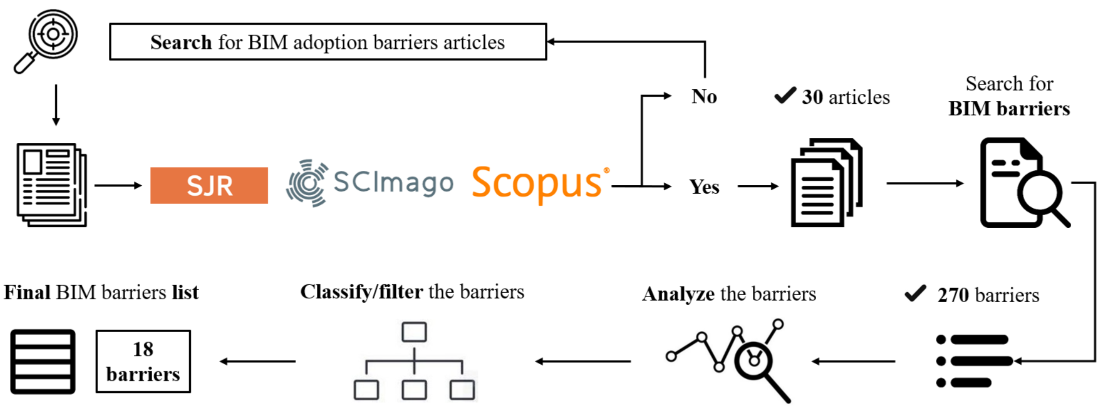


Figure 7: collect and analyze BIM adoption barriers

First, collecting BIM barriers based on a literature review study that focuses on BIM implementation in the building industry and its barriers according to the industry's active firms and practitioners. The study carefully reviews 30 journal articles and conference papers published between 2010-2023, to derive and list included BIM adoption barriers. The study searches for published scientific papers by using the following search keywords: BIM adoption and BIM implementation combined with a third expression, including barriers, difficulties, or challenges, the research uses Google Scholar to search for the published articles. Then the research performs a reliability check for collected articles, by taking into consideration papers that are only SJR classified (meaning that the paper's publisher should be distinguished by the SCImago database which is powered by Scopus), if the paper does not meet the SJR recognition then it is neglected from the study. The work collects 30 different published scientific papers between 2010-2023, deeply reviews the content of the collected papers, and finally lists all included BIM barriers (with a total of 270 barriers) in the reviewed papers.

After listing all BIM barriers which are included in the collected and reviewed academic sources, the research prepares the barriers for the analyzation processes. The preparation includes summarizing the description of the BIM barrier to be more compact and avoiding long and complex descriptions (only if needed) for facilitating the later classification, merging, and demonstration steps. E.g., the following BIM barrier that is described as "collaboration with different stakeholders (e.g., contractors) to adopt workflows and spread investment risks" will be prepared to the analysis processes and minimized to the following description "multi-party collaboration to adopt workflows", this preparation step is applied on every listed BIM barrier. Please check the first two columns of the following Table 6 to see all listed BIM barriers aligned with their references.

Table 6: collect and analyze BIM barriers, the first two columns align collected BIM barriers to their references. On the other hand, the rest of the columns demonstrate the allocation of the collected BIM barriers to their group from the associated level (L1, L2, and L3)

Collect and analyze BIM barriers						
Align collected BIM barriers with their sources		**Sorting level & ID**				**List of arranged BIM barriers by level & ID**
R.	**List of BIM barriers included in the sources**	**L1**	**L2**	**L3**	**ID**	**Allocation of BIM barriers**
	Lack of defined business process				b001	Lack of defined business process
	Industry resistance to change practices				b002	Establishing new workflows
	Lack of BIM knowledge				b003	Lack of effective implementation processes
	Benefits unmatch implementation costs				b004	Lack of BIM methods capabilities
	Lack of guaranteed benefits				b005	Undefined BIM roles and responsibilities
	Lack of assured financial gain				b006	Lack of management for BIM definition
	Economic support for hardware/software				b007	Weak organizational/delivery methods
	Risk of BIM business from liability point				b008	Difficulty of digitization methods
[51]	No demand for BIM use				b009	Change in work processes
	Establishing new workflows				b010	Difficulty obtaining process information
	Training staff				b011	Lack of strategic planning of implementation
	Lack of effective implementation processes				b012	Interoperability of processes and methods
	Difficulty establishing client's requirements				b013	Difficulty implementing digital methods
	Risk of liability				b014	Lack of well-developed practical strategies
	Software licenses investment				b015	Lack of BIM implementation guide
	Common data liability				b016	Insufficient interoperability
	Multi-party collaboration to adopt workflows			1	b017	Lack of methodology for BIM
	Lack of financial support				b018	Lack of tech. capabilities and methodologies
	Lack of BIM methods capabilities				b019	Lack of industry's BIM workflow clarity
	Lack of government incentives				b020	Lack of adequate BIM guidelines
	Lack of collaborative working environment				b021	Weak theoretical foundation for processes
	Lack of teamwork to BIM execution				b022	Lack of domestic-oriented BIM methods
	Undefined plans/objectives for BIM				b023	Lack of methods compatibility
	Lack of common standards				b024	Lack of BIM methods adoption in operation
	Uncertain usage of information				b025	Lack of guidelines to perform specific task
[52]	Lack of appropriate IT infrastructure				b026	Lack of guidelines
	Lack of technical support				b027	Definition processes issues
	Undefined BIM roles and responsibilities				b028	Project scale-based methods
	Lack of management for BIM definition				b029	Complexity of BIM adoption process
	Lack of training and consultancy	1st	A		b030	Lack of well-established BIM workflows
	Lack of support from the client/management				b031	Difficulty of working process and material
	Selection of delivery systems/contract				b032	Absence of methods to execute projects
	Unaligned objectives of BIM and project				b033	Lack of familiarity with BIM workflows
	Weak organizational/delivery methods				b034	Difficulty establishing client's requirements
	Lack of proper training				b035	Undefined plans/objectives for BIM
[53]	Fragmented nature of the AEC industry				b036	Uncertain usage of information
	Industry's resistance to change				b037	Unaligned objectives of BIM and project
	Unclear standards and roles				b038	Lack of uses and objectives of BIM models
	Incompatibility of software and hardware				b039	Proper definition of the uses
	Lack of uses and objectives of BIM models				b040	Incompatibility of uses
	Lack of experience				b041	Uses of digital adoption
	Lack of collaborative approach			2	b042	Use
[54]	Fear of low success or significant failure				b043	Complexity of uses
	Fear of low economic profit				b044	Interoperability issues of BIM use
	Time required for skill acquisition				b045	Information requirements and quality issues
	Conservative approach of leadership				b046	BIM objectives only for delivery phase
	Lack of standards				b047	Uses and interoperability issues
	Lack of resources because of low profit				b048	Uses and interoperability
	Lack of expertise				b049	Lack of use definitions and interoperability
	Lack of discipline motivation for designers				b050	Uncertain uses
	Significant investment in BIM tools				b051	Multi-party collaboration to adopt workflows
[55]	Lack of education				b052	Lack of collaborative working environment
	Lack of time for implementation				b053	Lack of teamwork to BIM execution
	Change team mindset				b054	Lack of collaborative approach
	Difficulty of digitization methods			3	b055	Coordination with other industry branches
	Lack of professional motivation				b056	Lack of cooperation between participants
	Contractual issues				b057	Lack of collaborative working processes
[56]	Resistance and cooperation/example absence				b058	Fragmented system, multi-location storages
	Management issues				b059	Interoperability issues of collaboration

	Financial issues of tools				b060	Lack of collaboration/cooperation
	Security and liability issues				b061	Fragmented nature of the AEC industry
[57]	Staff motivation		B	4	b062	Risk of BIM business from liability point
	The economic cost of tools' change				b063	Risk of liability
	Coordination with other industry branches				b064	Common data liability
	Change in work processes				b065	Security and liability issues
	Difficulty obtaining process information				b066	Legal issues
[58]	Lack of collective knowledge				b067	Lack of ownership definition for BIM data
	Proper definition of the uses				b068	Lack of clear allocation for responsibilities
	Legal issues				b069	Poor distribution of responsibilities
	Conservative approach of leadership				b070	Safety in terms of liability
	Lack of strategic planning of implementation				b071	Unclear responsibilities for BIM users
	Financial investment of training				b072	Fear of sharing information with participants
	Lack of motivation for clients				b073	Poor security performance of BIM
	Lack of training				b074	Liability/privacy concerns of digital processes
	Lack of ICT infrastructure				b075	Ownership of the project
	Software distribution				b076	Legal issues
	Technological barriers				b077	Liabilities and data loss
[59]	Interoperability of processes and methods			5	b078	Selection of delivery systems/contract
	Difficulty implementing digital methods				b079	Contractual issues
	Lack of well-developed practical strategies				b080	Management issues
	Lack of ownership definition for BIM data				b081	Different management approaches
	Lack of BIM implementation guide				b082	Contract issues
	Lack of BIM standards				b083	Weak management support for BIM
	Lack of clear allocation for responsibilities				b084	Contractual related issues
	Learning difficulties of BIM				b085	Management resources
[60]	Poor distribution of responsibilities				b086	Lack of support from senior management
	Different management approaches				b087	Need to develop specific contracts
	Contract issues				b088	Legal ownership issues
[61]	Lack of knowledge				b089	Unmatching existing contracting methods
	Lack of experienced BIM implementers				b090	Lack of management for adoption
	Lack of standards for BIM implementation				b091	Management issues
[62]	Insufficient interoperability				b092	Contract issues
	Lack of methodology for BIM				b093	Lack of top management commitment
	Unclear investment returns			6	b094	Lack of common standards
[63]	Lack of tech. capabilities and methodologies				b095	Unclear standards and roles
	Lack of recognition of innovative value				b096	Lack of standards
	Lack of industry's BIM workflow clarity				b097	Lack of BIM standards
[64]	Cost of training				b098	Lack of standards for BIM implementation
	Cost of BIM software				b099	Lack of standards
	Weak technical knowledge and awareness				b100	Legalization based on business standards
	Lack of adequate BIM guidelines				b101	Unclear relevant processes and standards
	Huge BIM up frontal investment for training				b102	Lack of standards to guide implementation
[65]	Lack of qualified in-house staff				b103	Lack of protocol and criteria for BIM adoption
	Lack of professional training				b104	Lack of standard scopes for operation phase
	Lack of BIM education				b105	Limited standards
	Lack of standards				b106	Lack of standards
	Lack of client demand				b107	Standard issues
[66]	Weak management support for BIM				b108	Lack of standard
	Cost of BIM processes training				b109	Lack of standards
	Incompatibility of uses				b110	Lack of standards and guidelines
	Contractual related issues				b111	Lack of process standardization
	Clients' culture related issues				b112	Lack of standards
[67]	Legalization based on business standards				b113	Lack of mandatory BIM standards
	Clients' culture	2nd	C	7	b114	Economic support for hardware/software
	Technology				b115	Software licenses investment
	Cost of infrastructure				b116	Lack of financial support
	Uses of digital adoption				b117	Significant investment in BIM tools
	Safety in terms of liability				b118	Financial issues of tools
	Management resources				b119	The economic cost of tools' change
	Use				b120	Cost of BIM software
	Expertise				b121	Cost of infrastructure
	Complexity of uses				b122	High cost of BIM software
[68]	Lack of support from senior management				b123	Initial cost to adopt BIM technologies
	Lack of cooperation between participants				b124	Initial cost of software
	Lack of experience in using BIM				b125	Cost of updating software and hardware

	Unclear responsibilities for BIM users				b126	High cost of software and hardware
	Lack of collaborative working processes				b127	High cost of BIM software licenses
	Fear of sharing information with participants			8	b128	Financial investment of training
	Owners' lack of demand for BIM				b129	Cost of training
	High cost of BIM software				b130	Huge BIM up frontal investment for training
	High risk of ROI				b131	Cost of BIM processes training
	Lack of benefits brought by BIM				b132	High cost for training
	Lack of knowledgeable talent				b133	Resources and cost issues for expertise
	Learning BIM-related technologies				b134	High cost of BIM experts
	Unavailability of proper training on BIM				b135	Cost of implementation and training
	Unclear relevant processes and standards				b136	High cost of BIM experts
	Weak theoretical foundation for processes				b137	High cost of training
	Lack of standards to guide implementation				b138	High cost of BIM specialists
	Difficulty changing habits				b139	High training and running costs
	Lack of domestic-oriented BIM methods				b140	Cost of training for BIM implementation
	Poor experience in different BIM software				b141	High upfront investment for professionals
	Complexity of existing BIM software				b142	High training and implementation cost
	Poor interoperability of BIM software		D	9	b143	Lack of assured financial gain
	Poor security performance of BIM				b144	Fear of low success or significant failure
	Incomplete functions in BIM software				b145	Unclear investment returns
[69]	Practice culture resistance				b146	High risk of ROI
	Need for multi software tools to adopt BIM				b147	Lack of proof of return on investment
	Need to develop specific contracts				b148	No proof for return on financial investment
	Lack of qualified staff				b149	Profit risk or challenge concerns
	Initial cost to adopt BIM technologies			10	b150	Benefits unmatch implementation costs
	Lack of protocol and criteria for BIM adoption				b151	Fear of low economic profit
	Initial cost of software				b152	Lack of resources because of low profit
	Cost of updating software and hardware				b153	Lack of guaranteed benefits
	Legal ownership issues				b154	Lack of benefits brought by BIM
	Interoperability issues of BIM use				b155	Unclarity of potential benefits of BIM
	Lack of local business BIM motive				b156	Lack of perceived benefits
	Lack of methods compatibility				b157	Uncertain benefits
[70]	High cost of software and hardware				b158	Poor awareness of BIM benefit
	High cost for training	3rd	E	11	b159	Industry resistance to change practices
	Weak BIM adoption knowledge for managers				b160	Industry's resistance to change
	Difficulty choosing software provider				b161	Conservative approach of leadership
	Lack of experience in BIM adoption				b162	Lack of discipline motivation for designers
	Reluctance to change reliable methods				b163	Change team mindset
	Fragmented system, multi-location storages				b164	Lack of professional motivation
	Information requirements and quality issues				b165	Resistance and cooperation/example absence
	Lack of BIM methods adoption in operation				b166	Staff motivation
	Lack of BIM research in operation phase				b167	Conservative approach of leadership
	Interoperability issues of collaboration				b168	Practice culture resistance
	Unavailability of proper BIM training				b169	Lack of local business BIM motive
	Need to proof effectiveness				b170	Reluctance to change reliable methods
	BIM objectives only for delivery phase				b171	Industry resistance to change
	Unmatching existing contracting methods				b172	Difficulty of mindset changing
	Lack of standard scopes for operation phase				b173	Staff resistance
	Unclarity of potential benefits of BIM				b174	Resistance to change practice
	Lack of regulations from policy makers				b175	Resistance of industry to change
	Limited standards				b176	Corporate culture resistance
	Liability/privacy concerns of digital processes			12	b177	No demand for BIM use
[71]	Uses and interoperability issues				b178	Lack of support from the client/management
	Liabilities and data loss				b179	Lack of motivation for clients
	Lack of guidelines to perform specific task				b180	Lack of client demand
	Resources and cost issues for expertise				b181	Clients' culture related issues
	Time to develop templates				b182	Clients' culture
	Difficulty finding proper training				b183	Owners' lack of demand for BIM
	Industry resistance to change				b184	Difficulty Changing habits
	Difficulty of mindset changing				b185	Owners' resistance to change
	Lack of management for adoption				b186	No client demand
	Ownership of the project				b187	Lack of demand
	Lack of government support				b188	No client demand
	Lack of standards				b189	No client demand
	Increased efforts at the initial stages				b190	Lack of market demand
[7	Owners' resistance to change				b191	Resistance changing production habits

	Lack of proper knowledge level	4th	F	13	b192	Lack of BIM knowledge
	Software learning curves				b193	Lack of education
	Lack of training skills				b194	Lack of knowledge
	Lack of mandate				b195	Learning difficulties of BIM
	No client demand				b196	Lack of collective knowledge
	Lack of collaboration/cooperation				b197	Weak technical knowledge and awareness
	Standard issues				b198	Lack of BIM education
	Lack of proof of return on investment				b199	Lack of knowledgeable talent
	Lack of perceived benefits				b200	Learning BIM-related technologies
[73]	Lack of standard				b201	Weak BIM adoption knowledge for managers
	Lack of guidelines				b202	Lack of BIM research in operation phase
	Lack of training expertise				b203	Lack of proper knowledge level
	Lack of expertise				b204	Software learning curves
	High cost of BIM experts				b205	Lack of research on BIM implementation
	Lack of research on BIM implementation				b206	Lack of awareness
[74]	Cost of implementation and training				b207	Lack of required knowledge
	Legal issues				b208	Lack of essential knowledge
	High cost of BIM experts				b209	Lack of BIM-based awareness
	Uses and interoperability				b210	Lack of BIM-based knowledge
	Lack of awareness				b211	Lack of professional knowledge
	Staff resistance				b212	BIM major lack of knowledge
	Definition processes issues				b213	Lack of recognition of innovative value
	Management issues			14	b214	Training staff
	Lack of demand				b215	Lack of training and consultancy
	Project scale-based methods				b216	Lack of proper training
	Technology issues				b217	Lack of experience
	Lack of required knowledge				b218	Lack of expertise
	High cost of training				b219	Lack of training
	Contract issues				b220	Lack of experienced BIM implementers
	Lack of standards				b221	Lack of qualified in-house staff
[75]	Lack of government support				b222	Lack of professional training
	Lack of standards and guidelines				b223	Expertise
	Lack of essential knowledge				b224	Lack of experience in using BIM
	No client demand				b225	Unavailability of proper training on BIM
	Lack of in-house expertise				b226	Poor experience in different BIM software
	Resistance to change practice				b227	Lack of qualified staff
	Lack of use definitions and interoperability				b228	Lack of experience in BIM adoption
	Lack of BIM-oriented training				b229	Unavailability of proper BIM training
	No proof for return on financial investment				b230	Difficulty finding proper training
[76]	Potential of BIM is unclear				b231	Lack of training skills
	BIM software is complex to use				b232	Lack of training expertise
	Complexity of BIM adoption process				b233	Lack of expertise
	Lack of process standardization				b234	Lack of in-house expertise
	High cost of BIM specialists				b235	Lack of BIM-oriented training
	High training and running costs				b236	Non-availability of BIM expertise
	Lack of BIM-based awareness				b237	Lack of specialized BIM engineers
	Long time required for full adoption				b238	Lack of BIM training expertise
	Non-availability of BIM expertise				b239	Shortage of cross-field specialists
	Lack of government support		G	15	b240	Lack of appropriate IT infrastructure
	Lack of BIM-based knowledge				b241	Lack of technical support
	No client demand				b242	Incompatibility of software and hardware
[77]	Lack of standards				b243	Lack of ICT infrastructure
	Cost of training for BIM implementation				b244	Software distribution
	Lack of specialized BIM engineers				b245	Technological barriers
	Lack of time for BIM implementation				b246	Technology
	Lack of market demand				b247	Complexity of existing BIM software
	Lack of BIM training expertise				b248	Poor interoperability of BIM software
[78]	Lack of mandatory BIM standards				b249	Incomplete functions in BIM software
	Lack of government support				b250	Need for multi software tools to adopt BIM
	Resistance of industry to change				b251	Difficulty choosing software provider
	High cost of BIM software licenses				b252	Technology issues
	High upfront investment for professionals				b253	BIM software is complex to use
	High training and implementation cost				b254	Lack of support analysis software tools
	Lack of top management commitment	5th	H	16	b255	Lack of government incentives
	Shortage of cross-field specialists				b256	Lack of regulations from policy makers
	Lack of support analysis software tools				b257	Lack of government support

	Lack of well-established BIM workflows				b258	Lack of mandate
[79]	Lack of professional knowledge				b259	Lack of government support
	Difficulty of working process and material				b260	Lack of government support
	Absence of methods to execute projects				b261	Lack of government support
	Corporate culture resistance			17	b262	Time required for skill acquisition
	Inability to evaluate and quantify				b263	Lack of time for implementation
	BIM major lack of knowledge				b264	Time to develop templates
	Profit risk or challenge concerns				b265	Long time required for full adoption
	Uncertain benefits				b266	Lack of time for BIM implementation
	Uncertain uses			18	b267	Need to proof effectiveness
[80]	Lack of familiarity with BIM workflows				b268	Increased efforts at the initial stages
	Resistance changing production habits				b269	Potential of BIM is unclear
	Poor awareness of BIM benefit				b270	Inability to evaluate and quantify

After preparing the compact version of the collected BIM barriers, the research analyzes these compact BIM barriers. The process includes carefully going through the descriptions of all barriers and trying to find the common theme between different descriptions (e.g., BIM barriers that describe economic and financial aspects will belong to the economical theme). It is noteworthy that multi-level classification is needed since there are general, specific, and more specified themes, based on the collected sample. Hence, the analysis suggests five different main groups (that will be called later primary groups) for which all BIM barriers will be allocated, the allocation of collected BIM barriers accounts for 42%, 17%, 12%, 23%, and 6%, representing the 1st (methods/standards), 2nd (economical), 3rd (cultural), 4th (abilities/capabilities), and 5th (other) groups, accordingly. Please see the following Figure 8, which demonstrates the allocation of the collected 270 barriers on the defined 5 classification groups and their allocation percentages. Although barriers share the same main theme in one primary group, at many groups further classification is required due to the variation among the barriers regarding the specific theme. Hence, primary groups will include one or more subgroups for further specific allocation of the BIM barriers, these subgroups will represent the so-called secondary groups. The allocation of the collected BIM barriers will be 23%, 19%, 11%, 6%, 12%, 18%, 6%, and 6%, accounting for each of the following secondary groups: processes/uses, legal/management, adoption cost, financial profit, conservative culture, awareness/skills, infrastructure, and government/leverage, respectively.

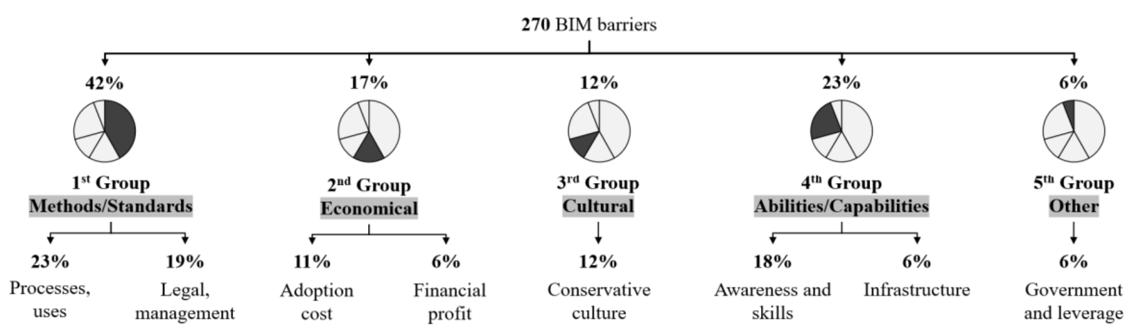


Figure 8: allocation of collected BIM barriers for primary and secondary groups with their percentages

The analysis' main objectives include defining main and subclassification themes, filtering synonyms and barriers with similar content, and merging barriers on the subgroup level to produce one comprehensive BIM barrier. The three analyzation objectives are essential to ease dealing with the collected information, avoid duplication among listed barriers, and provide summarized BIM barriers that best describe and represent the reference collection. The final intention of deriving a few summarized and pinpointed BIM barriers will facilitate the inclusion process in the upcoming survey study that will form the core of this chapter. Hence, and after defining the secondary group, a comprehensive review of the allocated BIM barriers is conducted to evaluate the possibility of merging process for included barriers on the secondary group level, the results of this review show that there is a need for another third subgroup in which specific barriers included in the secondary group will be classified and allocated to more specific subgroups based on their detailed and specified themes. The last subgroup will be called tertiary group, and barriers which are included in in one tertiary group share almost identical descriptions and contents. This will facilitate the last analyzation process that includes merging similar and identical BIM barriers on the tertiary group level to derive a single comprehensive barrier that best describes the merged group.

For more detailed information regarding the collected BIM barriers and the allocation of each one to its relevant group from the three different levels, please check Table 06, in which the 1st, 2nd, 3rd, 4th, and 5th subgroups represent the primary group (L1), including methods and standards, economical, cultural, abilities and capabilities, and other, respectively. Also, at the same table the capital letters A, B, C, D, E, F, G, and H represent the secondary group (L2), including processes/uses, legal/management/standards, implementation cost, financial profit, conservative culture, awareness/skills, infrastructure, and government/leverage, respectively. Moreover, the last tertiary group (L3) includes 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, and 18 subgroups, that represent BIM-based methods, BIM uses, BIM-based collaboration, legal/liability, management/contracts, business standards, tools cost, expertise cost, return, benefit, business related, client related, knowledge, experience, ICT, policy, time, and efficiency, respectively.

After performing multi-level sorting and allocation processes, the only remaining step is to formulate the list of comprehensive BIM barriers that correspond to their merged barriers on the tertiary group level. Please find the attached Figure 46 at the attachments chapter for more demonstration about all three levels including primary (methods/standards, economical, cultural, abilities/capabilities, and other), secondary (processes/uses, legal/management/standards, implementation cost, financial profit, conservative culture, awareness/skills, infrastructure, and government/leverage), and tertiary (BIM-based methods, BIM uses, BIM-based collaboration, legal/liability, management/contracts, business standards, tools cost, expertise cost, return, benefit, business related, client related, knowledge, experience, ICT, policy, time, and efficiency) groups. Also, the figure demonstrates the formulated federated BIM barriers that best describe their corresponding merged barriers from the associated tertiary group, each comprehensive BIM barrier will be marked with an ID number that starts with a capital letter "B" followed by a two-digit number from 01-18.

The following Figure 9 focuses on the derived 18 comprehensive BIM barriers and the number of their associated BIM barriers which are merged on the tertiary group level. The federated BIM barriers include B01: lack of BIM adoption definition methods/workflows, B02: lack of BIM Uses definitions and objectives, B03: lack of project parties' collaboration, B04: undefined security, legal liability, and responsibility, B05: management/contractual BIM processes (BEP), B06: undefined related business standards for BIM adoption, B07: cost of BIM tools (e.g., software, hardware, etc.), B08: cost of expertise and training support, B09: risk of return on investment and financial profits, B10: unclarity of financial benefits and economic risks, B11: industry resistance and difficulty to change processes, B12: client's resistance and lack of market demand, B13: lack of BIM knowledge, awareness, and research, B14: lack of BIM experience, experts, and trainings, B15: lack of IT infrastructure (software, hardware, etc.), B16: lack of mandate regulations and policy support, B17: lack of time for full BIM adoption and skill developing, and B18: lack of proof for efficiency, and potential of BIM.

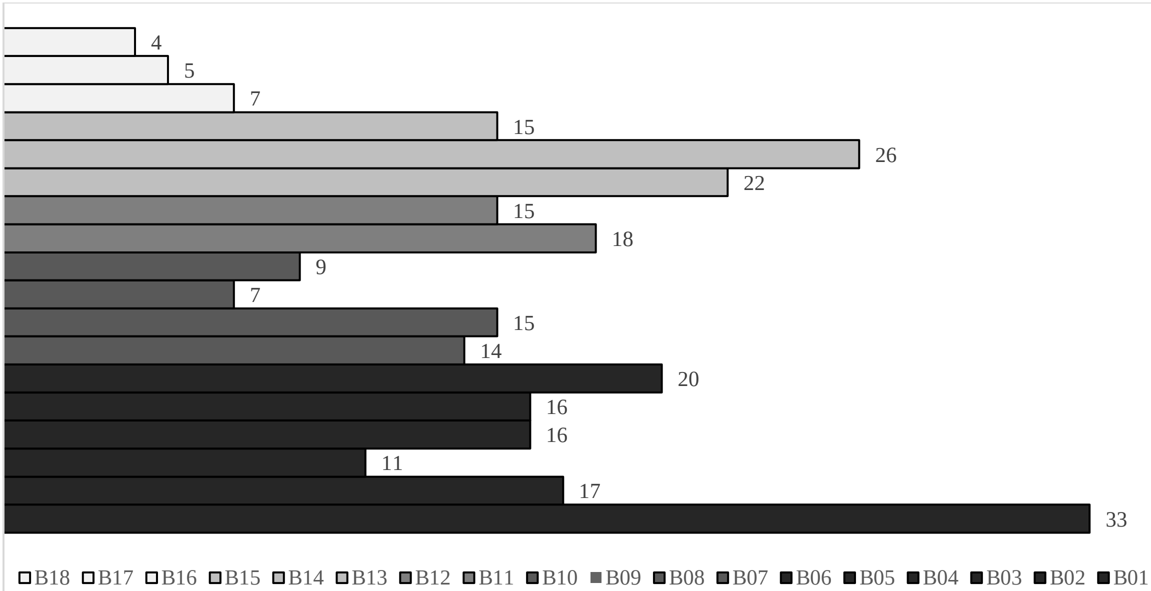


Figure 9: derived comprehensive BIM barriers after merging the analyzed BIM barriers on the tertiary group level

3.2. Survey structure and details

In this chapter, survey studies will be conducted to define two main points: the status of BIM implementation in local AE firms, and key barriers against the implementation of BIM at the same firms. Hence, the research will include the defined 18 federated BIM barriers that are derived from the previous subchapter in the intended survey studies. The structure of the intended two survey studies will be almost identical, since the locations of the reference organizations for the participants are different (some participants belong to local building industry firms from outside the ST region, and other participants belong to the defined potential AE SMEs from the ST region).

3.2.1. Survey structure

The survey structure is divided into three sections, the survey structure and its sections are identical in both survey rounds. The main target of the planned sections and the included questions is to get the needed information with least amount of time required to fill in the survey, so the survey does not focus on general and irrelevant questions regarding the topic (e.g., warming up and background questions), the survey focuses directly on the important questions which their answers will play critical role in influencing the results and achieving the overall objectives of the research study. All questions will appear respectively based on the relevant section from the 1st to the 3rd. Questions from all section are compulsory to be answered, meaning that the participant cannot skip one question without answering it and move to the next one. The survey tries to include direct and close-ended questions as much as possible to make more user-friendly experience in answering the questions (by facilitating the process of choosing the answer from already given choices, by taking less time to think about the answer and record it), and to ease the later on intended analyzation process for all responses.

The first section includes personal and company related questions (total three questions), starting with the first question regarding the position of the respondent, and for this question there are two possible answers, whether the respondent is a high-level employee (in terms of position and years of experience) and this group usually includes junior professionals who are representatives from the management team, or a low-level employee (in terms of position and years of experience) and this group usually includes senior professionals who are representatives from the operational team. Please note that the expressions high and low in the previous two answers do not reflect the significance of the employee within the group work, the expressions reflect the years of experience and position on the hierarchy structure of the company, no one can deny the importance of all employees within the supply chain at any company in the building industry, regardless of their positions and collective years of experience.

The second question is in connection with the scope of the company, the scope of the building industry company represents the main activities, functions, and services provided by the company. There are seven possible answers that the respondent will be able to choose one of them to proceed with the next question, including architectural engineering, structural/civil engineering, building services engineering (MEP/HVAC), building construction, facility management, manufacturer, or other (for this choice the respondent is asked to define the exact scope of the related building industry firm). The third question is the last question in the first section of the survey, the question is asking directly about the size of the company regarding the number of employees, this size indicator will not be hard to define for the respondent (since the majority of target respondents are high-level employees) or at least the respondent is able to give an estimation regarding this answer, the most important point is to make it easy for the respondent to answer, that is why it was decided to leave this question as an open-ended question to give the respondent the freedom to type in the exact number or range that best answers the number of employees' question.

The second section of the survey focuses on the BIM implementation level at the respondent's organization, the survey applies a 1 to 7 scale for measuring the level of BIM adoption at the building industry company, in this scale rank 1 stands for "never" and rank 7 stands for "always" and in between there are 5 different ranks that indicate the level of BIM implementation, which varies from low to high, presented by 2 to 6, respectively. It was clarified for the respondent what level of BIM the survey is interested in, and as mentioned previously, and based on the NBS BIM Levels, the interest of this survey study is to investigate the adoption of BIM Level 02 according to the NBS BIM Levels. The second question in this section, is to validate the answer of the first question in this section, the inclusion of this validation question was recommended by one of the supervisors and based on his personal experience with respondents from the local building industry market, which can be summarized by the fact that most of the building industry professionals think that they use BIM-based workflows, and in reality they are not. Since this statement is an observational statement based on collective experience in the local market, and it is not measured by factors and numbers, it was hard to define the associated verification question by which we can validate the respondent's answer regarding the BIM implementation. Then, the idea of including a question regarding the usage of business standard appears, the business standards (ISO 19650) is considered the constitution for all high-level BIM practitioners and their daily workflows, and since the target respondents for this survey are high-level employees, it was decided to formalize the second validation question around the usage of ISO 19650 business processes in the companies' daily workflows. For this question the survey applies the same 1 to 7 scale for measuring the level of ISO 19650 business processes application at the surveyed building industry company, in this scale rank 1 stands for "never" and rank 7 stands for "always" and in between there are 5 different ranks that indicate the level of ISO 19650 business processes implementation, which varies from low to high, presented by 2 to 6, respectively. It is noteworthy that if the answer of the 1^{st} and 2^{nd} questions from the survey's second section are far apart, then the claim of BIM adoption in the surveyed company is questionable!

The last section of the survey includes one question regarding BIM adoption barriers, the question asks the participant to rank the listed 18 BIM barriers (that are concluded from the previous subchapter) based on their relative importance on a scale from 1 to 9, at which 1 stands for not relevant at all, and 9 stands for very relevant. The respondent should rank each listed BIM barrier, and skipping the rank of any barrier is not allowed. Finally, the survey asks the participant to provide his contact information (email address) for later research purposes.

3.2.2. 1st survey round

This survey round leans on non-probability sampling method called "convenience sampling" in which the sample is being drawn from that part of the population that is close to hand [81]. Hence, the participants of the first survey are high-level building industry professionals who participated in one of the following two programs: Pollack Expo 2024 or the professional BIM program's workshop 2024 at the University of Pécs, Faculty of Engineering and Information Technology (PTE MIK), participants from both events have been surveyed separately, and the results have been combined to form the first survey. The participants in the first survey are high-level building industry professionals who come from companies based in different Hungarian regions, the following points highlight the importance of the first survey in this subchapter:

- Demo survey: the first survey will give the author feedback and insights about the workability of the whole applied method, scale, and structure, by providing initial results that may give potential directions and possibilities.
- Control survey: the first survey will act as a reference control survey compared to the second one for comparison reasons. This means that results derived from the second survey will be compared with the results derived from the first survey to see how professionals from AE companies that are based in different regions will respond to BIM implementation and BIM barriers questions.

The Pollack Expo is an annual professional event in which engineering companies and their professionals exhibit their latest expertise and products. The event is not only a trade show, but also an opportunity for business deals, strategic cooperations, and professional training, by enlightening visitors with the latest technologies/techniques and their associated experiences from the industry. Moreover, the event is considered as an annual opportunity for students to gain knowledge and experience by meeting the local industry and engineering community [82]. This particular event took place in the Expo Center, Pécs, on the 18th and 19th of April 2024. There are two core sections in the Expo, the exhibition and presentation sections, the majority of the collected responses are from the exhibition section with few responses collected from the presentation section.

The survey study used the SurveyMonkey platform to collect responses from participants. The questions of the survey were uploaded to the SurveyMonkey with the planned sequence and structure of the survey, then a link and QR code have been generated, and the participant needs to click on the link or scan the QR code in order to reach the survey sheet and answer the questions. The distribution of the survey among participants in the Expo event includes the following steps: a) access the survey on a movable device (tablet) with large/clear monitor and easy to use accessory (touch pen), b) searching for building industry firms among the exhibition desks, c) approach the desk that belongs to certain building industry firm and introduce the research, d) ask about the position details of the firm's representative, e) ask about the intention of the participant to take part in two surveys (the current first survey and another upcoming one), f) provide the tablet for the participant to fill the survey, g) take the contact information of the participant, and H) repeat the process to collect as much responses as possible from the participating building industry firms. Due to the shortage of time, density of the event's visitors and activities, uncertainty about positive responses in case of traditional distribution, sensitivity of the survey participant's position, commitment needed from the participant to answer the second survey, and need for the participant's contact information, it was highly recommended to follow the previously introduced steps to distribute the survey among participants. The main target group among the professionals is high-level employees in the surveyed building industry firms. The research tried to avoid junior participants, this helps to provide more accurate and relevant insight regarding the topic, since BIM implementation and barriers toward the implementation are usually high-level decisions at the organization level. Luckily, the majority of the approached representatives for the surveyed companies were high-level employees, sometimes even higher than expected (e.g., CEOs, founders, managers, etc.), the reason for that refers to the fact that most of the surveyed AE firms are smaller sized firms, and that is why many of the company's management and leadership teams attended the event. In addition, the event is considered a great environment for business deals and strategic partnerships, hence, the presence of high-level representative from the participating building industry firm is essential.

The professional BIM program's workshop 2024 at PTE MIK, is a professional postgraduate program that aims to provide comprehensive knowledge and experience regarding BIM workflows in the building industry. Participants in this program are usually senior professionals with several years of experience who are seeking more practical experience and information regarding BIM implementation in building projects. The workshop took place on the 20th of April 2024, at building A of PTE MIK. The participants come from different specialized companies and based in different regions across the country, the distribution method was similar to the previous Expo distribution method, the only difference at this time that all participants were in one room and the survey distributor managed to introduce the research and communicate the survey structure, conditions, and objectives at once for all of the participants before they scan the presented QR code and fill the survey.

POLLACK EXPO

BIM SZAKMÉRNÖK SZAKIRÁNYÚ TOVÁBBKÉPZÉS

Respondents allocation	#	%
Pollack Expo	33	54%
PTE/BIM	28	46%

Close allocation

Figure 10: the responses allocation from the Pollack Expo and BIM engineering workshop

In the 1st survey round, the total number of received responses is 61, with 33 responses collected from the Pollack Expo accounting for 54% of the total responses, and 28 responses collected from the professional engineering workshop accounting for 46% of the total responses, with final similar proportions from both events, please see Figure 10. Out of the total 61 responses there are 46 relevant responses, accounting for 75% of the total responses, and 15 irrelevant responses, accounting for 25% of the total responses. The reason for having some irrelevant responses is the difficulty of controlling the sample and specifically the background disciplines of target respondents or the size of their organization. Irrelevant responses include response bias (e.g., the main activity of the respondent is neither 71.11 architectural activities nor 71.12 engineering activities and related technical consultancy, the respondent is not a high-level employee, and/or the company is not an SME based on the number of employees). The relevant responses represent the responses answered by high-level employees, who belong to building industry firms with one of the following NACE main activities: 71.11 architectural activities or 71.12 engineering activities and related technical consultancy. In addition, the building industry firms should tend to be on the smaller sized according to the number of employees (the number of employees should be less than 41, the previously defined limit in the 2nd chapter), please see the following Table 7 for more illustration.

Table 7: relevant responses and their affiliation breakdown (1st survey round)

Responses	**#**	**%**	**Relevancy scope**
Total	61	100%	Including firms from all disciplines, and high/low-level respondents.
Irrelevant	15	25%	Bias (firms out of the AE SMEs scope and/or low-level respondents)
Relevant	46	75%	Including firms from the AE SMEs scope and high-level respondents.
Breakdown of relevant responses including the number, percentage, and relevancy scope:			
Arch.	34	74%	71.11 architectural activities
Structural	8	17%	71.12 engineering activities and related technical consultancies (combined allocation accounts for 26%)
MEP	4	9%	

3.2.3. 2nd survey round

This survey round leans on intentionally selecting participants based on pre-defined criteria under the so-called "purposive sampling" [83]. Hence, the target participants in this research are high-level representatives from the previously defined potential AE SMEs located in the studied ST region.

According to the results derived from chapter 2 that define the potential building industry SMEs located in the ST region, including building industry firms from 71.11 and 71.12 business classes, refereeing to architectural activities and engineering activities & related technical consultancies, respectively, a list of 98 different AE firms that belong to the mentioned business activities are located in the ST region. The first step on the second survey round includes comprehensive research including collecting contact information for each company included in the list. The second step includes distributing the survey for the companies with available contact information to measure BIM implementation and its barriers at the region's level.

Similar to the 1st survey round, the 2nd survey study uses the SurveyMonkey platform to collect responses from participants. The questions of the survey are uploaded to the SurveyMonkey with the planned sequence and structure, then a link and QR code are generated. The participant needs to click on the link or scan the QR code in order to reach the survey sheet and answer the questions. The distribution of the survey includes the following steps: a) generate the survey link and QR code, b) write an email for the target companies, introduce the research and highlight that only one response is needed from a high-level employee within a maximum 1 month duration, c) distribute the survey among all potential AE firms with available contact, and d) re-send a survey reminder every week for one month to all potential AE firms with available contact, with clarifying at the beginning of the email that it is only a reminder, and for those companies that already responded the email can be neglected.

The 2nd survey round is distributed among potential AE SMEs with available contact information. According to the results of the comprehensive contact information research, more than 60% of the potential AE SMEs located in the studied region are reachable, meaning that more than half of the listed firms can participate in the survey. The list of potential AE firms includes a total of 98 firms, of which 62 firms have contact information and are considered reachable, accounting for 63%. On the other hand, 36 firms have no contact information and are considered unreachable, accounting for 37%. The 2nd survey is sent to 62 firms through the official email address of each company and by following the previously mentioned distribution steps. The total surveyed 62 firms include 43 (69%) architectural activity firms (71.11) and 19 (31%) engineering activity and related technical consultancy firms (71.12). The total received 46 responses account for 74% response ratio, including 33 (53%) responses from architectural activity firms (71.11) and 13 (21%) engineering activity and related technical consultancy firms (71.12). Please see the following Table 8 for more illustration.

Table 8: relevant responses and their affiliation breakdown (2nd survey round)

<table>
<tr><td>Responses</td><td>#</td><td>%</td><td colspan="3">Availability scope</td></tr>
<tr><td>Total</td><td>98</td><td>100%</td><td colspan="3">Including all potential AE firms from the ST region (71.11 & 71.12).</td></tr>
<tr><td>Available</td><td>62</td><td>25%</td><td colspan="3">Including all firms with available contact information.</td></tr>
<tr><td>N/A</td><td>36</td><td>75%</td><td colspan="3">Including all firms without available contact information.</td></tr>
<tr><td colspan="6">Breakdown of surveyed and responded firms and their affiliation</td></tr>
<tr><td>B. Class</td><td colspan="2">Surveyed</td><td colspan="2">Responded</td><td>Affiliation</td></tr>
<tr><td>71.11</td><td>43</td><td>69%</td><td>33</td><td>53%</td><td>Architectural activities.</td></tr>
<tr><td>71.12</td><td>19</td><td>31%</td><td>13</td><td>21%</td><td rowspan="2">Engineering activities and related technical consultancies.</td></tr>
<tr><td>Sum</td><td>62</td><td>100%</td><td>46</td><td>74%</td></tr>
</table>

3.3. BIM implementation in local AE firms

One of the core objectives from the conducted survey studies is to reveal the actual status of BIM adoption in the local Hungarian AE firms, and on the first place the defined potential AE SMEs located in the ST region. As shown in the previous subchapter, two survey rounds have been conducted, and accordingly, there will be two results for the BIM adoption in local AE firms:

- First: BIM adoption level based on the results from the 1st survey round that represents local Hungarian AE firms based in different regions of the country; the study is based on convenience sampling method and targets high-level representatives of different local Hungarian AE SMEs who participated in the Pollack Expo 2024 and BIM specialized engineering workshop 2024.
- Second: BIM adoption level based on the results from the 2nd survey round that represents local Hungarian AE SMEs based in the ST region, this study is based on purposive sampling method and targeting high-level representatives from the defined potential AE SMEs in the ST region based on the results derived from chapter 2.

Based on the relevant responses from the 1st survey round, around 76.09% of the studied local AE SMEs that are based on different Hungarian regions across the country tend to not implement BIM workflows in their daily work, according to the NBS BIM Levels, these firms belong to BIM Level 0 and BIM Level 1, including no collaboration and 2D CAD drafting for BIM Level 0, and 3D CAD for conceptual work combined with 2D CAD for statutory approval documentation for BIM Level 1. On the other hand, around 21.74% of the firms claim to implement BIM workflows in their daily work, meaning that these firms belong to BIM Level 02 and 03 according to the NBS BIM Levels. On the other hand, and in connection with the second validation question in this section of the survey, 89.13% of the AE companies tend to not use the business processes provided in the ISO 19650 series, and only 9% of the companies tend to use ISO 19650 business process in their firms' workflows. So as expected, there is inconsistency between the responses of some firms regarding the adoption of BIM workflows and business standards according to ISO 19650 which form the backbone for all BIM-based business workflows for any BIM-compliant company, mainly when the representatives of these companies who filled in the survey are considered high-level employees in their organizations. Hence, 11.74% of the surveyed AE firms claim to adopt BIM workflows without implementing ISO 19650 business process, making their claim regarding BIM adoption (minimum NBS Level 02) questionable. Consequently, the percentage of AE firms that tend to not adopt BIM processes in their workflows will increase to 89.13 %. To sum up, BIM adoption among local AE firms based on different Hungarian regions that are surveyed based on a convenience sampling method is lagging behind the industry, the percentage of the firms that adopt BIM processes (minimum NBS BIM Level 02) is very low, accounting for 21.74% at the optimal cases, and goes down to 9% after taking into the consideration the responses to the validation question. So, it is highly recommended to investigate more the barriers against the implementation of BIM workflows and the adoption of this transition in the industry processes. Please check the following Figure 11 for more details regarding the level of BIM adoption in local AE firms from different Hungarian regions (based on the 1st survey round).

Level of BIM adoption among studied firms						
Scale	**BIM work**	**%**		**ISO19650**	**%**	
1: never	7	15.22%		29	63.04%	
2	19	41.30%	**76.09%**	10	21.74%	**89.13%**
3	9	19.57%		2	4.35%	
4	1	2.17%	2.17%	1	2.17%	2.17%
5	2	4.35%		0	0%	
6	5	10.87%	**21.74%**	3	6.52%	**9%**
7: always	3	6.52%		1	2.17%	

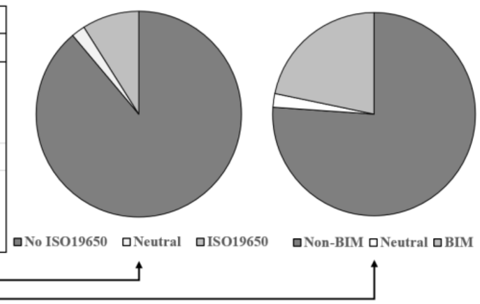


Figure 11: level of BIM adoption in local AE firms from different Hungarian regions

Based on responses from the 2nd survey round, around 63.05% of the studied local potential AE firms that are based in the studied ST region tend to not implement BIM workflows in their daily work, according to the NBS BIM Levels, these firms belong to BIM Level 0 and BIM Level 1, including no collaboration and 2D CAD drafting for BIM Level 0, and 3D CAD for conceptual work combined with 2D CAD for statutory approval documentation for BIM Level 1. In addition, around 21.74% of the firms claim to implement BIM workflows in their daily work, meaning that these firms belong to BIM Level 02 and 03 according to the NBS BIM Levels. On the other hand, and in connection with the second validation question in this section of the survey, 78.27% of the AE companies tend to not use the business processes provided in the ISO 19650 series, and only 13.04% of the companies tend to use ISO 19650 business processes in their firms' workflows. Similarly to the 1st round survey, there are inconsistencies between the responses of some firms regarding the adoption of BIM workflows and business standards according to ISO 19650 which form the foundation for all BIM-based business workflows for any BIM-based firm, mainly when the representatives of these companies who filled in the survey are high-level employees in their organizations. Hence, 8.7% of the surveyed AE firms claim to adopt BIM workflows without implementing ISO 19650 business process, making their claim regarding BIM adoption (minimum NBS Level 02) questionable. Consequently, the percentage of AE firms that tend to not adopt BIM processes in their workflows will increase to 78.27 %. To sum up, BIM adoption among AE SMEs that are surveyed based on a purposive sampling method (derived from the previously defined list of potential AE SMEs in the ST region) is lagging behind the industry, the percentage of the firms that adopt BIM processes (minimum NBS BIM Level 02) is considered low, accounting for 21.74% at the optimal cases, and goes down to 13.04% after taking into the consideration the responses to the validation question. So, it is highly recommended to investigate more the barriers against the implementation of BIM workflows and the adoption of this transition in the industry processes. Please check the following Figure 12 for more details regarding the level of BIM adoption in potential AE firms at the ST region (based on the 2nd survey round).

Level of BIM adoption among studied firms						
Scale	**BIM work**	**%**		**ISO19650**	**%**	
1: never	2	4.35%		17	36.96%	
2	10	21.74%	**63.05%**	12	26.09%	**78.27%**
3	17	36.96%		7	15.22%	
4	7	15.22%	15.22%	4	8.70%	8.70%
5	6	13.04%		3	6.52%	
6	2	4.35%	**21.74%**	1	2.17%	**13.04%**
7: always	2	4.35%		2	4.35%	

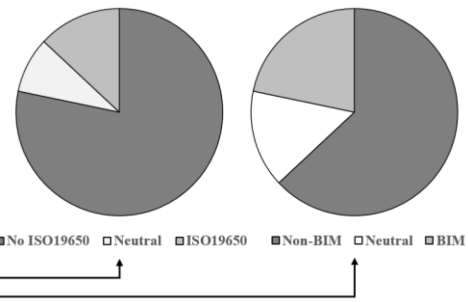


Figure 12: level of BIM adoption in local AE firms in the ST region

3.4. Key implementation barriers in local AE firms

This subchapter covers the last section of the survey that includes one question associated with defining key barriers against BIM implementation in the surveyed firms; by ranking listed 18 BIM barriers based on how important they are according to the practice indicators in real-life for a company that intends to carry out BIM-based appointments. Hence, the research will use a method that scientifically assists to numerically describe the relevancy of each BIM barrier, take a decision regarding key BIM barrier/s, and set BIM implementation mission that will be the base for the upcoming chapters.

There are several research contributions that apply MCDA (Multi-Criteria Decision Analysis) which is also known as MCDM (Multi-Criteria Decision-Making) in different BIM-related approaches, with high expectation to improve information integration and decision making within the building industry by enhancing the synergy between BIM and MCDA [84], [85]. Although, there is a clear lack in scientific contributions regarding the applications of MCDA/MCDM in assisting the definition of BIM barriers, previous research that targets SMEs of the construction industry in New Zealand successfully applied a multi-criteria analysis of barriers to BIM implementation in the studied firms [86]. Similarly, this work is going to target smaller size AE firms in the 1st and 2nd survey rounds to define key BIM barriers by using single criteria analysis of barriers against BIM implementation in local Hungarian SMEs.

AHP (Analytical Hierarchy Process):

There are many ways to support single and multiple criteria decision making, under the umbrella of mathematical models for decision support [87]. This study will apply Thomas L Saaty's AHP which is a decision making tool that leverages pairwise comparisons to derive priority scales of complex criteria and constraints based on mathematical models by using linear algebra [88], [89]. Apparently, the AHP is the most used (cited) technique compared to other MCDA/MCDM techniques [90]. But there are several strengths and limitation of applying the AHP as MCDA/MCDM in scientific researches [91], the strengths include:

- AHP allows decision-makers to break down complex issues into a hierarchy of criteria and alternatives, to enhance understanding and analysis processes.

- Incorporating qualitative and quantitative factors, to facilitate a comprehensive evaluation of alternatives.
- Providing a consistent framework for pairwise comparison of criteria and alternatives, to ensure transparency and reduce mistakes or biases.

On the other hand, the limitations of using the AHP include:

- The process is highly influenced by the accuracy and consistency of pairwise comparisons, which can be subjective and affected by individual biases.
- The potential of oversimplification for decision problem, since the AHP may not sufficiently capture the interactions and dependencies among criteria.
- The calculation of AHP weights is time-consuming and requires significant effort to obtain reliable and meaningful results.

The AHP is a basic approach for decision making, by enabling the user to choose the best from a number of alternatives evaluated with respect to several criteria, the approach starts with simple pairwise comparison and then carries out this comparison furthermore to develop a comprehensive set of priorities for ranking the given alternatives [92]. The simplest form to initiate the AHP is by using a three-level hierarchy structure, starting with defining first the main goal of applying the process, in this research subchapter the main goal is to define key BIM barriers for the surveyed AE firms, the main goal will occupy the top level of the hierarchy pyramid structure. Then on the second level of the hierarchy pyramid comes the criteria by which the alternatives which are located at the very bottom third level will be evaluated, in this research there is one criterion (significance/importance) which the respondents are going to rank the given alternatives (18 BIM barriers) based on, to serve the overall objective of defining one or more key BIM barriers that will have high priority, and most likely will be the base for upcoming research work that will intend to introduce a methodology for overcoming these key BIM barriers.

The AHP follows the so-called fundamental scale which includes values to represent the intensities of judgments by the respondent who judges a certain alternative based on defined criterion, see Table 9, the fundamental scale has been validated by several applications and through theoretical justification regarding the comparison of homogeneous elements, the scale will assist to compare elements and verbally estimate the comparison between elements [93].

Table 9: the fundamental scale for the AHP

Based on importance		**Comparison between two activities**
Intensity	**Definition**	**Explanation**
1	Equal	Two activities contribute equally to the objective.
2	Weak	Experience and judgement slightly favor one activity over another.
3	Moderate	
4	Moderate plus	Experience and judgement strongly favor one activity over another.
5	Strong	
6	Strong plus	An activity is favored very strongly over another, its dominance is demonstrated in practice.
7	Very strong	
8	Very, very strong	The evidence favoring one activity over another is of the highest possible affirmation.
9	Extreme	
Reciprocals of the above: if activity (i) has one of the above nonzero numbers assigned to it when compared with activity (j), then (j) has the reciprocal value when compared with (i).		

Rational: ratios arising from the scale if consistency were to be forced by obtaining (n) numerical values to span the matrix.

This explains the reason for using nine-levels ranking scale in the last section of the survey structure. The last section of the survey includes a single question regarding the definition of key BIM barriers (as a main goal), the high-level representatives from different local AE companies are asked to rank a list of 18 barriers based on their significancy/importance in inhibiting BIM implementation according to their practical experience and knowledge, the used rank scale is identical to the AHP's fundamental scale, so that the responses will be applicable for later analysis procedures according to the AHP.

By receiving the responses for the survey, including the rankings based on the introduced fundamental scale. There are several steps to be conducted in order to derive the weights of the included barriers and define priorities based on the respondents' answers, the steps and their related formulas are explained in detail at the following content (please be advised that the following steps and their formulas refer to Thomas L. Saaty in his book "Models, Methods, Concepts & Applications of the Analytic Hierarchy Process" [93] and research paper "How to make a decision: The Analytic Hierarchy Process" [94]).

Step 1: Pairwise Comparison Matrix (PCM), PCM is the first essential step in the AHP after obtaining the ranked responses. In order to construct the pairwise matrix (A) where each element a_{ij} represents the relative importance of alternative i compared to alternative j. E.g., if $a_{ij} = 5$, it means that alternative i is 5 times more important than alternative j. On the other hand, since the matrix is reciprocal, then $a_{ji} = \frac{1}{a_{ij}}$, and all diagonal values are 1 (e.g., $a_{ii} = 1$), please see the following PCM formula, where A is the matrix of the size $n \times n$, when n is the number of alternatives:

Equation 5: PCM formula

$$A = \begin{pmatrix} 1 & a_{12} & a_{13} & \cdots & a_{1n} \\ 1/a_{12} & 1 & a_{23} & \cdots & a_{2n} \\ 1/a_{13} & 1/a_{23} & 1 & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & \cdots & 1 \end{pmatrix}$$

Step 2: Eigenvector Method to Compute Weights, the AHP uses the principal eigenvector of the pairwise comparison matrix A to calculate the alternatives. First, by finding the eigenvalues and eigenvectors of the matrix A. Second, by normalizing the principal eigenvector. In the first step, the equation to find the eigenvalues and eigenvectors for matrix A is:

Equation 6: the eigenvectors and eigenvalues equation for matrix A

$$A.w = \lambda.w$$

Where w is the eigenvector, and λ is the corresponding eigenvalue. On the other hand, the second step intends to derive the relative weights of the alternatives, which are presented by the so-called principal eigenvector, which is the eigenvector that corresponds to the largest eigenvalue

λ_{max}. Normalizing this eigenvector so that the sum of the elements equals 1, this assists to give the final weight vector W.

The following three formulas will provide a more detailed breakdown of the calculation procedure to calculate the weight vector W, assuming the establishment of the pairwise matrix A including certain number of columns and rows based on the studied alternatives: a) sum the columns of the pairwise comparison matrix A (in Equation 7 column sums are denoted with sum_j), b) normalize the pairwise comparison matrix A through dividing each element by the sum of its column then an important step is required to ensure that the elements of each column sum to 1 (please see Equation 8), and c) compute the row averages of the normalized matrix (Equation 9) to derive the weight or the so-called relative weight w_i of each alternative, which combined together will form the weight vector W, which is described mathematically as $W = (w_1, w_2, \cdots, w_n)$, each alternative from the related A matrix will have its own weight w_i that numerically describes its relevance compared to other alternatives in the related issue.

Equation 7: column sums from the pairwise comparison matrix A

$$sum_j = \sum_{i=1}^{n} a_{ij}$$

Equation 8: normalizing matrix A through the division of each element by the sum of its column

$$a'_{ij} = \frac{a_{ij}}{sum_j}$$

Equation 9: the weight for each alternative from matrix A

$$w_i = \frac{1}{n}\sum_{j=1}^{n} a'_{ij}$$

Step 3: Consistency Check, the last step in the AHP is to check the consistency of the results, to ensure that the pairwise comparisons are consistent. This is done by calculating the Consistency Ratio (CR), which is the result of dividing the Consistency Index (CI) by the Random Consistency Index (RI), see Equation 11. The RI is a standard value that depends on the size of the pairwise comparison matrix and the associated number of alternatives within the matrix, in this research the number of alternatives (included BIM barriers in the PCM) is 18, and according to that the RI for 18 alternatives will be 1.615 [95]. On the other hand, the CI is calculated by subtracting the number of alternatives (n) from the largest eigenvalue (λ_{max}) of the related PCM, and then dividing the value resulting from that subtraction by the number of alternatives minus one ($n - 1$), please see Equation 10. It is noteworthy that if the CR < 0.1, the consistency is acceptable, and the derived weights can be trusted (the work is statistically significant), if the CR ≥ 0.1, the matrix is considered inconsistent, and the comparisons may need to be reviewed and adjusted (the work is statistically not significant).

Equation 10: consistency index

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

Equation 11: consistency ratio

$$CR = \frac{CI}{RI}$$

But as introduced in the previous subchapter, the survey study has two rounds, which are more or less identical in most of the aspects, with few differences, mainly in the reference region of the surveyed company. The first survey targets high-level representatives from Hungarian local AE SMEs based on different regions across the country. On the other hand, the second targets high-level representatives from Hungarian local potential AE SMEs exclusively based on the ST region. Consequently, the research will perform two AHP analysis, and the results from the intended analysis will be comparable and final conclusions can be drawn.

3.4.1. 1st survey round

This round will represent the rank responses that are collected from the 1st survey round, starting with listing all the alternatives (BIM barriers) that are included in the survey, and the total sum of ranks per alternative. Then, an average for each total sum is calculated and aligned to the related alternative as shown in Table 10.

Table 10: sums and averages of the 1st survey's rankings

	B01	B02	B03	B04	B05	B06	B07	B08	B09
∑	332	333	266	260	340	337	173	168	142
Avg.	7.217	7.239	5.783	5.652	7.391	7.326	3.761	3.652	3.087
	B10	**B11**	**B12**	**B13**	**B14**	**B15**	**B16**	**B17**	**B18**
∑	168	204	202	201	201	147	165	194	156
Avg.	3.652	4.435	4.391	4.37	4.37	3.196	3.587	4.217	3.391

After calculating the sums and averages of each alternative, the next step of the AHP is to conduct pairwise comparison between the alternatives. In this case, there are homogeneous elements among the list of alternatives, meaning that all of the alternatives that the process intends to choose from belong to the same type (BIM barriers). In addition, there is only a single criterion for respondents to rank the alternatives, based on the potential or significance of the BIM barrier, meaning that the more challenging and important is the BIM barrier the higher its priority and the higher its rank on the fundamental scale, and vice versa. Making the upcoming related calculations in connection with the AHP simpler. Starting with the PCM which is approached by listing all ranked alternatives from the survey at the upper and left sides of the matrix, as an attempt to create a pairwise comparison between each possible pair formed by two identical or different alternatives (according to Equation 5), the values in the matrix are derived by performing a mutual division process between the mean values associated with each of the compared alternatives. Please see the following Table 11 for more information regarding the 1st survey round's pairwise comparison matrix.

Table 11: pairwise comparison matrix of the ranked BIM barriers (1st survey round)

	B01	B02	B03	B04	B05	B06	B07	B08	B09
B01	**1**	1	1.25	1.28	0.98	0.98	1.92	1.98	2.34
B02	1	**1**	1.25	1.28	0.98	0.99	1.93	1.98	2.34
B03	0.8	0.8	**1**	1.02	0.78	0.79	1.54	1.58	1.87

B04	0.78	0.78	0.98	**1**	0.76	0.77	1.5	1.55	1.83
B05	1.02	1.02	1.28	1.32	**1**	1.01	1.97	2.02	2.39
B06	1.02	1.01	1.27	1.3	0.99	**1**	1.95	2.01	2.37
B07	0.52	0.52	0.65	0.67	0.51	0.51	**1**	1.03	1.22
B08	0.51	0.51	0.63	0.65	0.5	0.5	0.97	**1**	1.18
B09	0.43	0.43	0.53	0.55	0.42	0.42	0.82	0.85	**1**
B10	0.51	0.51	0.63	0.65	0.5	0.5	0.97	1	1.18
B11	0.61	0.61	0.77	0.79	0.6	0.61	1.18	1.22	1.43
B12	0.61	0.61	0.76	0.78	0.6	0.6	1.16	1.2	1.43
B13	0.61	0.6	0.76	0.78	0.59	0.6	1.16	1.19	1.41
B14	0.61	0.6	0.76	0.78	0.59	0.6	1.16	1.19	1.41
B15	0.44	0.44	0.55	0.56	0.43	0.44	0.85	0.88	1.03
B16	0.5	0.5	0.62	0.64	0.49	0.49	0.95	0.98	1.16
B17	0.58	0.58	0.73	0.75	0.57	0.57	1.12	1.16	1.37
B18	0.47	0.47	0.58	0.6	0.46	0.46	0.9	0.93	1.1
	B10	**B11**	**B12**	**B13**	**B14**	**B15**	**B16**	**B17**	**B18**
B01	1.98	1.63	1.64	1.64	1.64	2.26	2.01	1.71	2.13
B02	1.98	1.63	1.65	1.66	1.66	2.26	2.02	1.72	2.14
B03	1.58	1.3	1.32	1.32	1.32	1.81	1.61	1.37	1.71
B04	1.55	1.27	1.29	1.29	1.29	1.77	1.57	1.34	1.67
B05	2.02	1.67	1.68	1.69	1.69	2.31	2.06	1.75	2.18
B06	2.01	1.65	1.67	1.68	1.68	2.29	2.04	1.74	2.16
B07	1.03	0.85	0.86	0.86	0.86	1.18	1.05	0.89	1.11
B08	1	0.82	0.83	0.84	0.84	1.14	1.02	0.86	1.08
B09	0.85	0.7	0.7	0.71	0.71	0.97	0.86	0.73	0.91
B10	**1**	0.82	0.83	0.84	0.84	1.14	1.02	0.86	1.08
B11	1.22	**1**	1.01	1.02	1.02	1.39	1.24	1.05	1.31
B12	1.2	0.99	**1**	1	1	1.37	1.22	1.04	1.29
B13	1.19	0.98	1	**1**	1	1.37	1.22	1.04	1.29
B14	1.19	0.98	1	1	**1**	1.37	1.22	1.04	1.29
B15	0.88	0.72	0.73	0.73	0.73	**1**	0.89	0.76	0.94
B16	0.98	0.81	0.82	0.82	0.82	1.12	**1**	0.85	1.06
B17	1.16	0.95	0.96	0.96	0.96	1.32	1.18	**1**	1.24
B18	0.93	0.76	0.78	0.78	0.78	1.06	0.94	0.81	**1**

The base of the AHP is established by completing the PCM according to the mutual division process of the previously calculated mean values of each ranked alternative. The pairwise matrix provides a comprehensive representation of the relative importance of each of the BIM barriers based on the respondents' ranks. Hence, the next step is to calculate the relative weights of each alternative to derive key BIM barriers from the list. There are different ways to calculate the relative weights and derive the vector of priorities from the matrix [93], this research is going to follow the previously introduced Equation 7, 8, and 9 to derive the weight w_i of each alternative. Please see the following Table 12 that represents the sum of each alternative column sum_j from the established PCM.

Table 12: sum of each alternative column from the established PCM (1st survey round)

	B01	**B02**	**B03**	**B04**	**B05**	**B06**	**B07**	**B08**	**B09**

sum_j	12.02	11.99	15	15.4	11.75	11.84	23.05	23.75	28.06
	B10	**B11**	**B12**	**B13**	**B14**	**B15**	**B16**	**B17**	**B18**
sum_j	23.75	19.53	19.77	19.84	19.84	27.13	24.17	20.56	25.59

After defining sum_j for each column, then the research normalizes the PCM by creating a new matrix with the same size and same alternatives. The elements' values (a'_{ij}) of the normalized matrix will be the results of dividing each element from the matrix with the associated sum_j for its column, please refer to Equation 8 for more details. After deriving the normalized PCM, the following step is to derive the weight of each alternative by averaging the associated alternative row from the normalized PCM. Lastly, a consistency check is performed to validate and ensure the results of the established PCM and derived weights, by calculating the CI and CR according to Equation 10 and 11. Before calculating the CI and CR, the research will calculate the eigenvalues λ for each alternative and derive the largest eigenvalue λ_{max}, a multiplying process is performed between all elements in one row at the non-normalized PCM with the relative weight w_i of the same alternative, and then by adding up all the results from the multiplying processes in one row together, the result will be one value that represents the eigenvalue λ for the related row's alternative. By repeating the process for all rows, the result will be 18 λ values for each alternative, the average of these 18 λ values will represent λ_{max}. Please see the following Table 13 for more details.

Table 13: calculating λ values for each alternative, and deriving λ_{max}, and checking the consistency of the established PCM (1st survey round)

	w_i	λ	RI
B01	0.083181	18.01627	0
B02	0.083464	18.07735	0
B03	0.06661	17.87224	0.58
B04	0.065094	18.00323	0.9
B05	0.085204	18.02	1.12
B06	0.084521	18.08845	1.24
B07	0.043381	18.13651	1.32
B08	0.042178	18.05286	1.41
B09	0.035662	17.80806	1.45
B10	0.042178	18.05286	1.49
B11	0.051203	18.04824	1.51
B12	0.050615	17.84137	1.48
B13	0.050406	18.1232	1.56
B14	0.050406	18.1232	1.57
B15	0.036808	17.88351	1.59
B16	0.041411	18.15707	1.605
B17	0.048572	17.82	1.61
B18	0.039107	18.02641	**1.615**

λ_{max}
$\lambda_{max} = \bar{x}\lambda = \bar{x}\sum A.w_i$
By averaging all λ values
λ_{max} = 18.00838

Consistency Index CI
$CI = \frac{\lambda_{max} - n}{n - 1}$
CI=0.0005 which is < 0.1
Consistency index is significant

Consistency Ratio CR
$CR = \frac{CI}{RI}$
CR=0.00031 which is < 0.1
Consistency ratio is significant

3.4.2. 2nd survey round

This section will represent the rank responses that are collected from the 2nd survey round, starting with listing all the alternatives (BIM barriers) that are included in the survey, and the total sum of ranks per alternative. Then, an average for each total sum is calculated and aligned to the related alternative as shown in Table 14.

Table 14: sums and averages of the 2nd survey's rankings

	B01	B02	B03	B04	B05	B06	B07	B08	B09
∑	293	308	283	308	328	303	156	174	173
Avg.	6.37	6.696	6.152	6.696	7.13	6.587	3.391	3.783	3.761
	B10	**B11**	**B12**	**B13**	**B14**	**B15**	**B16**	**B17**	**B18**
∑	173	209	176	217	183	152	193	173	146
Avg.	3.761	4.544	3.826	4.717	3.978	3.304	4.196	3.761	3.174

After calculating the sums and averages of each alternative, the next step of the AHP is to conduct pairwise comparison between the alternatives. In this case, there are homogeneous elements among the list of alternatives, meaning that all alternatives belong to the same type (BIM barriers). In addition, there is a single criterion for respondents to rank the alternatives, based on the potential or significance of the BIM barrier, meaning that the more challenging and important is the BIM barrier the higher its priority and the higher its rank on the fundamental scale, and vice versa. This makes the upcoming related calculations in connection with the AHP simpler. Starting with the PCM which is approached by listing all ranked alternatives from the survey at the upper and left sides of the matrix, as an attempt to create a pairwise comparison between each possible pair formed by two identical or different alternatives (according to Equation 5), the values in the matrix are derived by performing a mutual division process between the mean values associated with each of the compared alternatives. Please see the following Table 15 for more information regarding the 1st survey round's pairwise comparison matrix.

Table 15: pairwise comparison matrix of the ranked BIM barriers (2nd survey round)

	B01	B02	B03	B04	B05	B06	B07	B08	B09
B01	1.00	0.95	1.04	0.95	0.89	0.97	1.88	1.68	1.69
B02	1.05	1.00	1.09	1.00	0.94	1.02	1.98	1.77	1.78
B03	0.97	0.92	1.00	0.92	0.86	0.93	1.81	1.63	1.64
B04	1.05	1.00	1.09	1.00	0.94	1.02	1.98	1.77	1.78
B05	1.12	1.06	1.16	1.06	1.00	1.08	2.10	1.88	1.90
B06	1.03	0.98	1.07	0.98	0.92	1.00	1.94	1.74	1.75
B07	0.53	0.51	0.55	0.51	0.48	0.51	1.00	0.90	0.90
B08	0.59	0.56	0.61	0.56	0.53	0.57	1.12	1.00	1.01
B09	0.59	0.56	0.61	0.56	0.53	0.57	1.11	0.99	1.00
B10	0.59	0.56	0.61	0.56	0.53	0.57	1.11	0.99	1.00
B11	0.71	0.68	0.74	0.68	0.64	0.69	1.34	1.20	1.21
B12	0.60	0.57	0.62	0.57	0.54	0.58	1.13	1.01	1.02
B13	0.74	0.70	0.77	0.70	0.66	0.72	1.39	1.25	1.25
B14	0.62	0.59	0.65	0.59	0.56	0.60	1.17	1.05	1.06
B15	0.52	0.49	0.54	0.49	0.46	0.50	0.97	0.87	0.88
B16	0.66	0.63	0.68	0.63	0.59	0.64	1.24	1.11	1.12
B17	0.59	0.56	0.61	0.56	0.53	0.57	1.11	0.99	1.00
B18	0.50	0.47	0.52	0.47	0.45	0.48	0.94	0.84	0.84
	B10	**B11**	**B12**	**B13**	**B14**	**B15**	**B16**	**B17**	**B18**
B01	1.69	1.40	1.67	1.35	1.60	1.93	1.52	1.69	2.01

B02	1.78	1.47	1.75	1.42	1.68	2.03	1.60	1.78	2.11
B03	1.64	1.35	1.61	1.30	1.55	1.86	1.47	1.64	1.94
B04	1.78	1.47	1.75	1.42	1.68	2.03	1.60	1.78	2.11
B05	1.90	1.57	1.86	1.51	1.79	2.16	1.70	1.90	2.25
B06	1.75	1.45	1.72	1.40	1.66	1.99	1.57	1.75	2.08
B07	0.90	0.75	0.89	0.72	0.85	1.03	0.81	0.90	1.07
B08	1.01	0.83	0.99	0.80	0.95	1.14	0.90	1.01	1.19
B09	1.00	0.83	0.98	0.80	0.95	1.14	0.90	1.00	1.18
B10	1.00	0.83	0.98	0.80	0.95	1.14	0.90	1.00	1.18
B11	1.21	1.00	1.19	0.96	1.14	1.38	1.08	1.21	1.43
B12	1.02	0.84	1.00	0.81	0.96	1.16	0.91	1.02	1.21
B13	1.25	1.04	1.23	1.00	1.19	1.43	1.12	1.25	1.49
B14	1.06	0.88	1.04	0.84	1.00	1.20	0.95	1.06	1.25
B15	0.88	0.73	0.86	0.70	0.83	1.00	0.79	0.88	1.04
B16	1.12	0.92	1.10	0.89	1.05	1.27	1.00	1.12	1.32
B17	1.00	0.83	0.98	0.80	0.95	1.14	0.90	1.00	1.18
B18	0.84	0.70	0.83	0.67	0.80	0.96	0.76	0.84	1.00

The base of the AHP is established by completing the PCM according to the mutual division process of the previously calculated mean values of each ranked alternative. The pairwise matrix provides a comprehensive representation of the relative importance of each of the BIM barriers based on the respondents' ranks. Hence, the next step is to calculate the relative weights of each alternative to derive key BIM barriers from the list. Similar to the calculation that are conducted in the 1st survey round, this section will apply Equation 7, 8, and 9 to derive the weight w_i of each alternative. Please see the following Table 16 that represents the sum of each alternative column sum_j from the established PCM.

Table 16: sum of each alternative column from the established PCM (2nd survey round)

	B01	**B02**	**B03**	**B04**	**B05**	**B06**	**B07**	**B08**	**B09**
sum_j	13.46	12.79	13.96	12.79	12.05	13.02	25.32	22.67	22.83
	B10	**B11**	**B12**	**B13**	**B14**	**B15**	**B16**	**B17**	**B18**
sum_j	22.83	18.89	22.43	18.19	21.58	25.99	20.48	22.83	27.04

After defining sum_j for each column, then the research normalizes the PCM by creating a new matrix with the same size and same alternatives. The elements' values (a'_{ij}) of the normalized matrix will be the results of dividing each element from the matrix with the associated sum_j for its column, please refer to Equation 8 for more details. After deriving the normalized PCM, the following step is to derive the weight of each alternative by averaging the associated alternative row from the normalized PCM. Lastly, a consistency check is performed to validate and ensure the results of the established PCM and derived weights, by calculating the CI and CR according to Equation 10 and 11. Before calculating the CI and CR, the research will calculate the eigenvalues λ for each alternative and derive the largest eigenvalue λ_{max}, a multiplying process is performed between all elements in one row at the non-normalized PCM with the relative weight w_i of the same alternative, and then by adding up all the results from the multiplying processes in one row, the result will be one value that represents the eigenvalue λ for the related row's alternative. By repeating the process for all rows, the result will be 18 λ values for each alternative, the average of these 18 λ values will represent λ_{max}. Please see the following Table 17 for more details.

Table 17: calculating λ values for each alternative, deriving λ_{max}, and checking the consistency of the established PCM (2nd survey round)

	w_i	λ	RI
B01	0.074215	16.05578	0
B02	0.078056	16.88578	0
B03	0.071715	19.21896	0.58
B04	0.078056	21.56185	0.9
B05	0.083048	17.54282	1.12
B06	0.076688	16.39238	1.24
B07	0.039561	16.51744	1.32
B08	0.04399	18.8069	1.41
B09	0.043825	21.8575	1.45
B10	0.043825	18.735	1.49
B11	0.052965	18.64706	1.51
B12	0.044588	15.69863	1.48
B13	0.054932	19.7284	1.56
B14	0.046306	16.6276	1.57
B15	0.03846	18.66243	1.59
B16	0.048963	21.44293	1.605
B17	0.043825	16.05857	1.61
B18	0.036981	17.02718	**1.615**

λ_{max}
$\lambda_{max} = \bar{x}\lambda = \bar{x}\sum A.w_i$
By averaging all λ values
λ_{max} = 18.19262

Consistency Index CI
$CI = \frac{\lambda_{max} - n}{n-1}$
CI=0.01133 which is < 0.1
Consistency index is significant

Consistency Ratio CR
$CR = \frac{CI}{RI}$
CR=0.007016 which is < 0.1
Consistency ratio is significant

3.5. Deriving key barriers overcoming mission

The last step in this chapter includes summarizing the results from the two conducted survey rounds in a BIM implementation mission form, to be continued with in the next chapter. The mission is going to be formulated based on the defined key barriers against BIM implementation according to local AE SMEs. The mission's main objective will be to assist in overcoming key barriers with high relevant weights to facilitate BIM adoption for AE SMEs, by defining the scope of development work for the upcoming research steps in connection with the identified key barriers, meaning that the research will have consistent workflow to further develop and investigate in potential fields and relevant challenges facing AE firms and their professionals in the adoption journey of BIM workflows.

The following Table 18 summarizes the outcomes of the chapter in connection with the definition of key BIM barriers, by pinpointing the key barriers which account for the highest relative weights among other federated BIM barriers; key BIM barriers are barriers with significantly high relative weights (≥ 0.075) compared to other barriers in the list, including B01, B02, B03, B04, B05, and B06, representing "lack of BIM adoption definition methods/workflows", "lack of BIM Uses definitions and objectives", "lack of BIM-based project parties' collaboration", "undefined security, legal liability, and responsibility", "management/contractual BIM processes (e.g., BEP)", and "undefined related business standards for BIM adoption", respectively. The shown results are based on two survey rounds that included responses from high-level professionals representing local Hungarian AE firms. There is a large gap between the relative weights of key

BIM barriers and other barriers within the list (shown with color-based highlight in Table 18), and this turns the light on the high relative importance of BIM processes/uses and legal/management aspects for any firm that intends to carry out BIM-based appointments, the reason for that may refer to the fact that these are basic and initial steps to understand at the beginning of any BIM-based project, and since all participants are considered high-level employees in their organizations, then this can explain the reason behind the scored weights for the defined key BIM barriers. In addition, the results provide an insight into the way with which high-level employees try to approach BIM-based workflows, and the level of consistency between their thoughts regarding that approach.

Table 18 demonstrates the three defined group levels as a result from the previously conducted gathering and analyzing processes, the group levels include primary, secondary, and tertiary groups aligned with their sum weights ($\sum w_i$) for the primary and secondary groups, and weights (w_i) for the tertiary group. In the last column the table suggests a weight-based evaluation for key BIM barriers by demonstrating the large gap in relative weights between the defined key barriers (dark grey) and rest of the barriers (light grey and white). The results of the two survey rounds conclude the high potential the primary level's 1st group (processes & standards) BIM barriers according to surveyed local AE SMEs, including the two groups from the secondary level (processes/uses and legal/management).

Table 18: weights comparison between the 1st and 2nd survey rounds

Pri.	$\sum w_{i1}$	$\sum w_{i2}$	Sec.	$\sum w_{i1}$	$\sum w_{i2}$	Ter.	w_{i1}	w_{i2}	Ev.
1st	0.4681	0.462	**1**	0.2333	0.2241	**B01**	0.0832	0.0742	7x – 8x
						B02	0.0835	0.0781	8x
						B03	0.0666	0.0718	7x
			2	0.2348	0.2379	**B04**	0.0651	0.0781	7x – 8x
						B05	0.0852	0.0831	8x – 9x
						B06	0.0845	0.0767	8x
2nd	0.1635	0.1712	**3**	0.0856	0.0834	**B07**	0.0434	0.0394	4x
						B08	0.0422	0.044	4x
			4	0.0779	0.0878	**B09**	0.0357	0.0439	4x
						B10	0.0422	0.0439	4x
3rd	0.1018	0.0976	**5**	0.1018	0.0976	**B11**	0.0512	0.053	5x
						B12	0.0506	0.0446	4x – 5x
4th	0.1376	0.1401	**6**	0.1008	0.1014	**B13**	0.0504	0.055	5x – 6x
						B14	0.0504	0.0464	5x
			7	0.0368	0.0378	**B15**	0.0368	0.0387	4x
5th	0.1291	0.1293	**8**	0.1291	0.1293	**B16**	0.0414	0.049	4x – 5x
						B17	0.0486	0.0439	4x – 5x
						B18	0.0391	0.0364	4x

Other BIM barriers scored intermediate or slightly upper intermediate relative weights (0.050-0.075); these barriers are highlighted with light grey in the evaluation column at Table 18 including B11, B12, B13, B14, B16, and B17, representing "industry resistance and difficulty to change processes", "client's resistance and lack of market demand", "lack of BIM knowledge, awareness, and research", "lack of BIM experience, experts, and trainings", "lack of mandate regulations and policy support", and "lack of time for full BIM adoption and skill developing", respectively. This group of BIM barriers may be suggested as second-class priority barriers that can be the base for future development research work after overcoming the first-class priority barriers that have been described as key BIM barriers. Finally, the third-class priority barriers scored for the lowest relative weights values among the listed federated barriers (0.025-0.050) with mostly slightly lower intermediate values including B07, B08, B09, B10, B15, and B18, representing "cost of BIM tools (e.g., software, hardware, etc.)", "cost of expertise and training support", "risk of return on investment and financial profits", "unclarity of financial benefits and economic risks", "lack of IT infrastructure (software, hardware, etc.)", and "lack of proof for efficiency, and potential of BIM", respectively.

Hence, The color-based evaluation suggests three different priority classes for dealing with BIM barriers, the first and significantly highest priority class refers to the dark grey highlighted BIM barriers (or the so-called key BIM barriers), that are going to be the base for the intended BIM implementation mission. Followed with the light grey second priority class, that includes barriers with intermediate or slightly upper intermediate relative weights. Lastly, the white-colored third priority class includes the barriers with lower and slightly lower intermediate relevant weights. The second and third priority classes are highly recommended to be further studied and analyzed to investigate any possibilities to develop BIM implementation strategies and methods that assist in overcoming the included barriers in these classes.

In this research, the overcoming BIM implementation mission will be based on the first-class priority group of key BIM barriers representing the 1st group from the primary level (processes/standards) with its six BIM barriers from the tertiary level. The research will derive a bullet point from each key barrier to be included in the overcoming mission, the bullet points will be then joined to form an overcoming mission that will be the base for the upcoming research work. It is noteworthy that all of the six defined key BIM barriers belong to the same group on the primary level, and then they are classified into two groups on the secondary level, and finally they are classified to six groups on the tertiary level, meaning that all of them have a common theme which may assist in joining them to form one mission.

- Despite the generality of B01 which stands for "lack of BIM adoption definition methods/workflows", the core of the barrier stands for a method or BIM method that can assist the implementation of BIM processes, regardless the nature of this method or approach.
- B02 stands for one of the fundamentals for workflows in BIM projects (BU), and the lack/difficulty to define this fundamental. BUs are the backbone for every BIM project, and without accurate definition for needed BUs, the success of the project is under risk. B02 that states "lack of BIM Uses definitions and objectives" is an essential step to be taken by high-level employees in the organization that intends to carry-out BIM-based project. Hence, the ability to define BUs is crucial for all AE firms that intend to carry out BIM-based projects.
- B03 stands for "lack of BIM-based project parties' collaboration", the collaboration between different parties is based on a clear agreement between participating parties at the beginning of the project. The absence of this agreement or any of its fundamentals will cause conflicts of interest and issues between the parties.
- In B04 "undefined security, legal liability, and responsibility" the fear of liability and undefined responsibilities and their workflows are the base for this barrier. It is essential to define the roles for each player and understand the parties' hierarchy structure in BIM-based projects. But the absence of knowledge and experience in BIM-based agreements may result in highlighting this barrier. Hence, clear legal pre-agreement between all project

parties assists in answering all questions related to what, how, who and when, will significantly help to overcome this barrier.

- B05 stands for the previously mentioned agreement, which is a contract-like document that represents an agreement between all parties for certain BIM-based project, then this agreement answers any question from any project party regarding the details of the workflow, collaboration, responsibilities, etc. This agreement is called BIM Execution Plan (BEP), and it is developed in every BIM-based project as a reference for all parties participating in the project. This barrier has a strong management theme, and it is the responsibility of the management team in any organization that intends to carry out BIM-based project.
- B06 stands for the undefined business standards for BIM adoption, business standards are considered the source for every BEP document's element. At the beginning of the BIM industry, lack of industry standards has been an issue for a while. But by the time the fist specialized international standard for BIM processes was published, the issue for lack of BIM standards started to vanish. But the existence of business standards does not mean necessarily that it is clear for entry-level initiatives to understand, navigate through, and adopt them immediately. Standards are high-level documents that describe the best business processes for the industry. Hence, the need to define potential points for companies that intend to carry out BIM-based projects is crucial to have successful practice experience.

To sum up, the mission should briefly describe the key BIM barriers based on the previous explanation for each one, in a way that it can introduce a solution or tool to overcome the reference barriers. The mission must include the following potential points: method/BIM method, BUs definition, BEP development or BIM-based projects execution (including coordination and responsibilities), and business standards. Consequently, this chapter suggests the following mission to be the starting point for the upcoming research work: "Developing a BIM Uses Definition Method Aligned with Business Standards to Facilitate BEP Development and BIM-projects Execution by the Management Team".

4. Introduce BUs definition method aligned with standards to facilitate BIM-based projects execution by the management team

This chapter of the dissertation is developed based on the derived results that are concluded from the previous research studies. After deriving the relative weight of the federated BIM barriers and identifying first-class priority barriers (six key BIM adoption barriers) for local AE SMEs including the potential AE SMEs that are based in the ST region. The research defined an implementation mission as an attempt to positively assist in BIM adoption at local AE SMEs, and overcome the defined key barriers, mainly for those firms that struggle to initiate their BIM-based appointments due to processes, uses, legal, and management barriers demonstrated by the lack of managerial procedures to translate Information Requirements (IRs) into applicable BUs based on practice guidelines. In addition to that, there is a shortage of awareness regarding business standards and their significancy in shaping nowadays BIM-based appointments and business processes.

4.1. Research drivers and mission

The motive to initiate and conduct this research in connection with BUs definition method for BIM-based projects execution and BEP development purposes with respect to the industry standards can be highlighted in two points: major and secondary motives. The major motive leans on neat scientific results and values derived from formerly conducted research to study BIM implementation and its barriers for local AE SMEs (explained in detail at chapter 3). In addition, this motive is highly influenced by the concluded mission, which aims to develop a BUs definition method aligned with business standards to facilitate BIM-based projects execution by the management team. Hence, the following study aims to introduce a method that fulfills all mission aspects, to accomplish practical and reachable solution for local AE firms seeking digitization, by overcoming their most effective challenges against BIM adoption in their daily work.

Furthermore, the secondary motive leans on scientific and practice observations collected during the duration of studying and practicing BIM workflows in the last 5 years. Practical observations for BIM appointments and their management aspects show that there is an absence in unified BUs definition method, meanwhile, literature and academic observations provide definitions and describtions for general and single-standing BUs, thorough descriptions, anlysis, and combination of BUs (including systematic BUs definition methods for BIM-based projects) are rare in the academia. Moreover, a direct link between specific BUs definition and real practice processes (e.g., linking BUs definition with practice standards) can not be found at previous research studies. The secondary motive includes the following drivers:

- Lack of common BUs definition among different parties in the same project team: this issue is observed in different BIM projects from practice, at the beginning of each BIM project the management team usually takes the responsibility to define necessary BUs for the project based on the employer's requirements and the project's scope. It is noticed that at this stage there is no clear method that is followed at each project to systematically pinpoint needed BUs. In addition, it is obvious that there is inconsistency in BUs definitions and scopes among the management teams of different parties, which is caused by the lack of common and clear BUs definition method. E.g., coordination BU can be described by different parties as: BIM audit, clash detection, 3D coordination, Mechanical, Electrical Plumbing, and Fire protection (MEPF) interference, and Virtual Design and Construction (VDC) correlation, these different descriptions may refer to the same BU (coordination), but different parties may have different meanings and expectations for the same BU (e.g., the BU BIM audit at party A represents clash detection, clash report, 3D coordination, and design validation, meanwhile for party B the same BU represents clash detection and clash report). Hence, there is a need to develop a systematic BUs definition method that can be used at the initial stage of any BIM-based project procurement to pinpoint needed BUs and include them in the later developed contractual document (BEP) to set the definitions and highlight the project requirements and expected deliverables.
- Most of the listed BUs in the academia are stand-alone and general BUs: this observation is derived from literature observations through the collective study duration and compared with professional experience derived from practice duration in the field of BIM. It is obvious that BUs definitions in academic sources are general descriptions for general informative matter, meanwhile in practice, the descriptions of certain BUs that must be applied at a BIM project to meet the required information should be specified and clarified with details, to avoid misunderstanding and misassumption. On the other hand, the academic sources tend to list BUs in a solo manner, which can be interpreted by providing easier material for the reader, but at the same time, this single-narrative way of listing BUs may mislead the reader in understanding the way how BIM project is approached. Since specific BUs in practice are approached through a series of pre-BUs that work together to reach the target BU and the intended information. For instance, and to clarify the contrast between the academia and practice regarding listing BUs, and by taking the following BU "documentation" as an example, in the academic manner this BU will be listed as "documentation", meanwhile in practice the same BU will be specified as "documentation

of interior architectural wall frames/finishes". Although, the academic manner generally lists the BU as "documentation", it lacks also the clarification regarding how this BU can be approached, meanwhile in practice the same BU is approached by series of prior BUs that work together to accomplish the intended purpose (documentation), e.g., capture existing conditions, author design, coordinate design, review design, annotation, and lastly documentation.

4.2. Method framework and components

The introduced method framework consists of two main components: the academic and practical components, representing two main sources (according to collective knowledge and experience) for any professional firm which intends to carry out BIM-based projects and appointments. The method's components are derived from a larger scheme framework that intends to cover all aspects of the major and secondary motives including the mission and drivers.

4.2.1. Academia

The first component of the introduced method is derived from the academic sources, by studying and reviewing related literature in connection with BIM, BUs, BIM management, BIM standards, and BIM applications. The research approaches literature from two main sources: particular and comprehensive. This research step intends to collect an overview regarding the fundamentals of BIM and BIM workflows and look for threads to define BUs and understand practical BIM applications from the academic point of view. The scope of this component is going to focus on BUs and their classifications and definition methods. Hence, the objectives of this component are searching and collecting listed BUs in the academic sources, understanding and comparing BUs classification criteria, and introducing BUs definition roadmap.

It is expected that this component will cover the BUs definition aspect from the previously defined mission. Thus, a crucial part of the task is expected to be accomplished by the end of this academic component study. On the other hand, the other parts of the task will refer to the second practice component that is going to focus more on the other aspects of the mission.

4.2.1.1. Comprehensive sources of information

As the name suggests for comprehensive academic sources, thorough and general academic sources in the field of BIM, BUs, and BIM applications are reviewed, all comprehensive sources are included such as textbooks, book sections, booklets, national/international guides, guidebooks, handbooks, etc. The review includes 25 different comprehensive sources regarding BUs and BIM applications, and as expected, the sources provide a rich content of 375 BUs in the AECO industry. The collection of BUs that is derived from comprehensive sources is going to be used for the later introduced BUs definition roadmap. But it is noteworthy that some of the collected comprehensive sources are directly focused on BUs definitions, structures, and classifications. These sources will be called potential sources from which one or more will play a major role in the introduced BUs definition method.

Starting with the BIM Guide Series, authored by the US General Service Administration (GSA), the series consists of several guides to document the learning experiences in a format that would be educational and supportive for GSA project teams and other AECO professionals. The first guide includes rough overview of BIM applications targeting junior BIM and AECO professionals [96], the second guide highlights the BIM rule in supporting the project's Program of Requirements (PORs) [97], the third provides guidelines for the solicitation of BIM and 3D imaging services [98], the fourth evaluates the applications of 4D modeling technologies in built projects

[99], the fifth guide introduces BIM role in maximizing energy efficiency/performance and keeping productivity [100], the sixth guide introduces BIM usage in facilitating design decisions to meet circulation requirements [101], the seventh elucidates BIM utilization in asset management, planning, operations, and maintenance [102], and the eighth highlights BIM technologies to support management and operations of buildings [103]. Other comprehensive sources address the issues/opportunities of BIM applications through the lifecycle of assets [9], focus on understanding BIM technologies with associated organizational issues and advantages of the right BIM usage [1], highlight strategic guides for BIM-based processes implementation during the design, construction, and operation of building projects [104], provide tactical guide for virtual design and construction firms to coordinate building projects by using BIM-based techniques [105], and support methods, workflows, tutorials, and professional advices for BIM applications in construction projects [2].

The collection of comprehensive sources includes references that thoroughly cover the key topics of innovative BIM solutions [106], support practitioners to understand and implement BIM processes for core quantity surveying tasks [107], highlight opportunities/challenges of BIM applications in current and future practices [108], discover BIM applications in facility management by demonstrating solutions for managing built assets [109], discuss the rule of BIM processes in facility management from practical views [110], and highlight strategies for BIM integration to enhance business outcomes for owners/developers [111].

On the other hand, some of the collected comprehensive sources are considered potential sources since they provide specialized thorough content in connection with BUs and their definitions, classifications, and structures, in addition to the extensive collection of listed practical BUs. Hence, any comprehensive resource directly mentions BUs and their ontologies will be nominated as potential source which will form the base for the introduced definition method. Starting with the BU Definition Standard authored by the US National Institute of Building Sciences (NIBS) which defines BUs scopes, objectives, and attributes; by focusing on the most common implemented BUs in the AEC industry and provides a common framework with consistent terminology to communicate the purposes of using BIM for a given project [112]. NIBS introduces the National BIM Guide for Owners (NBGO) that focuses on BIM for owners and investors, by generally defining BUs, and listing essential, enhanced, and owner-related BUs [113]. On the other hand, the most relevant approach for BUs is introduced by Ralph G. Kreider & John I. Messner in their well-known book (The Uses of BIM) that provides a clever systematic classification of BUs based on purpose [114]. Moreover, the relevancy between BUs and BEP related barriers is supported by the existence of potential source that intends to define BUs within the context of BIM execution planning, representing the tight relationship between BUs and BEP development in practice [115]. Other potential sources focus on classifying and selecting BUs [116], meanwhile others define and list BUs based on project task and phase [117].

According to the nominated 6 potential sources out of the total collected 25 comprehensive sources, and after deep review of these references and their approach toward BUs identification and classifications, it is obvious that there are many ways to approach BUs and their structures, each way may rely on different aspects or points of view. In addition, some references may share the same criteria for classifying BUs meanwhile other references may have totally different criteria for the same classification purpose. Hence, the question arises regarding which of the suggested BUs classification criteria (based on the nominated potential sources) is going to form the base for the intended BUs definition method? The answer to this question starts with listing the criteria for

BUs classification provided by each potential source, and then comparing the relevancy of each criterion with the objectives of the intended definition method.

There are three main criteria that are introduced by potential source to approach BUs classifications including objective, potential, and phase. Please see Table 34,35, 36, and 37 at the attachments chapter for detailed illustration regarding the allocation of each criterion and the related potential source. Based on the potential sources, BUs classification criteria can be approached as follows:

- Objective: based on the purpose of applying BIM processes on the built project, this criterion may be the most convenient to form the starting point for the intended BUs definition method. Since this method targets local firms that try to implement BIM processes at their daily workflows and BIM in definition does not intend to change the objective of the AECO task, but it intends to change the way the exact same objective is approached to fulfill the associated AECO task. Hence, the list of BUs based on purpose according to "The Uses of BIM" by Ralph G. Kreider & John I. Messner [114] and the US "National BIM Standard - Version 3" [116] is more relevant compared to the list of BUs based on purpose provided by "BIM Use Definitions Standard" [112], since the first list includes BUs based on consistent terminology for purposes/objectives that can be used in any built project whether it is BIM-based or not, meanwhile the second list includes a general collection of primary BUs based on objectives by focusing on the ones that are widely implemented across the construction industry.
- Potential: based on the relevant importance of the implemented BU at certain built project, this importance-based criterion is introduced by the „National BIM Guide for Owners" [113], "BIM Project Execution Planning Guide - Version 2.2" [115], and "The New Zealand BIM Handbook, Appendix D" [117]. Despite the common agreement regarding potential-based classification of BUs among the previously cited references, there is a question mark in connection with the applicability of the defined potential-based BUs classes on different AECO projects. Although, the author agrees that some of the BUs may be considered more important compared to other BUs in certain BIM projects, but this is not applicable on all BIM projects, since built projects are unique (meaning that what may be major BU at certain built project, could be secondary BU at another one) and various in size/complexity (meaning that a secondary BU in complex project may be considered a major BU at another simpler project). Hence, the author recommends excluding the potential/importance aspect in defining BUs, since it may be misleading for the users who are responsible to define related BUs for BIM-based projects.
- Phase: based on the built project phase, e.g., planning, design, construction, and operation, the main issue with this classification criterion is that some BUs can be used at several phases, and it is not always the case that BUs that belong to the design phase cannot be used at another phase (e.g., operation phase). Hence, the author suggests that a better approach would be the phase classification from point of view of practice. In professional practice, built assets have two main phases: delivery and operational. To avoid misleading and duplication, the intended definition method will stick with the phase identification at the practice section instead of the academic one, since it is more simple, clear, and professional.

4.2.1.2. Particular sources of information

The particular academic sources as the name suggests are specific references in the field of BIM, BUs, and their applications. These sources are more compact and reduced in length compared to the comprehensive sources, although they are generally less in length, but they are more specialized and intense in terms of content quality. The particular sources are going to be based on scientific contributions (journal and conference articles) that are published by SJR distinguished publishers to ensure the quality of the collected material. The research uses Google Scholar to search for the published related contributions, and then searches for the potential of the publisher through the SJR's official website, the collection of contributions that meet the requirements includes a total of 33 publications in connection with different BUs and their applications. Bearing in mind that the majority of the collected publications are specified in particular BUs fields, it is quite rare to find contributions in connection with BUs definitions, classifications, and ontologies. Hence, the particular sources are going to be more beneficial for collecting and listing specific BUs rather than introducing BUs ontologies and classifications.

The initial and most important detail that can be a common factor to connect all of the collected papers to form their initial contribution in the intended methodology is the model type (BIM model dimension), and this reminds the reader with the original simple definition of BIM as the process of using digital model to achieve certain AECO objective, which means that the first and the most common aspect between all different BUs is the fact that all of them are digital model based. Hence, the author suggests using this common factor as an initial definition step in the introduced method by defining the dimension of the digital model that is going to be developed by the project team.

Starting with the basic 3D BIM model that can be developed for spatial planning, quality assurance, design development, assembly support, drawings documentation, off-site support, Heating, Ventilation, and Air Conditioning (HVAC) design, gathering as-built information, defining potential design/construction issues, and supporting collaboration [118], [119], [120], [121], [122], [123], [124], [125], [126], [127]. And by adding the time dimension to the 3D model, a 4D BIM model is developed for time-based design/construction visualization, construction scheduling, time management, workflow time analysis, and construction sequence planning [128], [129], [130], [131], [132], [133].

By adding the cost dimension, a 5D BIM model can be developed to manage construction costs, survey quantities, develop cost-based material schedules, estimate expenses, and deliver cost-efficient projects [134], [135], [136], [137]. On the other hand, 6D BIM models take the operation stage of built assets to another level by facility operations support, managing MEPF systems, spatial/space management, maintenance support, supporting decision making, and managing built assets [138], [139], [140], [141], [142]. Later on, and by stepping forward toward more efficient and sustainable built assets, 7D BIM models are developed to enhance building analysis, support sustainable designs, evaluate environmental impact, design sustainable integrations, optimize design/construction, and increase construction/operation efficiency [143], [144], [145], [146]. Finally, by integrating health and safety dimensions into the delivery and operation stages of built asset, an 8D BIM model is developed to support construction safety, prevent construction accidents, assist safety planning, enhance prevention through design, facilitate project safety coordination, and manage temporary/permanent safety aspects [147], [148], [149], [150].

Despite the significant contribution of the reviewed particular sources regarding the model type/dimension criterion as a common point among all different BUs for any BIM-based project, which can be employed in the intended methodology as a first step to define the BUs for the intended BIM project, the reviewed particular sources also provide a rich collection of total 84 specific and unique BUs that can be added to the previously collected 375 specific BUs from the comprehensive sources, forming a single list of more than 450 specific BUs that can be employed later on at the intended BUs definition method. This will form a rich academic collection (library) for BUs that can be selected by the later intended users for the introduced method.

4.2.1.3. Introducing an academic BUs definition method

The research introduction of BUs definition method based on the academic sources (comprehensive and particular) is presented by three stages consisting of four different levels. Stage I includes Level 1, Stage II includes Level 2 and 3, and Stage III includes Level 4. Based on the material concluded from the previously studied comprehensive and particular sources, the main definition criteria are the digital model dimension/type together with the BU objective/purpose. Please see Figure 13 and the following bullet points for more details regarding the introduced academic BUs definition method.

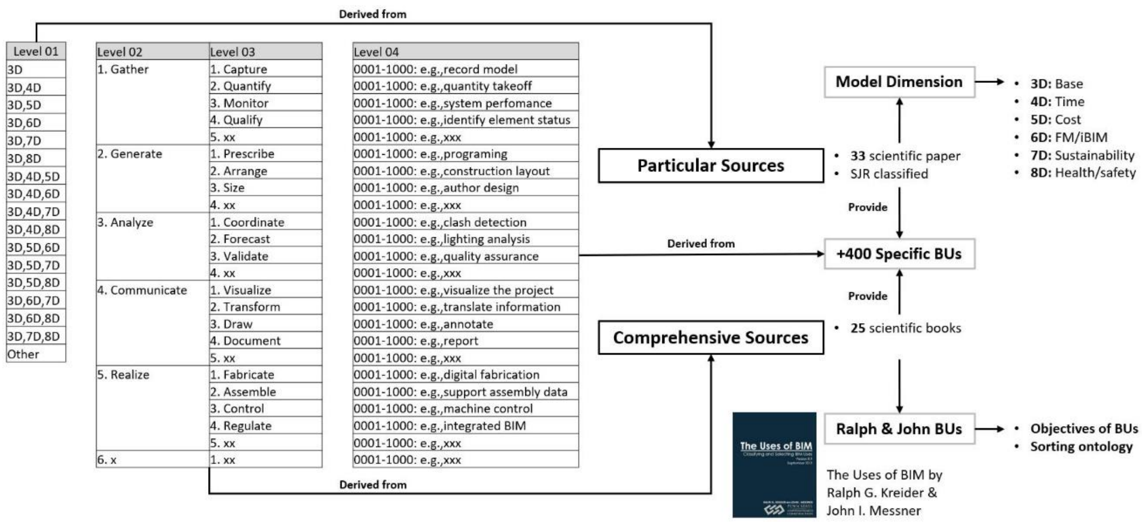


Figure 13: introduced academic BUs definition method

- Stage I: is the first step to define BUs for BIM-based project, starting with defining the needed BIM model type (dimension) based on the requirements of the project. Stage I includes Level 01 which consists of all possible model dimension combinations derived from the original 6 dimensions (3-8D) from the reviewed 33 scientific articles. In this level 3D, 4D, 5D, 6D, 7D, and 8D, refers to base, time, cost, Facility Management (FM), sustainability, and health/safety BIM model, respectively.
- Stage II: is the second step to define BUs for BIM-based project. Stage II includes Level 02 and 03 that represent major and secondary objectives, respectively. In this stage, BUs are going to be defined one by one, for each BU the user starts with defining the major objective of the BU from Level 02 (gather, generate, analyze, communicate, or realize), then one of the associated secondary objectives from Level 03 (capture, quantify, monitor, qualify, prescribe, arrange, size, coordinate, forecast, validate, visualize, transform, draw, document, fabricate, assemble, control, or regulate). Level 02 and 03 include all possible major and secondary objectives for BUs introduced in "The Uses of BIM" by Ralph G. Kreider & John I. Messner.
- Stage III: is the last stage in the academic BUs definition, the stage includes Level 04 that collects a list of various specific BUs per each counterpart secondary objective from Level 03. At Level 04 the user has to define the tertiary objective (final specific objective) of the BU, and the lists include more than 450 suggested specific BUs that have been gathered from comprehensive and particular sources.

4.2.2. Practice

In the building industry practice, and like any other industry, there are standards and regulations that control the process of management, production, delivery, and supply. Standards are usually the formula that describes the best way of doing something, and when things do not work as they should, usually standards are absent. Hence, the research work leans on the international standard series regarding organization and digitization of information about buildings and civil engineering works, including building information modeling, developed by ISO, which is an independent, non-governmental, and international standard development organization composed of experts and representatives from different member countries. ISO's objective is to provide practical solutions for real-world professional problems and issues, by bringing global experts together to agree on the best way of doing practical workflows from 13 different sectors, including health, IT & related technologies, transport, environmental sustainability, management & services, security/safety/risk, food & agriculture, building & construction, energy, engineering, materials, diversity & inclusion, and government.

The ISO 19650 series includes six parts, until now five of these parts are published and only one is under development, the standard series is officially called "organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM): information management using building information modelling", this document will refer to this standard series as ISO 19650. This standard series draws the outlines for the best BIM business processes, and it is considered the constitution for almost every BIM-based project and appointment in the building industry due to the fact that included standards in this series are applicable to all built projects with respect to the size and complexity of the project to ensure proportionate application.

ISO 19650 Part 1 (concepts and principles), published in 2018, the document outlines the principles for information management under the scope of "BIM according to the ISO 19650 series", by providing suggestions for general structure to manage information among different project actors, including exchanging, recording, versioning, and organizing. Since the document provides comprehensive overview and framework, then it is applicable for the whole life cycle of any built project including planning, design, engineering, development, documentation, construction, daily operation, maintenance, refurbishment, repair, and end-of-life. It is noteworthy, that the document is versatile, meaning that it can be adapted to projects of any scale and complexity, meaning that there are no obstacles to hamper the applicability of this document in any BIM-based appointment, with respect for being proportionate in adapting the included business processes based on the project size and nature [151].

ISO 19650 Part 2 (delivery phase of the assets), published in 2018, this part of the series specifies requirements for information management, in a process roadmap form that includes the delivery phase of built assets and the information exchanges within that phase by applying BIM workflows, regardless of the chosen procurement strategy, this part of the ISO 19650 can be used by all types and sizes of building industry organizations [152].

ISO 19650 Part 3 (operational phase of the assets), published in 2020. This document specifies requirements for information management, in a process roadmap form that includes the operational phase of built projects and the information exchanges within that phase by applying BIM workflows. Requirements in this document can be approached by direct actions carried out by the organization in question or delegated to another party. Like the previous part, this part of the series can also be used by all types and sizes of building industry organizations and firms, regardless of the chosen procurement strategy [153].

ISO 19650 Part 4 (information exchange), published 2022, this document aims to ensure the quality of the developed project information model or asset information model, by specifying the detailed procedure and criteria for decision making when executing an information exchange. This part of the series highlights the concepts of ISO 19650-1. The document is applicable for any information exchange in the delivery stage and any operational trigger event in the operational stage, covered by ISO 19650-2 and ISO 19650-3, respectively. The document is adaptable to projects of all sizes and all levels of complexity, including buildings, infrastructure networks, campuses, individual buildings, and pieces of infrastructure, bearing in mind that all requirements listed in the document have to be applied in a proportionate way to the scale and complexity of the project [154].

ISO/DIS 19650 Part 5 (security-minded approach to information management), published in 2020, this document lists the steps required to cultivate a proper and proportionate security culture and mindset across the organizations with access to sensitive information together with the need for monitoring and auditing compliance. The document specifies requirements and principles for security information management as defined in ISO 19650-1, in addition to the security management aspects of sensitive information in connection with related firms, projects, assets, products, or services. The standards outlined in this document are applicable where sensitive information is obtained, authored, processed, and/or stored, and throughout the life cycle of the planned or existing initiative, project, asset, product, or service. The document will be of interest to firms willing to protect their commercial information, personal data, and intellectual property. Moreover, the document is relevant to all building organizations involved in the use of information and technologies in the creation, design, construct, manufacture, operate, manage, modify, improve, demolish, and/or recycle of assets and products within the built environment [155].

ISO 19650 Part 6 (health and safety information), the status of this document is under development, and it is still not published yet, but a draft version is available to provide an introduction and foreword regarding the scope of the document. The heart of this document is going to specify the requirements to identify, record, use, and share information on safety and health and the accompanied risks which may result in harm to any person involved in the delivery or operation of the asset throughout its life cycle. The document intends to support representation of the nature and characteristics of the works being undertaken (site and asset), representation of health and safety risks, hazards, and associated factors, and share/reuse of health and safety experience and knowledge [156].

On the domestic Hungarian level, there is the Hungarian Institute for Standardization (MSZT), which is responsible for publishing and approving standardized business processes for the building industry and other business industries [157]. MSZT is a member body representing Hungary out of the total 172 national standards bodies that form the members of the ISO, MSZT is active member body and has participated in the work of ISO standards development since 1947 [158]. ISO 19650 is approved, published, and advertised by MSZT, meaning that local AECO companies that intend to carry out organization, digitization, and information management processes using BIM are obliged to apply and adopt ISO 19650 series at their workflows to ensure high quality, professional, and standardized outcomes.

The introduced practice BUs definition method is based on the ISO 19650-1/2 since the first part of the series includes thorough insight regarding the concepts, principles, and outlines for the delivery and operational stages of built assets and provides a comprehensive overview to adopt BIM-based processes in real world practice appointments. On the other hand, the second part of the series focuses more on the delivery phase of built assets and the information exchanges within that phase, which is considered the main scope for AE companies, since AE mostly work within the delivery stage (planning, design, and construction) of built assets. The intended practice BUs definition method aims to find key points that connect the academic BUs definition method with the practice one, these key points can be only defined by thorough study and understanding for ISO 19650-1/2. Hence, after the conducted deep review of the first two parts from the ISO 19650 series, the research pinpoints the potential topics that can be key points for connecting the practice processes with the introduced academic BUs definition method. These potential topics are information requirements, project phases, project parties, and information delivery plan. Covering these topics will fulfill the remaining unsolved parts of the BIM implementation mission to overcome key barriers that are related to management/contractual (BEP), party's coordination, liability/responsibility, and business standards.

4.2.2.1. Information requirements

Based on practice, the information requirements for a BIM-based project can be classified into two main groups. The first group includes information requirements from outside of the design and construction phases, this group stands for information requirements regarding the strategic scope and operation of the related built asset, e.g., Organizational Information Requirements (OIRs) and Asset Information Requirements (AIRs). On the other hand, the second group represents information requirements from the design and construction phases, meaning that this group includes project-specific requirements developed by the appointing party to be used exclusively during the whole delivery phase of the intended project, e.g., Project Information Requirements (PIRs) and Exchange Information Requirements (EIRs). Please see Figure 47 at the attachments chapter for more illustration.

The following Figure 14 illustrates the different types of information requirements and the contribution of these requirements to the information deliverables, in the chart the first group of information requirements that stands for information requirements from outside of the design and construction phases is called information requirements of the interested parties, including OIRs (referring to information requirements related to the organizational objectives) and AIRs (referring to information requirements related to the operation of the asset). The second group of information requirements that stands for information requirements from the design and construction phases is called information requirements of the appointment, including PIRs (referring to information requirements related to the delivery of an asset) and EIRs (referring to information requirements related to the appointment, usually derived from OIRs, AIRs, and PIRs combinations in contractual form). Finally, the intended information deliverables out of the previously listed information requirements are the Project Information Model (PIM), (referring to the information model associated with the project's delivery phase), and the Asset Information Model (AIM), (referring to the information model associated with the operational phase of the delivered built asset). Please see Figure 48 in the attachments chapter to illustrate the key point in connection with the information requirements section, by demonstrating the flow direction of information requirements and the potential of project-specific requirements (especially EIRs) in any BIM-based project and the intended definition method.

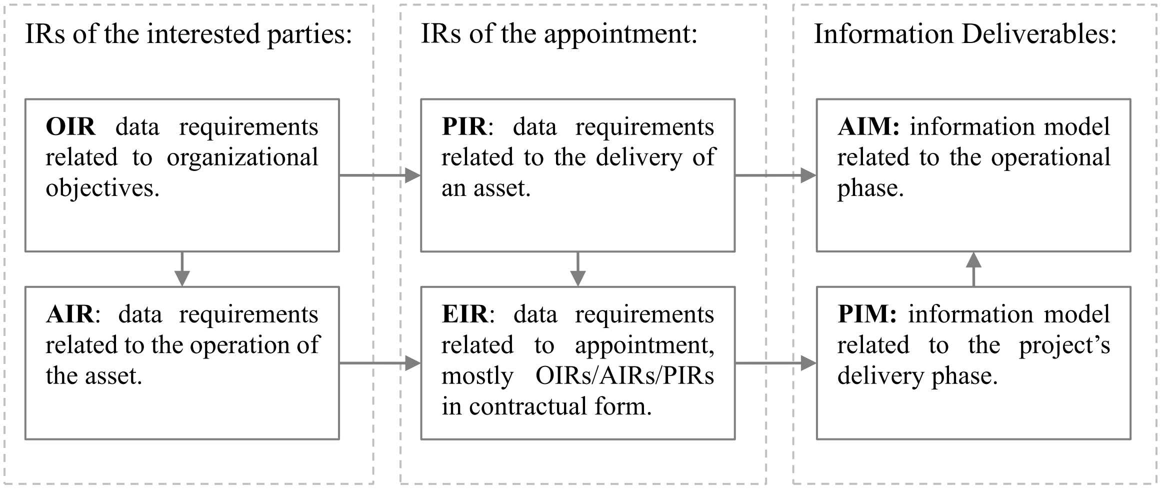


Figure 14: types of information requirements and the expected information deliverables based on ISO 19650-1/2

The critical (and perhaps the most important) information requirement in any BIM-based project is the EIR, since it is derived from a combination of different OIR, AIR, and/or PIR, and defined at early stages of the project. Hence, the research suggests choosing the IRs and particularly the EIRs as a base to the intended practice BUs definition method; by matching the defined BUs from the academic component with the needed/required IRs (EIRs) from the practice component, to reach an identical representation of defined BUs and needed IRs at both the academic and practice components of the introduced method. As a consequence of following this suggestion, the research overcomes the challenge of connecting the academic and practice components in a consistent, simple, and user-friendly way.

Despite the fact that there are two components of EIRs, management/commercial component (including information standards and production methods) and technical component (including the exact specification of information needed to answer the PIRs), in the introduced method the main focus will be on the reference set of the EIR instead of the type or component of the EIR. Generally during the delivery of BIM-based project, there are several appointments to fulfill the information requirements, each appointment includes several EIRs which combined form a single coherent set of EIRs that addresses the related OIRs, AIRs, and PIRs. Hence, a similar configuration of sets may also be assigned to the defined BUs from the academic components, since the base idea of the introduced method relies on matching the defined BUs with their corresponding IRs (EIRs) from the practice component. Since EIRs belong to different sets of EIRs in BIM-based projects according to the ISO 19650 standard, and since the intention of the research is to connect the IRs and specifically the EIRs with the defined BUs combination from the academic component, then the research highly recommend to introduce a method to classify defined BUs combinations into sets, after that the research will link the Set of Exchange Information Requirements (SEIRs) or the Set of Information Requirements (SIRs), with the corresponding defined Set of BIM Uses (SBUs). More details regarding this linking concept will be discussed in detail in the upcoming 4.3 subchapter.

4.2.2.2. Project phases

Unlike the academic sources that usually divide the project life cycle into four main phases (plan, design, construct, and operate), the practice considers two main phases for the project life cycle (delivery and operation). Information deliverables are presented by the delivered information models which can be classified as PIMs and/or AIMs. PIM is the model used during the delivery phase of the asset (during the planning, design, and construction). On the other hand, AIM is the model used for the operation phase of the built asset, bearing in mind that in many cases the AIM is a development of the PIM.

The key point from this section is to define the related project phase for each identified BU and its corresponding IR. The definition of project phase will be based on the practice configuration for project phases (delivery or operation). Although, the focus of the research is AE firms which have a practical scope within the delivery phase of built assets (including planning, design, and construction), some AE firms may carry-out appointments from the operation phase if they have related abilities and capabilities. Hence, the focus of the introduced method will be on delivery phase of built assets, but also without neglecting the operation phase, by giving the choice for the intended user who is going to use the introduced method to select the suitable phase for the defined BU. Please see Figure 49 in the attachments chapter for more illustration regarding project phases, associated information deliverables, and key points.

4.2.2.3. Project parties

Generally, the building industry is powered by multidisciplinary firms from different disciplines and specialties including planning, design, construction, operation, consulting, and manufacturing firms. The collaboration between multidisciplinary firms or multidisciplinary departments within the same firm is essential to deliver built projects. Based on the size and complexity of the project, a certain number of different stakeholders should cooperate to deliver and operate the related asset, and there are many ways to address or describe the teams of those different stakeholders, e.g., planning, design, contractor, surveying, supervision, construction management, facility management, maintenance, and investor teams, in addition to a huge variety of other phrases and expressions that describe teams of interest within the building industry. In BIM-based projects, and regardless of the original affiliation of the participating team (whether it is planning, design, construction, operation, consulting, management, third party, or manufacturing) there are three major parties for which the participating team will refer to, the three main parties including the appointing, lead appointed, and appointed parties, these three parties form the base for the project team hierarchy structure.

The following Figure 15 demonstrates the hierarchical structure for parties of interest in BIM-based project. At the top of the pyramid there is the appointing party who prepares/shares a set of information requirements related to the project. In the middle of the pyramid there is the connecting point between the project appointing and appointed parties, or the so-called lead appointed party who manages and allocates the tasks. The base of the pyramid is occupied by the appointed parties who are responsible for the production of information based on the defined authoring procedures/methods and standards. Exchange of information requirements and information deliverables takes place between each of the appointing and lead appointed parties, the lead appointed and the appointed parties. The flow of information (different requirements, inquiries, assignments, deliverables, and needs) between different project stakeholders should follow the hierarchy structure of the parties of interest, consequently the lead appointed party acts as a central connection point between the appointed and the appointing parties in the supply chain. Planning for information delivery starts with defining the information requirements by the appointing party, the information requirements will be then transferred to the lead appointed party who develops an information delivery plan that answers the submitted IRs by the appointing party, then these requirements will be translated into production map that will be executed by the appointed parties through the production of needed information that fulfill the assigned tasks and requirements. The produced information will be delivered following the same route backwards on the supply chain, starting with the information delivery from the appointed to lead appointed parties, then followed by the information delivery from the lead appointed to appointing parties.

As shown in Figure 15 each official contractual description for any party of interest within the project does have a counterpart reference team within the project, these teams are essential to understand the workflow and the relationship between different project groups and members. The teams' allocation is crucial to ease and simplify the relationship between different individuals from different work groups, especially at large and complex projects where multi-level structures of groups cooperate to deliver the built asset. Please see Table 38 in the attachments chapter for more illustration regarding parties of interest in BIM-based project, and the following bullet points describe the party-team correlation between different project stakeholders:

- Project team: all parties involved in the project including appointing, lead appointed, and appointed parties.
- Delivery team: includes the appointed parties and their lead appointed party which refer together to the same appointing party as one delivery team.
- Task team: includes the appointed parties who refer to the same lead appointed party.

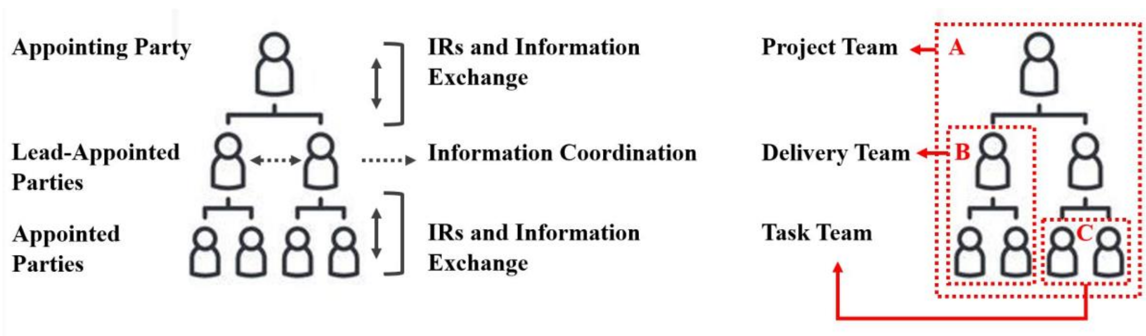


Figure 15: hierarchical structure for parties of interest in BIM-based project

- **Project parties and information exchange process:**

Understanding the structure of the project parties is essential for the information exchange process, without clear structure for project parties combined with allocated clear responsibilities the information exchange process (the process of receiving information requirements and submitting information deliverables) will be chaos. It is noteworthy that in the information exchange process the lead appointed party (presenting all appointed parties) will submit the information deliverables to the appointing party for checking, approving, and finalizing the project. At each information exchange process there is an information check step that includes two main levels, please see Figure 16 for more details regarding the information checking during the information exchange process. The first level (Level I Check) belongs to the lead appointed party including review of delivered information and provision of information deliverables that meet the requirements. On the other hand, the second level (Level II Check) belongs to the appointing party including review of delivered information and provision of information requirements (if any exists). The same two-level information check procedure is followed during the information exchange process between the lead appointed and appointed parties, at which the first level (Level I Check) belongs to the appointed party including review of authored information and provision of information deliverables that meet the requirements. On the other hand, the second level (Level II

Check) belongs to the lead appointed party including review of delivered information and provision of information requirements (if any exists).

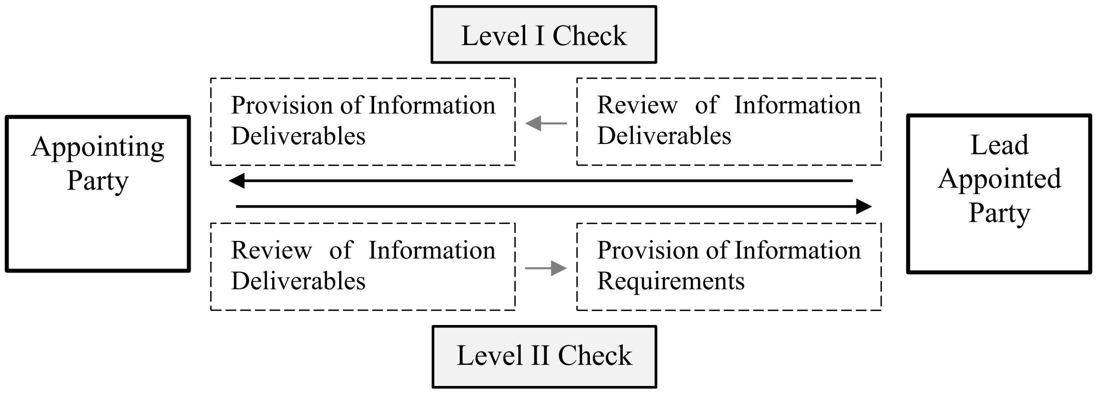


Figure 16: information check levels at the information exchange process

Figure 50 in the attachments chapter provides more detailed insights regarding the information check levels at the information exchange process, the figure breaks down the steps of Level I and II Checks by showing the different states of the delivered information together with the associated responsible check party within the same level. Level I Check starts with information containers in the work in progress state, then the information container goes through transition process of check/review/approve by the responsible Quality Assurance (QA) party within the same delivery team, the result of this transition process may have three different variations (a) information container in the shared state (waiting for approvement from other delivery teams), (b) information container in the shared state or client shared state (approved by all delivery teams and for sharing with the appointing party to be authorized), and (c) information container that has been rejected (modification is required) meaning that this information container will go back to the work in progress state. On the other hand, Level II Check starts with the client shared state information container that goes through transition process of review/authorize by the appointing party, and the result of this transition process may have three different variations: (a) denied information container (it does not meet the agreed IRs, modification is required and it is not ready to be used in other stages of the project), meaning that this information container will go back to the initial work in progress state, (b) published state: authorized information container that meet the IRs (ready to be used in other stages of the project), and (c) archive state: preserved information containers that have been shared and published.

- **Project parties and project information managemnt function:**

In BIM-based projects, the project information management function is assigned to the lead appointed party's project information manager, next to other duties the project information manager is responsible for establising project information standards, defining production methods and procedures, and establishing the project's Common Data Environment (CDE). On the other hand, task information management function is assigned to the appointed party's task information manager, the task information manager is responsible for managing the information requirements on the task team level, and to coordinate the information with other task information managers of other task teams. See the following Figure 17 which illustartes the information management functions and their associated project teams on the hierarchy structure of BIM-based project parties.

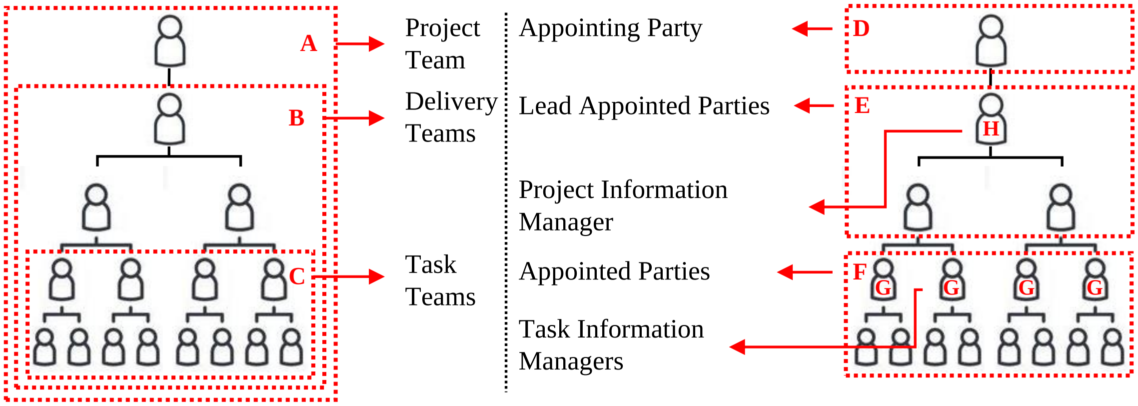


Figure 17: project teams and information management functions

➢ **Project parties and capabilities/capacities:**

Generally, at BIM projects the capabilities and capacities of the assigned delivery teams are reviewed in advance to ensure a smooth supply of information based on the defined requirements. The minimum aspects to be reviewed by the appointing party for the delivery team's capability and capacity include: (a) the commitment to work with the agreed information requirements, (b) the delivery team's ability of collaborative work (information container-based work experience), (c) the delivery team's access and experience on the agreed Information Technology (IT) to be used, and (d) the quantity of equipped and experienced ready to work members within the delivery team.

The capability and capacity of the appointed parties and their lead appointed party can be assessed by checking the following ability factors: professional experience, skills, and knowledge of the delivery team, or by checking the following capacity factors: available members, hardware, and software at the delivery team.

➢ **Project parties and information container-based collaborative workflow:**

Collaborative workflow is crucial in BIM-based projects among different participating parties of interest, this collaboration is based on the so-called Information Container (IC) workflow; this type of workflow allows different task teams to work on different model parts simultaneously, so a BIM-based project usually includes several multi-level information containers based on the size and complexity of the project, the configuration of the ICs will define the so-called breakdown structure of the information model, and consequently facilitate the responsibility allocation of different sub-teams within the project team; by defining the associated IC for each sub-team. Please see Figure 51 in the attachments chapter for more illustration regarding the principles of information container-based collaborative workflow, including (a) information produced by different BIM authors is subject to intellectual property, (b) provide clear and specific information requirements by all participating parties, (c) provide suitable, secured, and accessible CDE, (d) develop information models based on the recommendation and instructions provided by the ISO 19650 series, and (e) define infromation security procedures.

The key point from this project parties' section is to understand the hierarchy structure of project parties in BIM-based appointments and pinpoint the responsible task team (appointed party) for each identified BU, IR, and project phase. Or in more general picture, to connect each sub-team within the project team (including delivery teams and task teams) with its associated BU, IR, and project phase.

4.2.2.4. Information delivery plan

The information delivery planning is assigned to the lead appointed and appointed parties, timing of each information delivery should be defined in the information delivery plan (including the date and associated project phase). Please see Figure 52 in the attachments chapter for more details regarding the information delivery plan and its components, including (a) how the delivered information will meet the OIR, AIR, PIR, and EIR? (b) when will the information be delivered? (c) what information and how will the information be delivered? (d) how the delivered information will be coordinated by other generated information? And (e) who is going to deliver the information and who is the intended recipient?

The major components of the BEP are derived from the previously listed components of the information delivery plan. Hence, ISO 19650-1/2 defines the same principles for the development of information delivery plan and BEP (which is a plan prepared by the suppliers to explain how the information modeling aspects of a project will be carried out). Consequently, these principles and components of the information delivery plan will be taken into the account during the development of the intended BUs definition method, since these components are identical to the major components of the BEP document, that are essential to be identified and later aligned with the defined BUs, IRs, project phases, and responsible parties, as part of the development of the intended BUs definition method for building industry firms, seeking BIM adoption at the practice level.

There are two types of information delivery plans: Master Information Delivery Plan (MIDP) and Task Information Delivery Plan (TIDP). MIDP is developed by the lead appointed party as a collection of all TIDPs developed and submitted by different appointed parties (task teams), so the main difference between the MIDP and TIDP is that the latter informs the former. It is noteworthy that some parts of the TIDPs and MIDP should be developed by the appointed and lead appointed parties before the appointment and at the beginning of the project (and here comes the potential of the intended introduced method to assist the management team in pinpointing pre-BEP related information at the beginning of the project). Since parts of the delivery plans (pre-BEP: pre-appointment and delivery team's BIM execution plan) are going to be checked in the initial review performed by the appointing party, later on detailed delivery plans can be developed, reviewed, and agreed after the appointment is made.

A review by the delivery team of information management solutions should be performed in advance (before any design, construction, or management task takes place). There are minimum aspects that should be included in the review of information management solutions performed by the delivery team, including (a) preparation and agreement to appointment conditions, (b) information management processes are defined and in place, (c) the information delivery plans suit the delivery team's capacity and capability, (d) the coordination of delivered information with other generated information, and (e) the information management techniques are derived from ISO 19650 defined processes. In BIM-based projects, the information delivery follows a pre-defined information exchange which takes place between the appointing and lead appointed parties. Moreover, there are additional components that should be included in the information delivery plan, including (a) delivery time of each information delivery (date and project stage), (b) responsibility matrix, including responsible party and related information deliverable or task, and (c) federation strategy and breakdown structure of information containers. Bearing in mind that the previously listed additional components of the information delivery plan are usually included components in the BEP document. Hence, we can say that around 75% of the BEP document is derived from the information delivery plan's components, the rest 25% is more related to introduction and contractual details.

In BIM-based projects it is crucial to define federation strategy for ICs, the main objective of the federation strategy and different information containers is to support collaborative production of information (support the production of information by different appointed parties by collaborative workflow), this can be approached by the breakdown structure of the federated information model to sets of information containers and information containers. ICs that share common characteristics can be grouped together to form one Set of Information Containers (SICs). The result of combining all SICs of one project is the federated information model. ICs can be classified based on the functional, spatial, or geometrical characteristics of the included information. E.g., based on the functional characteristics, the breakdown structure of the federated information model for test project 01 includes the following: architectural SICs (including exterior IC, interior IC, and landscape IC), structural SICs (including sub-structural IC and sup-structural IC), and electrical SICs (including high-voltage IC and low-voltage IC). It is highly recommended that the federation strategy is proportionate to the size and complexity of the built project and serving the overall objective of BIM-implementation in the project. Hence, there is no fixed federation template or strategy that can fit all projects due to the uniqueness of each built project, but the federation logic including ICs, SICs, and federated information model can be applied to projects and assets from all different types and sizes, with respect to being proportionate with the application based on the requirements and complexity of the projects.

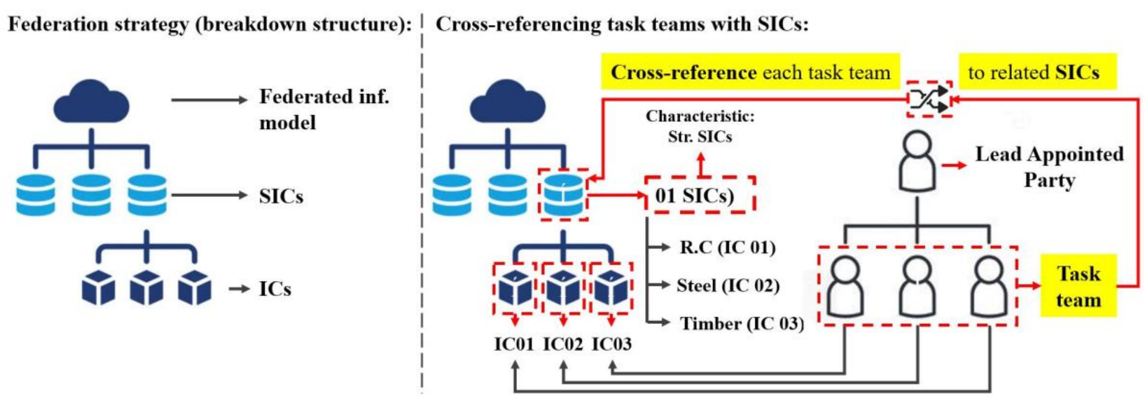


Figure 18: federation strategy and its correlation with task teams through cross-referencing appointed parties to related SICs

There are several advantages for the IC-based workflow and federation strategy, including (a) simultaneous workflow by allowing different delivery teams to work on the assigned task simultaneously, (b) support information security, e.g., avoiding file capacity/performance issues, and (c) ease of information exchange by reducing the size of each individual IC. With that being said, the research highlights one of the most important fundamentals of the federation strategy that can be an advantage connection point in the intended method, the rule states that SICs should be cross-referenced to task teams, meaning that each task team is responsible for one SICs, although the same task team can be responsible for one or more ICs within the reference SICs, but this task team is not responsible for other SICs within the same project. The advantage point of this rule in the intended developed method is facilitating the connection between the federation strategy (breakdown structure of the federated model, including SICs/ICs) and the identified BUs, IRs, project phases, and project parties (individuals). Supporting accurate and consistent definition for the BU starting with the academic component and moving to the practice component including the corresponding IR, type/format, date/phase, deliverer/receiver, and IC/SICs for that exact defined BU. Please refer to Figure 18 for more details regarding the federation strategy and its correlation with task teams through cross-referencing appointed parties with their associated SICs, and Figure 19 for more details regarding the structure for parties of interest and an example for cross-referencing appointed parties with their related SICs, in this figure the following alphabets (A), (B), and (C) represent the project, delivery, and task teams, respectively.

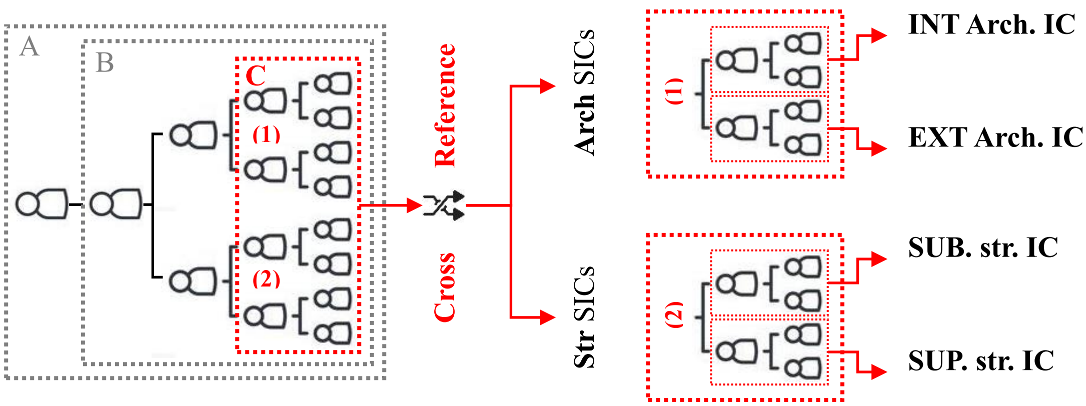


Figure 19: Parties of interest structure and example for cross-referencing task teams with their related SICs and ICs

It is essential to turn the light on the management of collaborative production of information, it is clear that the federation strategy and breakdown structure of ICs assist in collaborative-based workflow for BIM-based projects, but this can only be achieved through proper management for this collaborative production of information by the so-called CDE, the main objective of having CDE is to allow different project representatives to access, view, and modify information and data related to accomplish their assigned tasks. In addition, this information will have certain characteristics including the Level of Information Need (LOIn) which has to be defined for each information deliverable based on the purpose of this particular deliverable. Data aspects of LOIn include geometric, alphanumeric, and documentation data. It is highly recommended to produce high-quality information which simply means information that is understandable by all parties in the project. In order to have high-quality information, different representatives of the BIM-based project should have mutual agreement on several aspects, including (a) input and resources information format (e.g., PNG, DWG, PDF, etc.), (b) output and delivery information format (e.g., IFC, RVT, PDF, DOC, etc.), (c) structure of the information model, (d) structure of the information and means of classification (applied characteristics for classification), and (e) attributes names and nomenclature for metadata (e.g., properties of construction elements).

The original idea of the CDE is a cloud-based digital platform where all project's relevant information is stored in a structured manner to provide sufficient access for all project stakeholders. CDE is used for managing information during the project management and delivery processes. In addition, there are several advantages of using CDE in BIM-based projects, including (a) the responsibility of editing the information container remains with the authoring team (even after sharing and reusing), (b) shared information containers reduce time and cost in producing coordinated information, and (c) a full audit trail of information production during and after each project delivery. The revision (information check) of information containers within the CDE include four different states: work in progress, shared, published, and archive states, please refer to Figure 50 at the attachments chapter for more details regarding each revision state within the main two information check levels at the information exchange process between the appointing and lead appointed parties.

4.3. Align method components

The academic component introduces a three-stages BUs definition method derived from the comprehensive and particular sources as previously demonstrated. The research will align the academic and practice components to introduce a method that corresponds with the defined BIM implementation mission and its reference key BIM barriers. The method starts with the academic component by defining the model dimension for the intended project, the model dimension is defined at Stage 1 and based on the variations provided within Level 01, including 17 different choices, from which 16 choices are possible variations for model dimensions based on the current practice BIM model dimensions, including 3D (base), 4D (time), 5D (cost), 6D (FM), 7D (sustainability), and 8D (health/safety), and an undefined choice that allows the user to insert any later developed dimension in the future. Bearing in mind that the defined BIM model dimension applies to all later selected and defined BUs, meaning that in one BIM project/appointment there will be one defined BIM model dimension that applies to the whole project and through all later defined BUs in connection with that project/appointment. Please see the following Figure 20 for more illustration regarding the academic approach for the introduced BUs definition method.

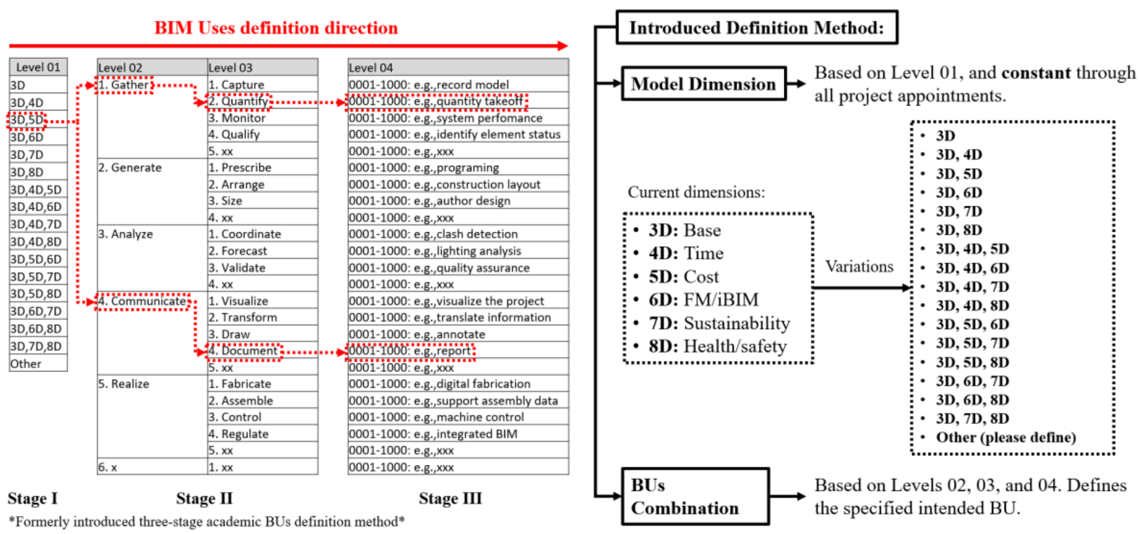


Figure 20: introduced BUs definition method (academic approach)

After defining the model dimension, the process of defining the objectives for BUs is initiated, starting with Stage II that gathers major and secondary objectives included within Level 02 and 03, respectively. Level 02 includes six major objectives of which one is undefined and gives the opportunity to develop a new major objective that is not provided in the list. By defining one major objective from Level 02, the user has to define one of the related secondary objectives from Level 03, bearing in mind that each major objective from Level 02 has its own collection of secondary objectives from Level 03, and the selection procedure accordingly follows this group logic. In total there are 24 brackets (representing secondary objectives) of which six brackets are undefined to give room for updating possible new defined secondary objectives in the future. The principal feature that is suggested by the introduced method is to associate each major or secondary objective with an ID number that represents the related defined BU objective.

The process of defining the objectives continues with Stage III, that includes Level 04 which combines lists of tertiary objectives (specific BUs objectives) that are associated with each defined secondary objective from Level 03, meaning that after defining one secondary objective from Level 03, the user can choose one of the listed tertiary objectives that are included on the counterpart bracket from Level 04 which is parallel with the associated bracket from Level 03, please see Figure 20 at which only one tertiary objective is shown by bracket on Level 04 due to shortage of space, but each bracket on Level 04 consists of several tertiary objectives (that are collected from the academic sources) that describe specific functions of the related previously defined secondary objective. In addition, there is a possibility to customize, add, and modify the list of tertiary objectives withing Level 4 brackets based on the scope of the user's firm, supporting future updates for newly developed specific objective BUs or personal customizations. The total number of the collected tertiary objectives is more than 400 specific objective BUs. Similar to the primary and secondar objective BUs, the introduced method suggests associating and ID number that represents each exact tertiary objective BU. By finalizing the last step through choosing the tertiary objective, the user will successfully define one BU for the intended BIM project (from the academic perspective), then the user can start again following the same method and path logic to define other needed BUs based on the project's needs.

An essential idea in this methodology is the ID number allocation for major, secondary, and tertiary objectives, allowing specific BUs definition with combination code that facilitates classification and provision of more detailed BUs. Please see the following Figure 21 for more details regarding the suggested code syntax for the BUs combination code that consists of 3 numbers followed by an alphanumerical description, the first, second, and third numbers from the code are identical to the reference IDs of the selected major, secondary, and tertiary objectives from Level 02, 03, and 04, respectively. The later alphanumerical description at the end of the code is derived from Level 04 and stands for the intended specific BU (tertiary objective description as listed on Level 04). The introduced code facilitates the classification of defined BUs into groups forming the suggested sets or Set of BUs (SBUs) which later on will be the fundamental point that links the academic defined BUs with practice. If two or more BUs share the same path but have final different tertiary objectives, meaning that their codes share the same first and second reference ID numbers, but have different third reference ID number and different alphanumerical description of the specific BU, then these defined BUs belong to the same SBUs. Please see the examples presented in Figure 21 for two different SBUs.

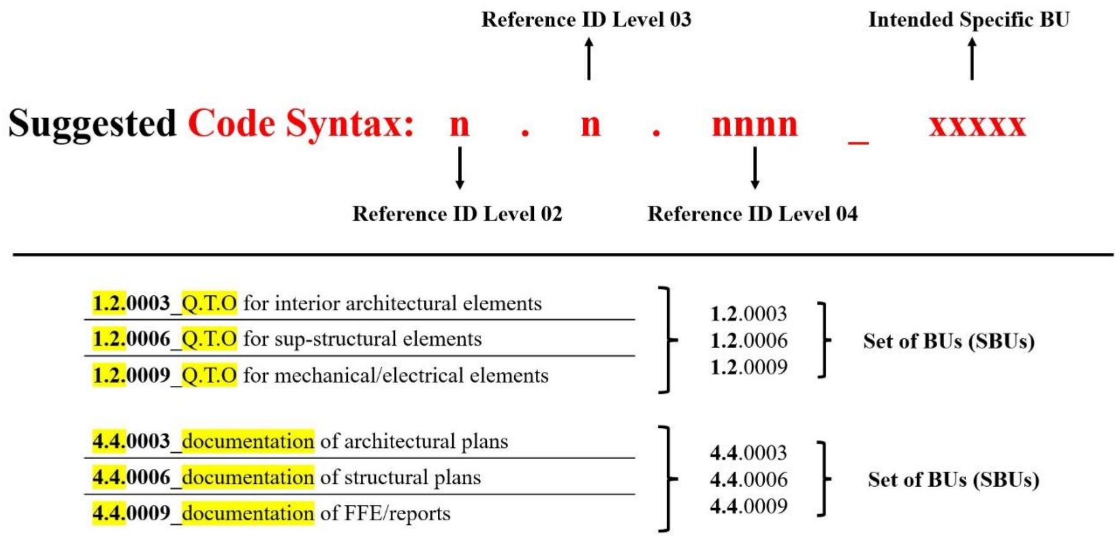


Figure 21: suggested code syntax for BUs combination code and examples for SBUs

The foundation for the introduced BUs definition method is to link the defined BUs and their SBUs from the academic component with their corresponding IRs and SIRs from the practice component. After defining the needed BIM model dimension, BUs are going to be selected based on the needs and requirements of the project, after that BUs are going to be classified into sets based on their generated BUs combination codes, so that each group of similar BUs that share the same Stage II path will belong to the same SBUs. Then the ID numbers for the SBUs and BUs will be copied to the ID numbers of IRs and SIRs from the practice component as main linking point between the academic and practice approaches. In accordance with matching SBUs to SIRs and BUs to IRs, the remaining practice potential points will be aligned to the defined BUs and the corresponding IRs, and the correct option will be selected, or the right information will be inserted for each practice related potential point, with respect to the corresponding BU and IR. Please see the following Figure 22 for more information regarding the practice potential points to be aligned with the defined BUs.

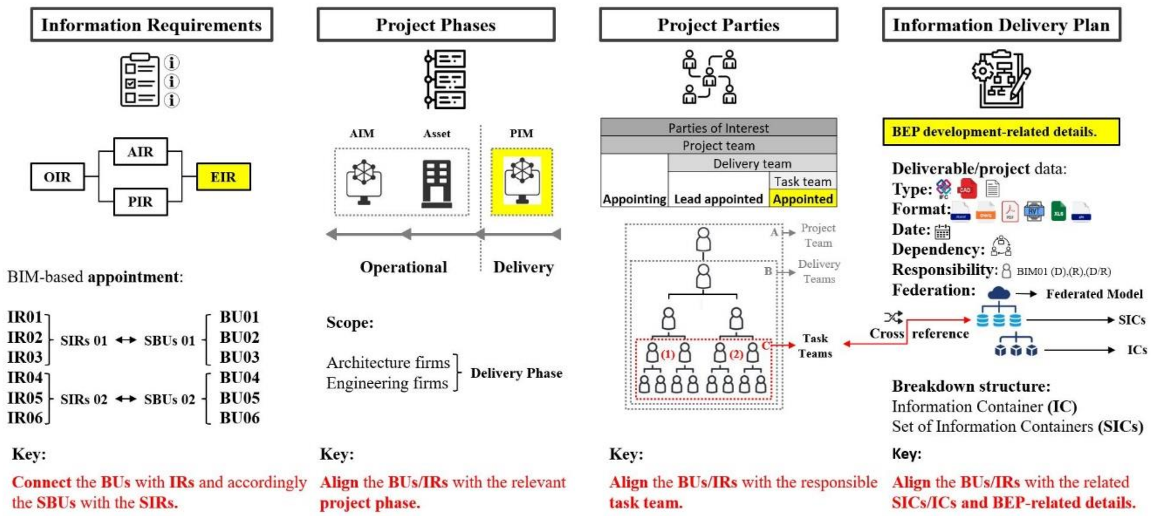


Figure 22: potential points from practice to be aligned with defined BUs, and to be selected or identified based on the intended project needs

The first potential point to be aligned with the defined BUs and SBUs is the information requirement. From this point the most important is to tick the right IR type which also answers the corresponding defined BU. The type of the IR may be OIR, AIR, and/or PIR, and since it is nominated to be an IR with corresponding BU then certainly that IR is an EIR. The second point is in connection with the project phase, and here the user has to select one of the two possible phases (delivery or operational) referring to the defined BU. The third and fourth points in connection with project parties and information delivery plan are going to be combined, since the most important aspect from the third point (project parties) regarding the task team is going to be cross-referenced to the content of the fourth point (information delivery plan), at this point the user has to select the right choice of the information delivery type, format, date, and responsible delivery/recipient party (appointed/lead appointed party), then the user should define the federation strategy based on the project needs and requirements including ICs and SICs. Each defined BU and SBUs will be aligned with the previous potential points from practice to form one comprehensive source of information for BIM adoption in the related project, to be used by the management team who is responsible for BEP development and project information management.

The downside of the introduced method is the applying complexity since it consists of complex multi-level steps, procedures, and contents. Consequently, more development and validations are required to make the method more user friendly and applicable for local AE firms seeking BIM adoption in real life projects, to assist in overcoming defined key barriers and accomplishing the associated BIM implementation mission. Hence, more refinements and validations are going to be provided in the next chapter of this dissertation.

5. Develop an application to overcome BIM adoption barriers

This chapter addresses the introduced methodology in the previous chapter that includes a BIM method to define objective BUs aligned with business standards to facilitate BIM-based projects execution including (coordination, liability/responsibility allocation, and BEP document development), as an attempt to support AE SMEs to carry out BIM-based projects. Thus, the main objective is to assist AE firms to employ BIM-based workflows in their practice, and mainly local

AE firms, since those firms defined in a previously conducted research work several key BIM adoption barriers from which a BIM implementation mission statement has been established to address the related key barriers, and later on this mission statement will be the backbone for developing the introduced methodology.

As demonstrated in the previous chapter, the introduced methodology consists of several elements, including BUs definition method, business standards, and BIM project execution plan. In order to find the right balance between all elements by combining them and developing the intended method, the research relies on workflow fundamentals from practice. It is necessary to understand that BUs definition for each BIM-based project is crucial and an initial step to kick off the project in the correct direction, since the right definition for BUs according to the project's needs and parties' requirements ensures smooth adoption of BIM processes and assures optimal fulfillment of project's objectives. In addition, it is important to understand that BUs definition is also a major contributor in developing the BEP document, since the development of BEP or pre-BEP documents significantly leans on the outlines of BIM application in the related project. Consequently, there is a relation between BEP development and BUs definition, since the highlights from the latest are going to form the main directions for BIM application in the intended project for which the BEP document is going to be developed. On the other hand, the business standards set a minimum requirement for BIM-based workflows and processes in BIM-based projects, and it is noteworthy that the standards are major contributors in the outlines and components of the BEP document. The business standards in this research work will be derived from the business processes included in the international BIM standards series (ISO 19650) with focus on the 1st and 2nd parts (since the scope is AE firms in the project's delivery stage) and BEP components are going to be derived from the ISO 19650 standards that represent the minimum level of BIM workflows in practice. Please see Figure 23 that demonstrates a flow chart for the mission breakdown.

The flow chart in Figure 23 highlights the introduced methodology as a final outcome for answering the mission's main point. This methodology will be tested at the end of this chapter, by the exact same AE professionals who defined key BIM barriers for the developed mission in the previously conducted research work. Hence, the necessity to develop an automated version from the developed method arises, due to the difficulty of manually apply the method for the intended objectives, and since the main intention of developing the method is to assist management teams of AE firms to carry out BIM-based projects, meaning that the method should be usable, workable, and applicable, hence, the research invests more time to automate the developed method for serving validation and usability/applicability purposes.

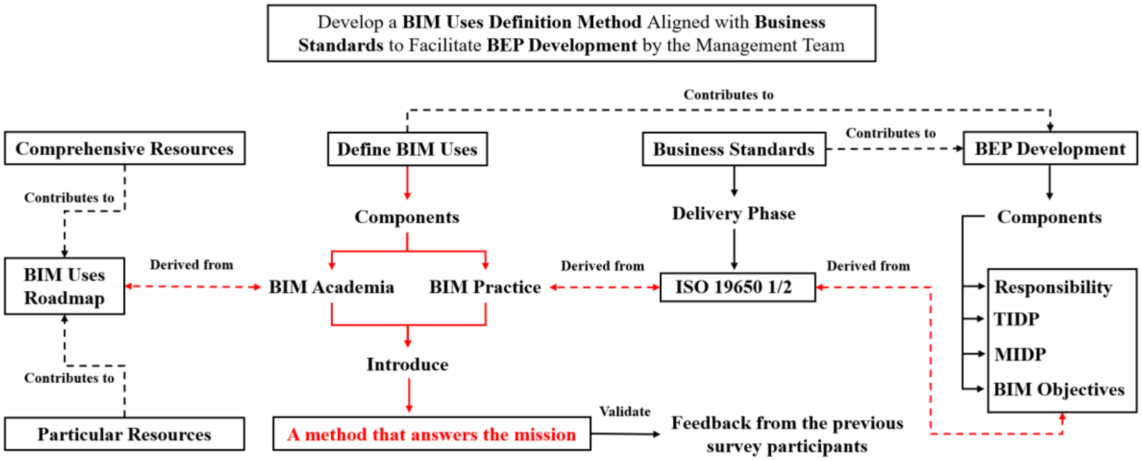


Figure 23: flow chart for the mission breakdown

5.1. Automation significance (why is there a need for an application?)

The developed method includes multi-level user engagement in order to properly fulfill the intended objectives. After performing several internal review rounds together with the supervisors and other BIM professionals, it was clear that the content and sequence of the developed method gain more positive points compared to the workflow (from the user point view) due to the complexity and variety of the levels where the user needs to engage (e.g., to fill-in a piece of information, choose from a list, etc.) in order to proceed with the method. The following bullet points include some of the method's issues and problems that will be partially or totally solved by automation:

- The user needs to manually insert the project base information including project title and appointment, and to choose from the provided BIM model dimension combinations according to the needs of the project, the user needs to manually record this information in a final results sheet.
- The need for two-step process for searching and recording one BU; the first step includes navigating through the listed levels and the included BUs with their reference IDs in a provided table, and the second step includes recording (in final results sheet) the defined needed BU and its predecessors. In addition, the need for collecting the IDs for each defined BU and its predecessors based on the previously suggested code syntax.
- The user needs to repeat the previous step for every single BU that is needed for the intended project.
- After collecting and recording all needed BUs in the final results sheet, the user needs to manually classify the defined BUs into sets based on the previously suggested code syntax (BUs that belong to the same SBUs have identical reference ID for Level 02 and 03).
- After arranging the defined BUs into sets, the academic part of the method is finalized, and the practice part of the method is initiated. In the practice part the user is asked to fill in the correct information for each defined BU and its counterpart from the practice section (in the final result sheet), e.g., what is the type of the IR which is associated with BU01? Who is the responsible party for BU01? What is the reference IC or SIC for BU01? And so on.
- Time and effort consumption with the high possibility for mistakes and misguidance.

Hence, the research intends to develop an application that automates the introduced method with all of its aspects and levels. The application will assist to significantly eliminate the previously mentioned obstacles in the manual method, of course the application will not fully automate the whole process, since direct engagement from the user is needed at many occasions for choosing or typing in the right choice or answer, but it will properly introduce the method and simply guide the user from the 1st step until the last one to save time, save effort, enhance workability, encourage applicability, attract users, support professionals, and serve the intended objectives, by ensuring smooth user experience with easy and simple workflow.

5.2. Application development

The research intends to develop an application which automates the previously introduced BIM method. Although the method has been introduced before in the previous chapter, associated with its drivers, framework, and components, it is still essential to clarify clearly the answers for the following two main questions before proceeding in any application development stages:

- Who are the target users for the intended developed application?
- ➢ The users for the intended application are high-level professionals from the building industry, mainly professionals from the management or planning team who are assigned to kick off and carry out BIM-based projects or appointments. The main scope of the users is AE professionals who belong to AE SMEs, although, the intended application can also be used by professionals from other disciplines in the building industry as long as they are intending to kick off and carry out BIM-based projects, since the main step associated with defining BUs in the introduced method leans on comprehensive collection of objective BUs that are valid for huge variety of different disciplines within the building industry, and the included practice standards are applicable for businesses from different sizes and specialties as long as their work is associated with BIM.
- What is the objective of using the application?
- ➢ The main objective of using the application is to kick off a BIM-based project by a building industry firm, mainly developed for AE firms, but due to the included features in the developed method it can be used for any building industry firm which intends to initiate and carry out BIM-based project. The reference target for the application is to assist AE SMEs to overcome previously defined key BIM barriers based on which a method has been introduced and an application which answers the introduced method is going to be developed in this chapter. In a simpler context, the application assets any high-level AE professional who intends to initiate BIM-based project with slight knowledge and experience in the following aspects: BUs, BEP (including liabilities, coordination, and responsibilities), and standards. In addition, assisting experienced and knowledgeable professionals in boosting the process of pinpointing needed BUs for certain project and establishing the required information to develop the pre-BEP and BEP documents, through outlining all the fundamental BUs, procedures, requirements, phases, teams, responsibilities, roles, and federations.

5.2.1. Workflow program for the application

Before initiating the development process of the application, the research reviews essential points from the previously developed and introduced method to be included in the application. After gathering the essential points that should be included, the research goes through these points and attempts to arrange them based on real-life practice workflow, starting with the earliest and finishing with the latest procedures in BIM-based workflows. In addition, other potential points arise during the brainstorming process regarding the development of the application, these potential points may have direct influence on the workability of the application and user experience. Hence, it is crucial to brainstorm all the ideas and points that are related to the introduced method and should be embedded in the application.

5.2.1.1. Workflow program for the application (academic component)

Following the method's main two components, the application will similarly have two main components, academic and practice components. According to the practice logic in BIM-based projects, the method should start with the academic component, since it includes the process of defining BUs for the project, which is considered an initial step before moving to the practice related details. In the academic component the application should enable the user from defining the project's BIM dimension (which is going to be applicable for the whole project), the dimension is an important initial step to narrow down the scope of the project, of course defining the model dimension is going to be based on the client's requirements and needs, the existing different BIM model dimensions and their variation and definitions have been explained in detail in the previous chapter, but briefly, the majority of the industry's professionals agree that there are currently 8 different dimensions of BIM models, meaning that there are 16 different combination of current model dimensions from which the user has to choose one of them. Also, the application should give the user the option to add more dimension combinations in case newly developed dimensions appear in the near or far future to ensure more versatility and flexibility for using the application in the long run.

After defining the needed BIM model dimension, the application should enable the user to start the definition process of the needed BUs. The definition process of one BU starts with Level 02 by defining the major BU objective, then moves to Level 03 by defining the secondary BU objective, and finally terminates at Level 04 by defining the tertiary objective (final specific objective) of the intended BU. It is noteworthy that primary and secondary objectives that are included in Level 02 and Level 03 are derived from the services' objectives that are provided by firms in the building industry, meaning that these objectives are identical whether the user follows BIM-based processes or non-BIM-based process to fulfill certain AECO task requirements. E.g., "communicate" as major objective from Level 02 and "document" as secondary objective from Level 03 can be approached by BIM-based and non-BIM based workflows (e.g., the difference between the production of 2D drawing by using 2D CAD software without a reference model, and the production of 2D drawing based on 3D BIM model that allows automatic generation of the intended drawing).

The application should provide the user with the ability to define as many BUs and variations as the project needs. There should be no limitations on the number of defined BUs, nor on the number of defined BUs combination variations. Also, the application should provide the ability to add more major, secondary, and/or tertiary BUs objectives, since the industry is in constant development, and new methods and procedures to approach new objectives may appear, meaning that the user should have the ability to include new or customized objective BUs that are not existing among the listed objectives of BUs.

An important feature that should be embedded in the application is the ability to automatically generate and record reference ID for each defined objective BU at any level, based on the previously suggested code syntax (n.n.nnnn_xxxx). Please check Figure 21 in the previous chapter for more illustration. The suggested code syntax represents a BUs combination code that consists of 3 numbers (separated by points) followed by an alphanumerical description (the numbers and the alphanumerical description are separated by an underscore). The first, second, and third numbers from the code are identical to the generated reference IDs of the selected major, secondary, and tertiary objectives from Level 02, 03, and 04, respectively. The later alphanumerical description at the end of the code is derived from Level 04 and stands for the intended specific BU (tertiary objective description as listed in Level 04). Hence, comes the potential of automated process to allocate reference IDs and generate code syntaxes for the defined BUs.

Another important point in the developed and introduced method is the classification of BUs into different sets of BUs. Thus, the generated code should support the classification of defined BUs into sets, this classification will be later on the fundamental point that links the academic and practice components of the method. The SBUs includes one or more BUs that share the same path but have final different tertiary objectives, meaning that their codes share the same reference ID numbers for Level 02 and Level 03, but have different reference ID numbers for Level 04 and different alphanumerical descriptions for specific BUs, then these defined BUs belong to the same SBUs. Hence, the application should have the ability to automatically group the defined BUs from the method's academic component into different SBUs based on their codes' paths.

Regarding the practice component that represents the second component of the introduced method, the main focus will be on the practice business processes that are derived from ISO 19650 I/II standards, but more important is to find the way to connect the academic and practice components together, to establish a linking point from which the user can connect the previously defined BUs from the academic component with their professional details and information from the practice component. As introduced in the previous chapter the potential linking point between the academic and practice components will be the IRs, the method suggests translating the defined BUs based on the project's needs and client's requirements into specific IRs at the practice components with identical reference IDs for each BU and its corresponding IR. Meaning that each defined BU will have a representing specific IR that intends to answer the objective of the defined BU.

5.2.1.2. Workflow program for the application (practice component)

The practice component of the introduced method starts with listing all defined BUs (classified and arranged into SBUs) with their associated IDs and align them with three main practice related sections; the details within each practice related section should be completed by the user of the application and according to the intended project. The user will have the ability to choose or type in the right practice information that best describes the related BU or group of BUs.

The first practice-related section is to define the type of the IR that answers the related defined BU, in this part the user will be asked to tick the right choice that best describes the type of the corresponding IR and its related BU, there are four different types for IRs including OIR, AIR, PIR, and EIR, the application should enable the user from ticking one or more of the mentioned IRs' types.

The second practice-related section contains details regarding the delivered information that answers the associated IR and BU. The application should enable the user to insert all data related to the delivered information, including the delivered information's nature (drawing, report, schedule, model, picture, video, document, etc.), format (PDF, DOC, XLS, IFC, RVT, PNG, PLN, NWD, etc.), delivery party/individual (the individual and/or the party who is responsible about the delivery of the intended information, e.g., BIM 01 individual from task team A), receiving party/individual (the individual and/or the party who is responsible about the delivery of the intended information, e.g., BIM 06 individual from the delivery team A), and time (date and phase).

The third practice-related section focuses on the breakdown structure or the initial allocation of the project's information containers and sets of information containers. This section defines the federation strategy for the produced information containers based on the project's needs and requirements to fulfill the intended objectives. The application should enable the user to create as many ICs and SICs as necessary with no limitations. Later on, and after defining the federation strategy based on the project's needs, the application should allow the user to tick the right IC that is related to the aligned IR and BU. E.g., BU01 and IR01 refer to the 1st reinforced concrete sub structural information container (01 R.C SUB-STR IC) which belongs to the second structural set of information containers (02 STR SICs). Hence, and by saving all previously mentioned information, the user will have a comprehensive overview regarding the most important practice-related details that are associated with the defined BUs and derived from business standards which cover the fundamental BUs, pre-BEP and BEP elements, coordination, liability, and responsibility aspects for the intended BIM-based project or appointment.

5.2.2. Technical details regarding the application development

By setting up the workflow program of the intended application, the following step is to develop the application based on the planned workflow program. Before starting the development of the application, a question was raised regarding the feature of the intended application, whether it is going to be windows-based application or web-based application. Although the windows-based application was immediately nominated based on the available abilities and resources of the research (including time frame and current programming knowledge and experience), the research was looking toward web-based application to target a wider range of users, offer cross-platform accessibility, and support centralized deployment. But based on the research time schedule and current abilities the idea of web-based application can be further developed in future research work. In addition, having windows-based application before publicly sharing it as web-based application will act as a demonstration version that allows to test, enhance, and develop the included features, by receiving feedback from users and reviewers regarding the workability and applicability of the program to enhance the overall outcome.

The research will develop software application that runs on the Microsoft Windows operation system, the user will be able to download an .exe file (which is a shortcut for executable file), this type of file formats is used by Microsoft Windows and Disk Operating System. The .exe file contains a program capable of being executed or run by the operating system; by double clicking on the file the operating system interprets the file as a command to start the program embedded within the file and launching its associated software application or process. The developed .exe file contains machine code instructions that are directly interpreted by the computer's processor when executed and is considered Graphical User Interface (GUI) file; this type of .exe files has a graphical interface (e.g., a window with buttons, menus, and icons) that is designed for user interaction in a desktop environment.

Technically the user needs two files to run the developed application, including Microsoft Excel and .exe files. The excel workbook file includes two main sheets from which the program is going to read the data; after reading the data the program will demonstrate it in an arranged manner at the right place and time in the application's interface, and the user will be able to choose from the arranged data the best answers that correspond to the intended project. The excel file acts as a database for the application, from which the application will access the included sheets within the file and present the data stored at these sheets at the right place in the application's interface. The following Table 19 illustrates sample example from the excel file that will be provided with .exe file to run the application, this sample shows an example from one of the sheets included in the excel file, the sheet includes different BUs' information and variations that will be read by the program and demonstrated for the user to choose from. Hence, this method supports customizability by the user or the company's management team based on the scope of the company. E.g., the scope of structural design firms varies from the scope of architectural or mechanical design firms, so "simulate" BUs may be more important for the structural design firms compared to "visualize" BUs that are considered more important for architectural design firms.

Table 19: sample example from the provided customizable excel file with the application

Level 01	**Level 02**		**Level 03**		**Level 04**	
Model D.	**ID**	**Description**	**ID**	**Des.**	**ID**	**Description**
3D	**1.**	**Gather**	1.	Capture	1	Capture existing condition (manual)
3D, 4D					2	Laser scanning
3D, 5D					3	Photogrammetry
3D, 6D					n	Example
3D, 7D			**2.**	**Quantify**	**1**	**QTO for interior wall frames**
3D,8D					2	QTO for exterior wall frames
3D,4D,5D					n	Example
3D,4D,6D			n.	Example	n	Example
3D,4D,7D	2.	Generate	1.	Prescribe	1	Spatial scoping
3D,4D,8D					2	BIM for building programming
3D,5D,6D					n	Example
3D,5D,7D			n.	Example	n	Example
3D,5D,8D	n.	Example	n.	Example	n	Example

In Table 19, the highlighted specific BU is "1.2.1_QTO for interior wall frames" may be frequent and important BU for the majority of BIM-based appointments carried out by an architectural office. On the other hand, the same highlighted specific BU may not be relevant and rarely used for the majority of BIM-based appointments that are carried out by a structural design office, so this office will have the ability to customize this specific BU to "1.2.1_QTO for interior structural framing" instead of "1.2.1_QTO for interior wall frames". This feature enables the users to freely customize BUs based on their preferences and according to the scopes of their projects. Another advantage for this feature is the fact that many times slight changes in the context of the BU is needed for certain projects, e.g., the highlighted BU "1.2.1_QTO for interior wall frames" may be optimal for appointment 01 based on the project's needs, but in another project it may require slight update to fit the project's needs, like "1.2.1_QTO for interior drywall frames" due to the fact that in this particular project interior wet walls are not included in the required QTO processes, so the ability to modify the BU or update new BU is important for such occasions.

This means that the method supports flexibility for the users to update BIM dimensions, BUs, or any other detailed information that can be revealed in the future to keep up with the industry's development and avoid outdated content. So that the user can customize the content of the excel sheet to match the scope of the intended firm. Moreover, specialized AE firms or any other building industry firms that have a more specific scope and BIM specialty will have the option to customize the BIM dimensions, BUs, or any other detailed information included in the method according to the scope of their company. This gives a huge plus for the method to be used by entry-level firms which are trying to carry out BIM-based projects, and by advanced-level firms which are currently major players in the market of BIM-based services, and they are seeking more organized, arranged, and structured method that forms a consistent guideline to successfully approach any BIM-based project, and developing a private database of specialized BUs and information details that belong to the company and its scope, and can be used in upcoming projects together with the ability to extend the database with more content based on new lessons and experiences. This database will save time and effort for the management team to kick-off BIM-based projects including defining the model dimension, pinpointing needed BUs and their associated IRs, providing IRs details, inserting delivered information specifications, and setting the federation strategy.

The following Figure 24 demonstrates the operational path of the developed application by the intended use. The user needs two files to use the application, the 1st is Microsoft Windows executable file and the 2nd one is Microsoft Windows excel file. The user has to double click on the .exe file to open the application, the interface of the application will consist of two pages, the 1st page includes all the menus, buttons, and icons which enable the user to choose the academic component related information (based on Level 01, 02, 03, and 04). But before defining the academic component related information (BUs combinations for the intended project), the user has to read the external provided excel file (which is also customizable) through the application, then proceed in pinpointing specific BUs based on the project's needs. After finishing with the 1st page which is more academic component-oriented, the user saves the defined BUs and hits next to move to the 2nd page which is more practice component-oriented, in the second page the user will fill in or choose the right information that best answers the defined BUs and their associated IRs. After finalizing all practice-related information the user can save and hit export, and the application will automatically generate an excel file with all related information including defined specific BUs and IRs aligned with their practice-related information that are necessary to develop the project's pre-BEP and BEP documents.

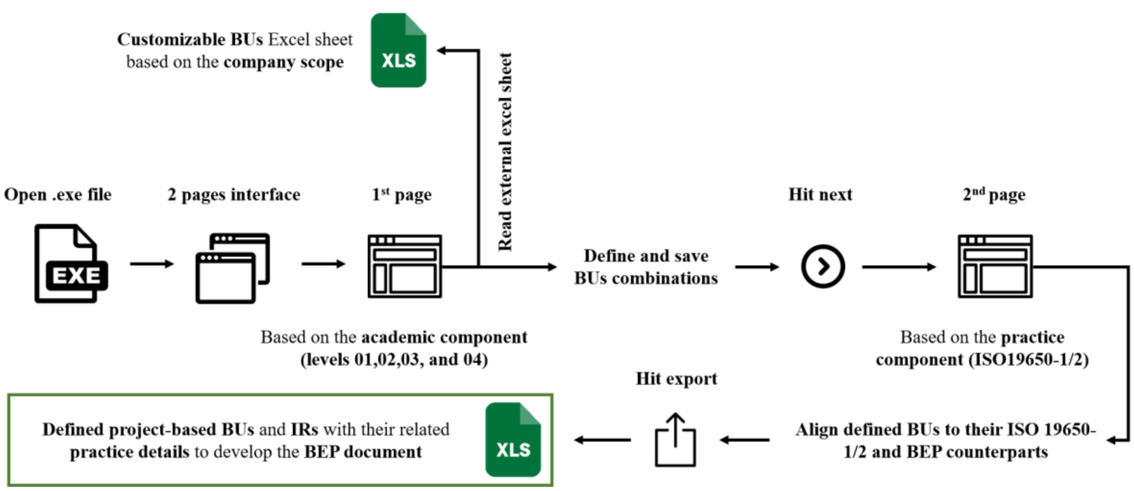


Figure 24: flowchart for the operation path of the developed application

5.2.3. Version 01

The development of the application occurred in several stages resulting in different application versions. The 1st version focuses more on the academic component of the introduced method, including the development of the application's interface, and mainly the 1st page of the interface. As shown in the following Figure 25 the 1st page of the interface includes simple allocation of menus, icons, and buttons to run the application. The user has to browse for the associated excel file, type in the title of the main and optional worksheets from the excel file, and hit "open data excel" button to give an order for the application to read the data from the excel sheets. After reading the data, the application will show the included data from the excel file on the left blank rectangular space of the interface, by the time Level 01's objective BUs are shown on the rectangular blank as demonstrated in Figure 26, the user will note that it is not possible to select any of the shown objective BUs, nor possible to hit the icon "save BIM use to list" since it is faded together with the "BIM use code" area, The reason for that refers to the undefined Level 01 field. This means that after reading the excel file. The user has to define the project's BIM model dimension from the drop-down menu that appears by clicking on "Level 1" icon, and type in the name of the project or appointment at the box shown right next to the "Level 1" icon.

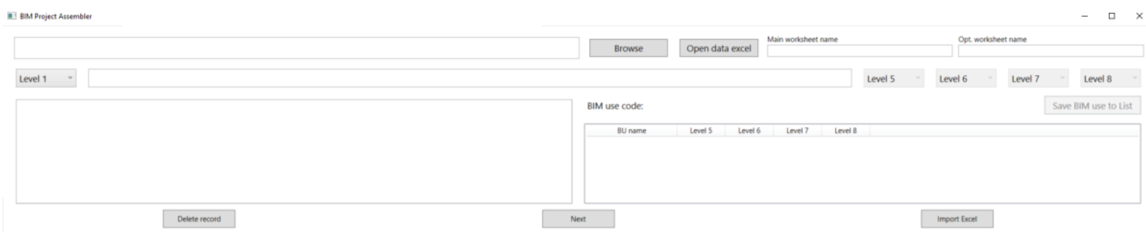


Figure 25: 1st version of the developed application, introduction

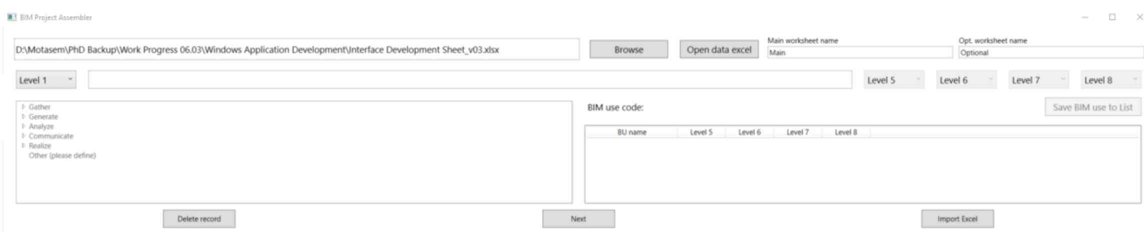
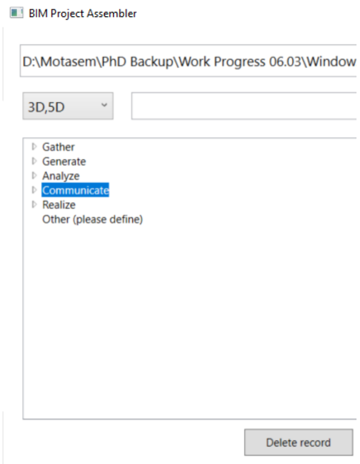
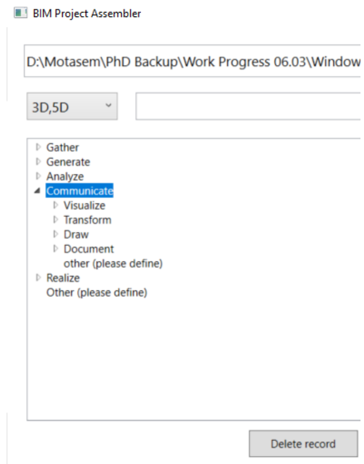


Figure 26: blanked primary BUs after reading the excel file due to undefined BIM model dimension (Level 01)

After defining the BIM model dimension that is needed for the intended BIM project and its appointments, then the application enables the previously faded options including the objective BUs area on the left side of the interface, "BIM use code" area on the middle of the interface, and the "save BIM use to list" icon on the middle-right side of the interface, meaning that the user will be able to navigate through the listed BUs, select the needed ones, and save them to the list. The application is going to apply hierarchy tree method to show the objective BUs from Level 02, 03, and 04. In order to define one BU for the project, the user has to click on the primary objective BU from Level 02 (e.g., communicate), the secondary objective BU from Level 03 (e.g., document), the tertiary objective specific BU from Level 04 (e.g., FFE specification & schedules), and on the icon "save BIM use to list", please see the following Figures 27, 28, and 29 for more details.





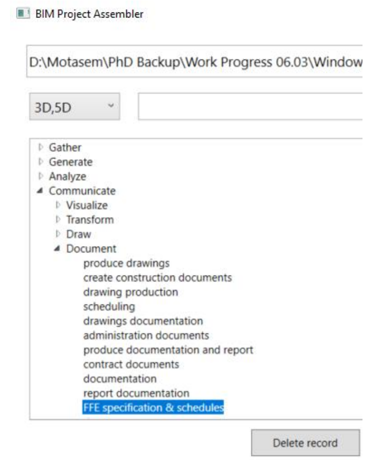


Figure 27: (to the left) definition of primary objective BU

Figure 28: (in the middle) definition of secondary objective BU

Figure 29: (to the right) definition of tertiary objective BU (specific BU)

After defining the needed specific BU and hitting "save BIM use to list" button, the user can repeat the procedure for every single BU that is needed to meet the project's needs (see Figure 30). It is noteworthy that following the classification sequence meanwhile defining different BUs is not necessary, since the application is able to automatically rearrange all defined BUs into sets based on their generated code. Hence, the user can randomly select and define needed specific BUs and leave the arrangement task for the application. At this stage, and after defining and saving the BUs that are needed for the intended project, the user can proceed with the following steps by hitting next, which will take the user to the 2nd page of the interface that is going to be developed in the 2nd version of the application. In case of having several projects with identical or partially identical BUs, then the application offers the option of importing a previously generated excel file (with the application) that will copy the defined BUs in the file, giving the user more flexibility to copy most frequently applied specific BUs between projects smoothly, and then have the choice to define more BUs or proceed with the copied BUs for the intended project, this will save the user's time instead of defining frequent BUs from the beginning by following the hierarchy tree for every single project or appointment, mainly in busy projects when large number of BUs has to be defined. In order to use the import feature, the user has to click on the "import excel" at the bottom right side of the interface and then choose the intended excel file from the device and open it.

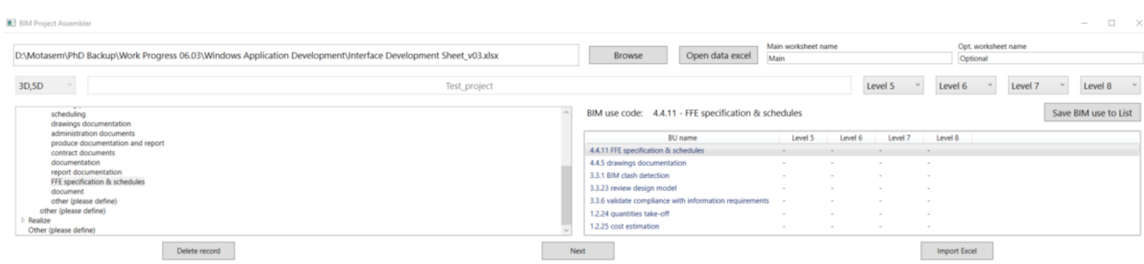


Figure 30: defining and saving different BUs for Test_project

5.2.4. Version 02

The 2nd version of the application includes the development of the 2nd window of the interface, the user can proceed to the 2nd window of the interface after defining the dimension of the intended

BIM model, the name of the project, and the needed specific BUs, by hitting next from the 1st window in the interface, the user will be directed to the 2nd window that focuses more on the practice component of the introduced method.

The 2nd window will automatically allocate the defined BUs into sets based on their generated codes, see the following Figure 31. The core of this classification procedure is based on the objective, meaning that BUs that have identical objective path, and at the same time different final specific objectives, will automatically join one group and share the same set. This allocation process will facilitate dealing with BUs (and mainly large number of BUs), and it will help the user to get more managerial insights regarding the size of the work, needed capacities/capabilities, price frames, and needed time.

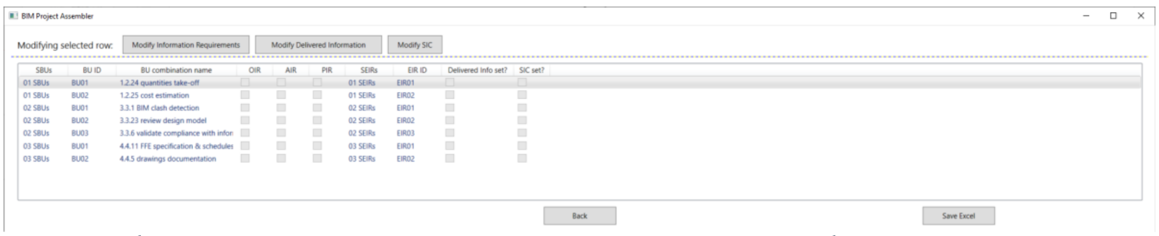


Figure 31: 2nd version of the developed application, introduction for the interface's 2nd window

The 2nd window will demonstrate the defined BUs and their sets, the linked IRs and their sets, and other practice related details in incomplete table form at rectangular space in the middle of the window. At the top of the window, there are three main practice related details that can be modified by using the application, including information requirements, delivered information, and federation strategy modifications, by clicking on the following icons shown at the top row of the application's interface 2nd window: "modify information requirements", "modify delivered information", and "modify SIC", respectively. The user has to select one of the defined BUs, and then update the practice related details for the selected BU including the previously mentioned three points. By selecting a BU and clicking on the 1st icon (modify information requirement) the application enables the user to click on the right choice that best describes the type of the IR that represents the intended BU, the user will have the ability to tick one or more types of the IR types including OIR, AIR, PIR , and/or EIR, after choosing the right type/s for the IR the user can hit confirm to save the answers and changes for the types of IR to the selected BU. Please see the following Figure 32, that demonstrates the pop-up window to modify IR's type, in the shown window only three types of IR are available, including OIR, AIR, and PIR, considering that the defined specific BU by default will be an EIR, but another extra EIR ticked box will be added in the next developed version of the application to provide more clarity for the user and avoid misunderstanding.

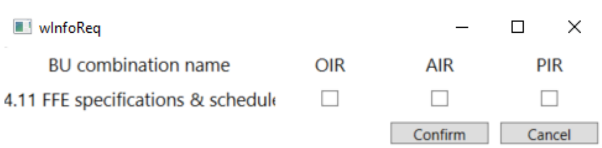


Figure 32: pop-up window to define the type of IRs, from the application's 2nd version

The next icon "modify delivered information" allows the user to set the delivered information details that are associated with the selected BU, including the delivered information's nature (e.g., drawing, report, document, model, schedule, etc.), format (IFC, RVT, PLN, PDF, DWG, DOC, XLS, etc.), delivery party or individual (e.g., task team A or BIM 03), receiving party or individual (e.g., delivery team 01 or BIM 07), date (e.g., 02/04/2024), and phase (e.g., delivery phase), all the choices for the deliverables, responsible parties, and time will be provided by drop-down menus by clicking on the related icon. Finally, and after finalizing all the delivered information related details, the user can confirm to save all the modifications and move to the next step, please check the following Figure 33 that demonstrates the pop-up window for delivered information details.

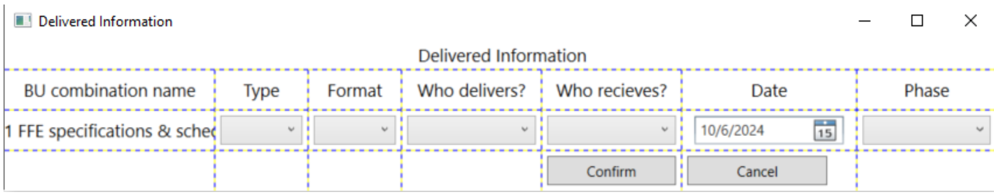


Figure 33: pop-up window to define delivered information details

The last practice related aspect that is included in the developed application is the project's federation strategy, the application will enable the user to define the federation strategy (breakdown structure of the ICs) for the intended project by clicking on the "modify SIC" icon, a pop-up window appears from which the user defines the federation strategy for the project including the number and titles of SICs and the included ICs. In this version of the application, the pop-up window functions and icons need more development to properly be able to add SICs and included ICs for the whole project, and then select the corresponding IC that is associated with the intended BU. In the next version of the application this section will be more refined.

5.2.5. Version 03

The final developed version of the application is more or less similar to the 1st and 2nd versions with some minor updates and improvements to make the application more refined and user friendly, the application's refinements include:

1. The 1st window of the interface has "delete record" button at the bottom left side of the window. The function of this icon is to delete unwanted saved BUs. There are two issues with this icon including the far location from BUs' definition rectangular space, and inability to delete two or more defined BUs together at once. In the application's 3rd version these issues have been solved, first by moving the icon right next to the "save BU" icon, in this case the user has both saving and deleting functions in two icons right next to each other, and second by enabling the user to select one or more BUs and perform deleting action on all of them at once instead of the previous single-deleting option.
2. The 2nd window of the interface demonstrates the defined and automatically arranged BUs into sets, together with their associated IRs and SIRs with their automatically generated IDs which are identical to the BUs and SBUs IDs. In the 2nd version of the application there is an issue in the procedure of defining practice related information for associated defined BUs, the issue is expressed with the inability to define practice related information for a group of defined BUs at once, meaning that the user is only able to select one BU and define the practice related information for that particular BU, and then move to the next one. In case of having large number of defined BUs, there is a high probability that many of the defined BUs partially or totally share the exact same practice related information. Hence, the 3rd version of the application allows the user to select different BUs at once and define any practice related section for all of the selected BUs at once, resulting in a more time efficient and convenient definition procedure.
3. The 2nd window of the interface includes three options by which the user can click on any of them to modify practice related details for the selected BU. The 1st option is "modify information requirement", by clicking on this option a pop-up window appears that includes 4 tick boxes each of them refers to IR type and aligned with the selected BU, the

user can simply tick the relevant IR type which best describes the selected BU. The issue with the previously developed pop-up window is that there are only three listed types (OIR, AIR, and PIR) instead of four types (OIR, AIR, PIR, and EIR), this issue has been solved in the application's 3rd version.

4. The last refinement is in connection with the third "modify SIC" icon at the 2nd interface page, the function of this icon is related to the federation strategy of the project. In the previous version the pop-up window for this function was not developed. In the 3rd version the pop-up window has been developed to enable the user to define the breakdown strategy for the whole project and then confirm it, then another pop-up window appears that enables the user to tick the related ICs for the selected BUs.

The following Figure 34 demonstrates the 1st window of the application's interface, the aim is to represent the final version of the application by using a demonstration example. The figure shows that the user of the application has applied several specific BUs (tertiary objective BUs or Level 04 BUs) customizations based on the intended project's scope and needs. After that, the user browsed for the customized excel file, typed in the titles of the target worksheets, and clicked "open data excel" icon to access the data from the customized excel file. Then the user typed in the name of the project (DEMO_Project), defined the needed BIM model dimension (3D, 5D), and started the procedure of defining needed specific objective BUs based on the project's requirements and needs. In total the user defined 12 different BUs, and as shown in the related figure at the BU name at the saved BU rectangular space, the defined BUs are randomly arranged with different affiliation (major and secondary objective BUs), as shown also the automatically generated codes for the defined BUs have some similarities and differences, at this stage the user can only view the saved BUs based on the definition sequence with no automatic classification.

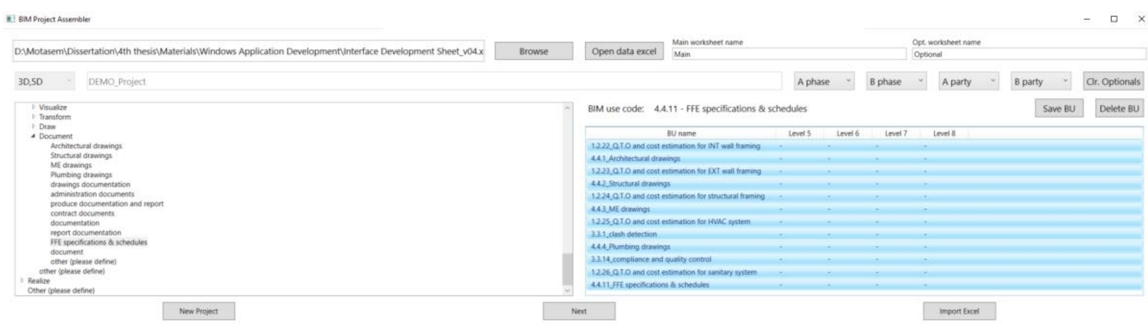


Figure 34: DEMO_Project, 1st window of the application's 3rd version

By hitting the "next" icon, the application takes the user to the 2nd window of the interface, which is shown in the following Figure 35, which proceeds with the same DEMO_Project example. The application's 3rd version interface is presented, and as shown the application has automatically allocated the defined BUs into 3 different sets based on their codes, and accordingly allocated the associated IRs into identical 3 different sets (based on the previously explained connection point between the academic and practice components of the introduced method). The user then will be able to select one or more BUs from the listed defined BUs combinations in the interface's 2nd window and initiate the practice related information definition for the selected BUs. Starting with defining the type of the IR by clicking on "modify information requirements" icon, a pop-up window appears for the user in which the application enables the user to tick one or more specific types of the IRs (including: OIR, AIR, PIR, and EIR) that are associated with the selected BUs, and by hitting confirm, the application will save the changes, and the user can move on to the following information deliverables' section. By clicking on the "modify delivered information" icon, a pop-up window appears in the interface, by which the user is able to select (from a drop down menu style) all the information related to the delivered information that are associated with the selected BUs, including nature (drawing, report, schedule, model, etc.), format (IFC, RVT, PLN, PDF, DWG, DOC, XLS, etc.), delivery party and/or individual (e.g., task team A and/or BIM 03 individual), receiving party and/or individual (e.g., delivery team 01 and/or BIM 07 individual), date (e.g., 02/04/2024), and phase (e.g., delivery or operation phase), after hitting confirm, the application will save all the changes and close the pop-up window.

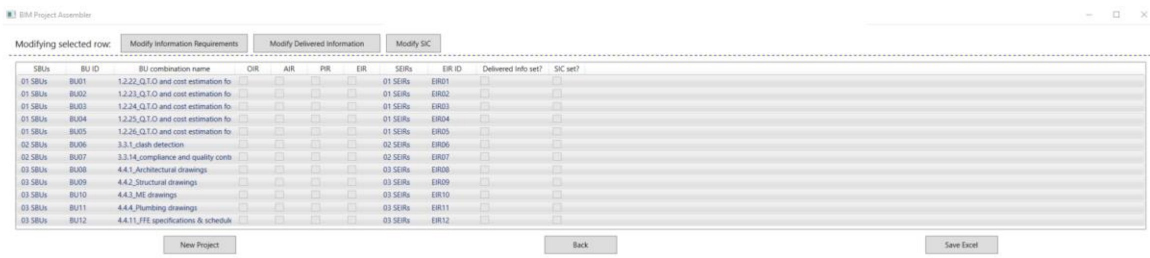


Figure 35: DEMO_Project, 2nd window of the application's 3rd version

Finally, the last step for the user is to define the related ICs with the corresponding selected BUs, in order to define the related information container/s the author has to define the federation strategy of the project's BIM model, the federation strategy includes the breakdown structure of the project's SICs and their included ICs. The process of defining the federation strategy for the intended project should be done once, since the same strategy is going to apply for all included BUs and their associated IRs in the entire project. On the other hand, the process of defining the related ICs should be done for all defined BUs and their associated IRs. The following Figure 36 demonstrates the pop-up window that appears to the user after clicking on "modify SIC" icon, this part has been refined in the 3rd version of the application, enabling the user to add one or more SICs by clicking on the "add group" icon, and then by selecting one SIC the user is able to add one or more ICs within the selected SIC by clicking on "add item" icon. Also, selecting any SIC or IC and clicking on "remove" icon will remove the selected groups and items. On the other hand, selecting any SIC or IC and clicking on "modify name" icon will enable the user to change the default generated title of the selected groups and items. Figure 37 shows the details that are associated with the previously introduced DEMO_Project example, the user in this case added three groups (three sets of ICs) including ARC, STR, and MEP. Also, the user added two items (two ICs) within each of the ARC, STR, and MEP sets of information containers, including INT/EXT, SUB/SUP, and ME/P, respectively.

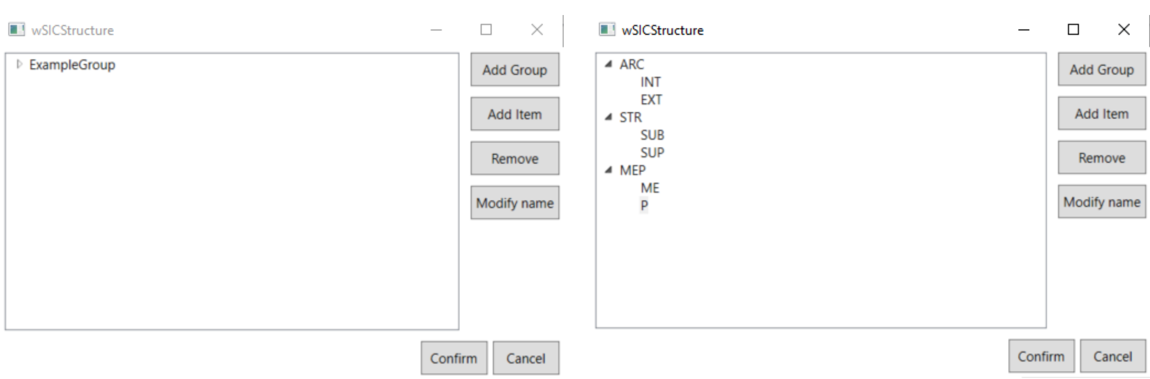


Figure 36: (to the left) pop-up window for the project's federation strategy

Figure 37: (to the right) an example for the defined DEMO_Project's federation strategy

By defining the SICs and ICs that are needed for the project and hitting the “confirm” button, the user adjusts the federation strategy for the whole project, not only for the selected BUs. Also, by hitting confirm another pop-up window appears for the user at which the application allows the user to tick the related ICs for the selected BUs, and from now on this pop-up window will appear every single time the user clicks on “modify SIC” icon in the 2nd window of the interface, in order to define the related ICs for the selected BUs (please see the following Figure 38). Moreover, if the user intends to change the federation strategy for the project after setting it, then the user has to click on the “Mod. SIC Structure” icon at the pop-up window, by clicking on this icon, the pop-up window that is shown in the previous Figure 37 will appear again for the user to make the intended changes on the breakdown structure of the SICs. As a demonstration, and in connection with the previously introduced DEMO_Project example, in Figure 38 the user ticked the INT, ME, and P information containers as related containers for the associated BU12 (4.4.11_FFE specifications and schedules).

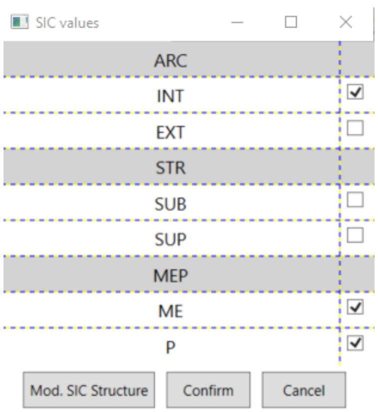


Figure 38: pinpoint the related ICs for the selected BUs

5.3. The application’s outcome

By defining needed BUs and their related information from the academic and practice components of the application, the user can finalize the method by hitting on the “save excel” icon at the 2nd window of the application’s interface. By hitting the save icon, the application will automatically export an excel file with a table that includes all information for the related project. The table is expected to assist AE SMEs to kick off and carry out BIM-based projects and overcome the previously defined key BIM barriers. The following Table 20, 21, and 22 represent the final saved table from the application for the previously introduced example DEMO_Project.

Table 20: saved table by the application for DEMO_Project (part 1)

Project Name: DEMO_Project		
Model Dimension: 3D, 5D		
Academic Related		
Defined BUs		
BUs Details		Objective Roadmap
SBUs	BU ID	BU Combinations
01 SBUs	BU01	1.2.22_Q.T.O and cost estimation for INT wall framing
01 SBUs	BU02	1.2.23_Q.T.O and cost estimation for EXT wall framing
01 SBUs	BU03	1.2.24_Q.T.O and cost estimation for structural framing

01 SBUs	BU04	1.2.25_Q.T.O and cost estimation for HVAC system
01 SBUs	BU05	1.2.26_Q.T.O and cost estimation for sanitary system
02 SBUs	BU06	3.3.1_Clash detection
02 SBUs	BU07	3.3.14_Compliance and quality control
03 SBUs	BU08	4.4.1_Architectural drawings
03 SBUs	BU09	4.4.2_Structural drawings
03 SBUs	BU10	4.4.3_ME drawings
03 SBUs	BU11	4.4.4_Plumbing drawings
03 SBUs	BU12	4.4.11_FFE specifications & schedules

Table 21: saved table by the application for DEMO_Project (part 2)

Project Name: DEMO_Project									
Model Dimension: 3D, 5D									
Practice Related									
Information Requirements						Delivered Information			
Related IR		Strategic		Project Sp.		Deliverables		Responsible Parties	
SIRs	IR ID	OIR	AIR	PIR	EIR	Nature	Format	Delivers	Receives
01 SIRs	IR01			✓	✓	Schedule	.XLS	BIM1	BIM5
01 SIRs	IR02			✓	✓	Schedule	.XLS	BIM1	BIM5
01 SIRs	IR03			✓	✓	Schedule	.XLS	BIM2	BIM5
01 SIRs	IR04			✓	✓	Schedule	.XLS	BIM3	BIM5
01 SIRs	IR05			✓	✓	Schedule	.XLS	BIM4	BIM5
02 SIRs	IR06	✓		✓	✓	Report	PDF	BIM2,3,4	BIM5,6
02 SIRs	IR07	✓		✓	✓	Model	IFC	BIM1	BIM5,6
03 SIRs	IR08			✓	✓	Drawing	PDF	BIM1	BIM5
03 SIRs	IR09			✓	✓	Drawing	PDF	BIM2	BIM5
03 SIRs	IR10			✓	✓	CAD	DWG	BIM3	BIM5
03 SIRs	IR11			✓	✓	CAD	DWG	BIM4	BIM5
03 SIRs	IR12	✓	✓	✓	✓	Report	PDF	BIM1,3,4	BIM5

Table 22: saved table by the application for DEMO_Project (part 3)

Project Name: DEMO_Project							
Model Dimension: 3D, 5D							
Practice Related							
Delivered Information		Breakdown Structure of Information Containers					
Time		ARC		STR		MEP	
Date	Phase	INT	EXT	SUB	SUP	ME	P
01/05	Delivery	✓					
01/05	Delivery		✓				
05/05	Delivery			✓	✓		
10/05	Delivery					✓	
10/05	Delivery						✓
15/05	Delivery	✓	✓	✓	✓	✓	✓
29/05	Delivery	✓	✓	✓	✓	✓	✓

01/05	Delivery	✓	✓				
05/05	Delivery			✓	✓		
10/05	Delivery					✓	
10/05	Delivery						✓
29/05	Delivery	✓				✓	✓

5.4. Application validation

As the title suggests, this subchapter will be dedicated to validate the developed application. The application that is introduced in this chapter is developed according to collective results derived from previously conducted research works. Starting with defining the studied region, target building industry SMEs, potential building industry SMEs (AE), BIM implementation among local AE SMEs, key BIM barriers against the implementation, deriving research mission to overcome defined key barriers, develop a method to answer the mission's objective to overcome barriers, and finally automate the developed method to accomplish the mission's objective. Hence, and at this stage, in order to validate the developed automated version of the introduced method, the main target is to check whether the developed application serves the main objective of the research's mission, including overcoming key BIM barriers or assisting to reduce the impact of defined key BIM barriers in the adoption process for local AE SMEs.

By thinking about the best way to test if the developed application and the introduced methodology is any good for local AE firms, the first thing that comes to mind is the high-level professionals who already defined key BIM barriers in the 1st and 2nd survey rounds in chapter three. The research suggests using the exact same sample of high-level employees from AE firms to evaluate the potential of the developed application in overcoming listed BIM barriers, and mainly the previously defined key BIM barriers. This can be accomplished by conducting 3rd and 4th survey rounds that are depending on the participants' sample from the 1st and 2nd rounds, then the results can be simply paired and associated accordingly for later on comparison purposes to derive conclusions.

5.4.1. Survey structure and details

In chapter three, the research conducted two survey rounds, the 1st survey round targeted high-level professionals from local AE SMEs based across the country's different regions. On the other hand, the 2nd survey round targeted high-level employees from the defined potential local AE SMEs that are based in the studied ST region. Accordingly, this chapter will perform two surveys that are targeting each group separately. The responses from each 3rd and 4th survey rounds will be collected and processed separately, and the outcomes will be listed and compared with the outcomes that are derived from the associated 1st and 2nd survey round.

Hence, the two intended survey rounds (3rd and 4th survey rounds) should have similar configuration and key characteristics compared to the 1st and 2nd rounds. Since the final intention of the validation stage is to perform paired comparison between the results of the associated survey rounds, hence the dependency between each associated survey pair will not only be limited to the participants' sample, but it will include dependencies among the ranking scale and listed alternatives, this will ensure simplicity and accuracy in the intended paired comparison between the results.

Similar to the previously conducted first two rounds, in the upcoming 3rd and 4th survey rounds the main focus in the surveys' structure will be to get the needed information with the least amount of time required to fill in the survey. The fact that the participants who responded to the 1st and 2nd survey rounds have already an idea about the necessity to get their feedback in the upcoming 3rd and 4th survey rounds helped a lot to minimize the length of the survey structure, because the research in this case is not totally new for the respondents, and they expect to receive a request to participate in the complementary survey round. The respondents of the 1st survey round will have to respond to the 3rd survey round, and respondents from the 2nd survey round will have to respond to the 4th survey round. The 3rd and 4th survey rounds have semi-identical structure, including three sections. The 1st section briefly reminds the participant with the research, introduces the results of the previous associated survey round, and thanks the participant for taking part in the research. The 2nd section includes the introduction of a short guide video to the developed application in action. Followed by the 3rd section that includes a rank and a request from the participant to rank the introduced developed application based on its relevancy to overcome or solve the associated BIM barrier, this section includes all 18 BIM barriers listed right after each other and aligned with tick boxes, each tick box is associated with a number from 1-9, 1 means that the application is not useful at all to overcome the associated BIM barrier, and 9 means that the application is very useful to overcome the associated BIM barrier. The participant is asked to tick the associated box based on the potential of the introduced application to overcome the aligned barrier, and by ranking all BIM barriers and hitting done the respondent completes the survey and the response will be recorded.

Irrelevant questions or questions with already known answers were not included in these rounds of the survey, e.g., personal and company-related (since the answers are already known from the previous rounds), BIM adoption-related (adoption level is known from the previous rounds), and contact information-related question. The survey study used the SurveyMonkey platform to collect responses from participants. The questions of the survey were uploaded to the SurveyMonkey with the planned sequence and structure of the survey, then a link and QR code have been generated, and the participant needs to click on the link or scan the QR code in order to reach the survey sheet and answer the questions.

5.4.2. Conducted survey rounds

The research will apply to the AHP that was implemented in chapter three in connection with key BIM barriers definition. The implementation of the AHP in the following two survey rounds will facilitate the comparison processes with the previously conducted associated surveys and provide more accurate results with ratios regarding the role of the developed application in overcoming defined key BIM barriers. In order to avoid duplication and repeated information, all of the AHP-related introduction, advantages, disadvantages, formulas, and fundamentals will be found in the third chapter at 3.4 "key implementation barriers in local AE firms" subchapter.

The 3rd survey round has been distributed among high-level building industry professionals who participated in one of the following two programs: Pollack Expo 2024 or the professional BIM program's workshop 2024 at PTE MIK, bearing in mind that the participants are the same who have already participated in the 1st round survey. The participants are high-level AE professionals who work for companies based in different Hungarian regions across the country, and please be notified that only high-level employees from AE firms (relevant respondents from the 1st round survey) participated in the 3rd survey round, low-level respondents or respondents from other building industry scopes or sizes (firms out of the AE SMEs scope) were excluded from participating in this survey round to ensure consistency among the participants' samples.

The 4th survey round is distributed to the responded AE firms that have been surveyed in the 2nd round survey, accounting for 74% of the total surveyed firms. Only one response is needed for each surveyed firm, and the response should be conducted by a high-level employee who is the same individual that answered the previous 2nd round survey, hence in that survey it was essential to get the contact information (email address) for the participant who is answering the survey in order to facilitate reaching up to the exact person in the complementary survey round.

5.4.2.1. 3rd survey round

This section represents the rank responses that are collected from the 3rd survey round, starting with listing all the alternatives (BIM barriers) that are included in the survey, and the total sum of ranks per each alternative. Then, an average for each total sum is calculated and aligned to the related alternative as shown in the following Table 23.

Table 23: sums and averages of the 3rd survey's rankings

	B01	B02	B03	B04	B05	B06	B07	B08	B09
∑	353	363	257	295	365	351	110	108	111
Avg.	7.67	7.89	5.59	6.41	7.93	7.63	2.39	2.35	2.41
	B10	**B11**	**B12**	**B13**	**B14**	**B15**	**B16**	**B17**	**B18**
∑	112	172	162	161	147	116	126	144	132
Avg.	2.43	3.74	3.52	3.5	3.2	2.52	2.74	3.13	2.87

After calculating the sums and means of each alternative, the next step of the AHP is to conduct pairwise comparison between the alternatives. In this research there are homogeneous elements among the list of alternatives (BIM barriers), and there is single criteria for respondents to rank the alternatives, according to the included request in section three of the survey's structure which asks the participant to rank the application's potential to overcome the listed alternatives (BIM barriers) on a scale from 1-9, at which 1 is very low potential to assist in overcoming the related barrier and 9 represents very-high potential to overcome the associated barrier. Starting with the PCM which is approached by listing all ranked alternatives from the survey at the upper and left sides of the matrix, as an attempt to create a pairwise comparison between each possible pair formed by two identical or different alternatives (according to Equation 5), the values in the matrix are derived by performing a mutual division process between the mean values associated with each of the compared alternatives. Please see the following Table 24 for more information regarding the 3rd survey round pairwise comparison matrix.

Table 24: pairwise comparison matrix of the application's potential to overcome related BIM barriers (3rd survey round)

	B01	B02	B03	B04	B05	B06	B07	B08	B09
B01	**1**	0.97	1.37	1.2	0.97	1.01	3.21	3.26	3.18
B02	1.03	**1**	1.41	1.23	0.99	1.03	3.3	3.36	3.27
B03	0.73	0.71	**1**	0.87	0.7	0.73	2.34	2.38	2.32
B04	0.84	0.81	1.15	**1**	0.81	0.84	2.68	2.73	2.66
B05	1.03	1.01	1.42	1.24	**1**	1.04	3.32	3.37	3.29
B06	0.99	0.97	1.36	1.19	0.96	**1**	3.19	3.25	3.17
B07	0.31	0.3	0.43	0.37	0.3	0.31	**1**	1.02	0.99
B08	0.31	0.3	0.42	0.37	0.3	0.31	0.98	**1**	0.98
B09	0.31	0.31	0.43	0.38	0.3	0.32	1.01	1.03	**1**
B10	0.32	0.31	0.43	0.38	0.31	0.32	1.02	1.03	1.01
B11	0.49	0.47	0.67	0.58	0.47	0.49	1.56	1.59	1.55

B12	0.46	0.45	0.63	0.55	0.44	0.46	1.47	1.5	1.46
B13	0.46	0.44	0.63	0.55	0.44	0.46	1.46	1.49	1.45
B14	0.42	0.41	0.57	0.5	0.4	0.42	1.34	1.36	1.33
B15	0.33	0.32	0.45	0.39	0.32	0.33	1.05	1.07	1.05
B16	0.36	0.35	0.49	0.43	0.35	0.36	1.15	1.17	1.14
B17	0.41	0.4	0.56	0.49	0.39	0.41	1.31	1.33	1.3
B18	0.37	0.36	0.51	0.45	0.36	0.38	1.2	1.22	1.19
	B10	**B11**	**B12**	**B13**	**B14**	**B15**	**B16**	**B17**	**B18**
B01	3.16	2.05	2.18	2.19	2.4	3.04	2.8	2.45	2.67
B02	3.25	2.11	2.24	2.25	2.47	3.13	2.88	2.52	2.75
B03	2.3	1.49	1.59	1.6	1.75	2.22	2.04	1.79	1.95
B04	2.64	1.71	1.82	1.83	2	2.54	2.34	2.05	2.23
B05	3.26	2.12	2.25	2.27	2.48	3.15	2.89	2.53	2.76
B06	3.14	2.04	2.17	2.18	2.38	3.03	2.78	2.44	2.66
B07	0.98	0.64	0.68	0.68	0.75	0.95	0.87	0.76	0.83
B08	0.97	0.63	0.67	0.67	0.73	0.93	0.86	0.75	0.82
B09	0.99	0.64	0.68	0.69	0.75	0.96	0.88	0.77	0.84
B10	**1**	0.65	0.69	0.69	0.76	0.96	0.89	0.78	0.85
B11	1.54	**1**	1.06	1.07	1.17	1.48	1.36	1.19	1.3
B12	1.45	0.94	**1**	1.01	1.1	1.4	1.28	1.12	1.23
B13	1.44	0.94	0.99	**1**	1.09	1.39	1.28	1.12	1.22
B14	1.32	0.86	0.91	0.91	**1**	1.27	1.17	1.02	1.11
B15	1.04	0.67	0.72	0.72	0.79	**1**	0.92	0.81	0.88
B16	1.13	0.73	0.78	0.78	0.86	1.09	**1**	0.88	0.95
B17	1.29	0.84	0.89	0.89	0.98	1.24	1.14	**1**	1.09
B18	1.18	0.77	0.82	0.82	0.9	1.14	1.05	0.92	**1**

The base of the AHP is established by completing the PCM according to the mutual division process of the previously calculated mean values of each ranked alternative. The pairwise matrix provides a comprehensive representation of the relative importance of the ranked application with respect to each associated barrier. Now the next step is to derive the relative weights of each alternative to conclude the potential of the developed application in overcoming each of the listed barriers. Similar to the 1st round survey, the 3rd round is going to follow the previously introduced and applied Equation 7, 8, and 9 to derive the weight w_i of each alternative, for that the research will calculate the sum of each alternative column sum_j from the established PCM, for more details please check the following Table 25. After that, the research normalizes the established PCM by creating a new matrix with the same size and same alternatives, the elements' values (a'_{ij}) of the normalized matrix will be the results of dividing each element from the matrix with the associated sum_j for its column, please refer to Equation 8 for more details. After deriving the normalized PCM, the following step is to derive the weight for each alternative by averaging the associated alternative row from the normalized PCM. Lastly, a consistency check is performed to validate and ensure the results of the established PCM and derived weights, by calculating the CI and CR according to Equation 10 and 11. Before calculating the CI and CR, the research will calculate the eigenvalues λ for each alternative and derive the largest eigenvalue λ_{max}; a multiplying process is performed between all elements in one row at the non-normalized PCM with the relative weight w_i of the same alternative, and then by adding up all the results from the multiplying processes in one row, the result value will represent the eigenvalue λ for the related row's alternative. By repeating the process for all rows, the result will be 18 λ values for each alternative, the average of these 18 λ values will represent λ_{max}. Please see the following Table 26 for more details.

Table 25: sum of each alternative column from the established PCM (3rd survey round)

	B01	B02	B03	B04	B05	B06	B07	B08	B09
sum_j	10.17	9.89	13.93	12.17	9.81	10.22	32.59	33.16	32.34
	B10	**B11**	**B12**	**B13**	**B14**	**B15**	**B16**	**B17**	**B18**
sum_j	32.08	20.83	22.14	22.25	24.36	30.92	28.43	24.9	27.14

Table 26: calculating λ values for each alternative, deriving λ_max, and checking the consistency of the established PCM (3rd survey round)

	w_i	λ	RI
B01	0.098451	18.06429	0
B02	0.101191	18.01584	0
B03	0.071724	17.9125	0.58
B04	0.08226	18.03902	0.9
B05	0.101769	17.94118	1.12
B06	0.097875	17.95816	1.24
B07	0.030601	17.75161	1.32
B08	0.030239	18.12333	1.41
B09	0.030931	17.94194	1.45
B10	0.031231	18.11613	1.49
B11	0.047915	17.95	1.51
B12	0.045175	18.05111	1.48
B13	0.044939	17.95778	1.56
B14	0.041081	18.01707	1.57
B15	0.032365	18.1875	1.59
B16	0.035258	18.11429	1.605
B17	0.040172	18.06	1.61
B18	0.036824	17.8973	**1.615**

λ_{max}
$\lambda_{max} = \bar{x}\lambda = \bar{x}\sum A.w_i$
By averaging all λ values
$\lambda_{max} = 18.0055$

Consistency Index CI
$CI = \frac{\lambda_{max} - n}{n - 1}$
CI=0.000324 which is < 0.1
Consistency index is significant

Consistency Ratio CR
$CR = \frac{CI}{RI}$
CR=0.0002 which is < 0.1
Consistency ratio is significant

5.4.2.2. 4th survey round

This section represents the rank responses that are collected from the 4th survey round, starting with listing all the alternatives that are included in the survey, and the total sum of ranks per alternative. Then, the mean value for each total sum is calculated and aligned to the related alternative as shown in the following Table 27.

Table 27: sums and averages of the 4th survey's rankings

	B01	B02	B03	B04	B05	B06	B07	B08	B09
$\sum$	362	390	358	366	395	389	81	82	79
Avg.	7.87	8.478	7.783	7.957	8.587	8.457	1.761	1.783	1.717
	B10	**B11**	**B12**	**B13**	**B14**	**B15**	**B16**	**B17**	**B18**
$\sum$	76	229	132	222	105	79	77	86	80
Avg.	1.652	4.978	2.87	4.826	2.283	1.717	1.674	1.87	1.739

After calculating the sums and means of each alternative, the next step of the AHP is to conduct pairwise comparison between the alternatives. Similar to the previously conducted 3rd round survey, in this round there is a list of homogeneous alternatives (BIM barriers), and there is single criteria for respondents to rank the alternatives, according to the included request in section three of the survey's structure which asks the participant to rank the application's potential to overcome the listed alternatives (BIM barriers) on a scale from 1-9, at which 1 is very low potential to assist in overcoming the related barrier and 9 represents very-high potential to overcome the associated barrier. Starting with the PCM which is approached by listing all ranked alternatives from the survey at the upper and left sides of the matrix, to create a pairwise comparison between each possible pair formed by two identical or different alternatives (according to Equation 5), the values in the matrix are derived by performing a mutual mathematical division between the mean values associated with each of the compared alternatives. Please see the following Table 28 for more information regarding the 4th survey round pairwise comparison matrix.

Table 28: pairwise comparison matrix of the application's potential to overcome related BIM barriers (4th survey round)

	B01	**B02**	**B03**	**B04**	**B05**	**B06**	**B07**	**B08**	**B09**
B01	**1.00**	0.93	1.01	0.99	0.92	0.93	4.47	4.41	4.58
B02	1.08	**1.00**	1.09	1.07	0.99	1.00	4.81	4.75	4.94
B03	0.99	0.92	**1.00**	0.98	0.91	0.92	4.42	4.37	4.53
B04	1.01	0.94	1.02	**1.00**	0.93	0.94	4.52	4.46	4.63
B05	1.09	1.01	1.10	1.08	**1.00**	1.02	4.88	4.82	5.00
B06	1.07	1.00	1.09	1.06	0.98	**1.00**	4.80	4.74	4.93
B07	0.22	0.21	0.23	0.22	0.21	0.21	**1.00**	0.99	1.03
B08	0.23	0.21	0.23	0.22	0.21	0.21	1.01	**1.00**	1.04
B09	0.22	0.20	0.22	0.22	0.20	0.20	0.98	0.96	**1.00**
B10	0.21	0.19	0.21	0.21	0.19	0.20	0.94	0.93	0.96
B11	0.63	0.59	0.64	0.63	0.58	0.59	2.83	2.79	2.90
B12	0.36	0.34	0.37	0.36	0.33	0.34	1.63	1.61	1.67
B13	0.61	0.57	0.62	0.61	0.56	0.57	2.74	2.71	2.81
B14	0.29	0.27	0.29	0.29	0.27	0.27	1.30	1.28	1.33
B15	0.22	0.20	0.22	0.22	0.20	0.20	0.98	0.96	1.00
B16	0.21	0.20	0.22	0.21	0.19	0.20	0.95	0.94	0.97
B17	0.24	0.22	0.24	0.24	0.22	0.22	1.06	1.05	1.09
B18	0.22	0.21	0.22	0.22	0.20	0.21	0.99	0.98	1.01
	B10	**B11**	**B12**	**B13**	**B14**	**B15**	**B16**	**B17**	**B18**
B01	4.76	1.58	2.74	1.63	3.45	4.58	4.70	4.21	4.53
B02	5.13	1.70	2.95	1.76	3.71	4.94	5.06	4.53	4.88
B03	4.71	1.56	2.71	1.61	3.41	4.53	4.65	4.16	4.48
B04	4.82	1.60	2.77	1.65	3.49	4.63	4.75	4.26	4.58
B05	5.20	1.72	2.99	1.78	3.76	5.00	5.13	4.59	4.94
B06	5.12	1.70	2.95	1.75	3.70	4.93	5.05	4.52	4.86
B07	1.07	0.35	0.61	0.36	0.77	1.03	1.05	0.94	1.01
B08	1.08	0.36	0.62	0.37	0.78	1.04	1.07	0.95	1.03
B09	1.04	0.34	0.60	0.36	0.75	1.00	1.03	0.92	0.99
B10	**1.00**	0.33	0.58	0.34	0.72	0.96	0.99	0.88	0.95
B11	3.01	**1.00**	1.73	1.03	2.18	2.90	2.97	2.66	2.86
B12	1.74	0.58	**1.00**	0.59	1.26	1.67	1.71	1.53	1.65
B13	2.92	0.97	1.68	**1.00**	2.11	2.81	2.88	2.58	2.78
B14	1.38	0.46	0.80	0.47	**1.00**	1.33	1.36	1.22	1.31
B15	1.04	0.34	0.60	0.36	0.75	**1.00**	1.03	0.92	0.99

B16	1.01	0.34	0.58	0.35	0.73	0.97	**1.00**	0.90	0.96
B17	1.13	0.38	0.65	0.39	0.82	1.09	1.12	**1.00**	1.08
B18	1.05	0.35	0.61	0.36	0.76	1.01	1.04	0.93	**1.00**

The base of the AHP is established by completing the PCM according to the mutual division process of the previously calculated mean values of each ranked alternative. The pairwise matrix provides a comprehensive representation of the relative importance of the ranked application with respect to each associated barrier. The following step is to calculate the relative weights of each alternative to conclude the potential of the developed application in overcoming each of the listed alternatives. Similar to all previously conducted survey rounds, the 4th round is going to follow the introduced and applied Equation 7, 8, and 9 to derive the weight w_i of each alternative. For that, the research will calculate the sum of each alternative column sum_j from the established PCM, for more details please check the following Table 29. After that, the research normalizes the established PCM by creating a new matrix with the same size and same alternatives, the elements' values (a'_{ij}) of the normalized matrix will be the results of dividing each element from the matrix with the associated sum_j for its column, please refer to Equation 8 for more details. After deriving the normalized PCM, the next step is to derive the weight for each alternative by averaging the associated alternative row from the normalized PCM. Lastly, a consistency check is performed to validate and ensure the results of the established PCM and derived weights, by calculating the CI and CR according to Equation 10 and 11. Before calculating the CI and CR, the research will calculate the eigenvalues λ for each alternative and derive the largest eigenvalue λ_{max}; a multiplying process is performed between all elements in one row at the non-normalized PCM with the relative weight w_i of the same alternative, and then by adding up all the results from the multiplying processes in one row, the result value will represent the eigenvalue λ for the related row's alternative. By repeating the process for all rows, the result will be 18 λ values for each alternative, the average of these 18 λ values will represent λ_{max}. Please see the following Table 30 for more details.

Table 29: sum of each alternative column from the established PCM (4th survey round)

	B01	**B02**	**B03**	**B04**	**B05**	**B06**	**B07**	**B08**	**B09**
sum_j	9.9	9.21	10.02	9.83	9.09	9.23	44.31	43.75	45.42
	B10	**B11**	**B12**	**B13**	**B14**	**B15**	**B16**	**B17**	**B18**
sum_j	47.21	15.66	27.17	16.16	34.15	45.42	46.59	41.7	44.88

Table 30: calculating λ values for each alternative, deriving λ_max, and checking the consistency of the established PCM (4th survey round)

	w_i
B01	0.100892
B02	0.108696
B03	0.099793
B04	0.102015
B05	0.110052
B06	0.10836
B07	0.022591
B08	0.022877
B09	0.022018
B10	0.021151

λ	**RI**
18.0485	0
18.0174	0
18.03	0.58
18.0706	0.9
18.0764	1.12
18.1278	1.24
17.7478	1.32
17.9696	1.41
18.0818	1.45
18.2	1.49

λ_{max}
$\lambda_{max} = \bar{x}\lambda = \bar{x}\sum A.w_i$
By averaging all λ values
$\lambda_{max} = 18.00737$

Consistency Index CI
$CI = \frac{\lambda_{max} - n}{n - 1}$

B11	0.063825
B12	0.036742
B13	0.061846
B14	0.02929
B15	0.022018
B16	0.021466
B17	0.024045
B18	0.022323

18.0188	1.51
17.9405	1.48
18.0226	1.56
17.64	1.57
18.0818	1.59
17.6273	1.605
18.1	1.61
18.3318	**1.615**

CI=0.000434 which is < 0.1
Consistency index is significant

Consistency Ratio CR
$CR = \frac{CI}{RI}$
CR=0.000268 which is < 0.1
Consistency ratio is significant

5.4.3. The potential of the developed application to overcome key BIM barriers by comparing the results

The research will conduct a comparison between the relative weight results of the listed alternatives. The core of the comparison is based on studying the change ratio between the potential of the alternative (relative importance of the alternative) and the potential of the developed application to overcome the same alternative. The change percentage will be based on the weight value that is derived from each survey round. Due to the fact that the performed survey rounds are paired, mainly in connection with the participant's sample, hence, the research is going to compare the weights of the alternatives from each survey with their counterparts from the paired survey. The 1st pair includes the 1st and 3rd survey rounds, the target respondents for the 1st pair surveys are high-level local AE professionals who represent local AE SMEs that are based in different regions across the country. On the other hand, the 2nd pair includes the 2nd and 3rd survey rounds, and the target respondents for these rounds are high-level AE professionals who represent the previously defined potential local AE SMEs based in the ST region.

This part of the research focuses on highlighting the potential of the developed application which will accordingly validate the methodology behind the application that was developed previously. The logic of using the comparative approach to validate the results is the simplicity and accuracy of this approach compared to other methods. This approach will enable simple outcomes' representation with accurate and understandable manner for the readers regardless of their backgrounds. Moreover, the ability to perform a paired comparison between the surveys' results is facilitated by contact accessibility to the same participants' sample from the associated previous survey (e.g., the availability of the contact information for high-level AE professionals who defined key BIM barriers in the 1st and 2nd survey rounds), the high level of similarity between the two associated survey rounds (including using the same presentation style and ranking scale), and finally the high interest from local AE professionals to adopt BIM-based workflows in their companies. The following Figure 39 demonstrates the weight scores differences between the 1st and 3rd survey rounds for each alternative BIM barrier. Figure 40 demonstrates the weight differences between the 2nd and 4th survey rounds.

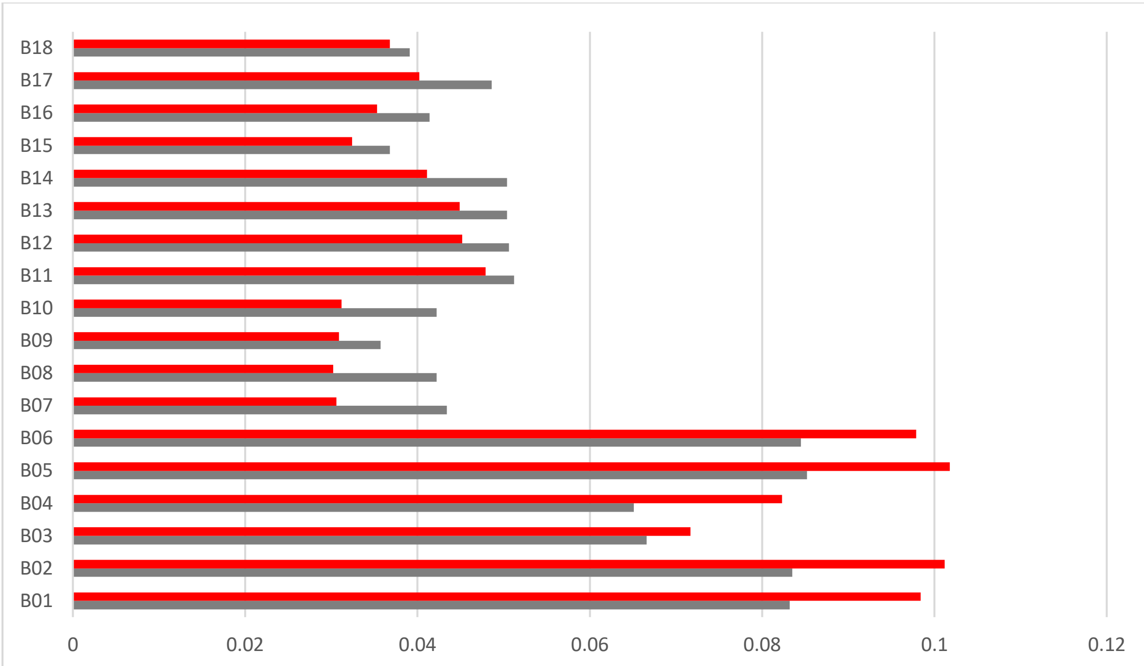


Figure 39: weight differences between the 1st (grey) and 3rd (red) survey rounds

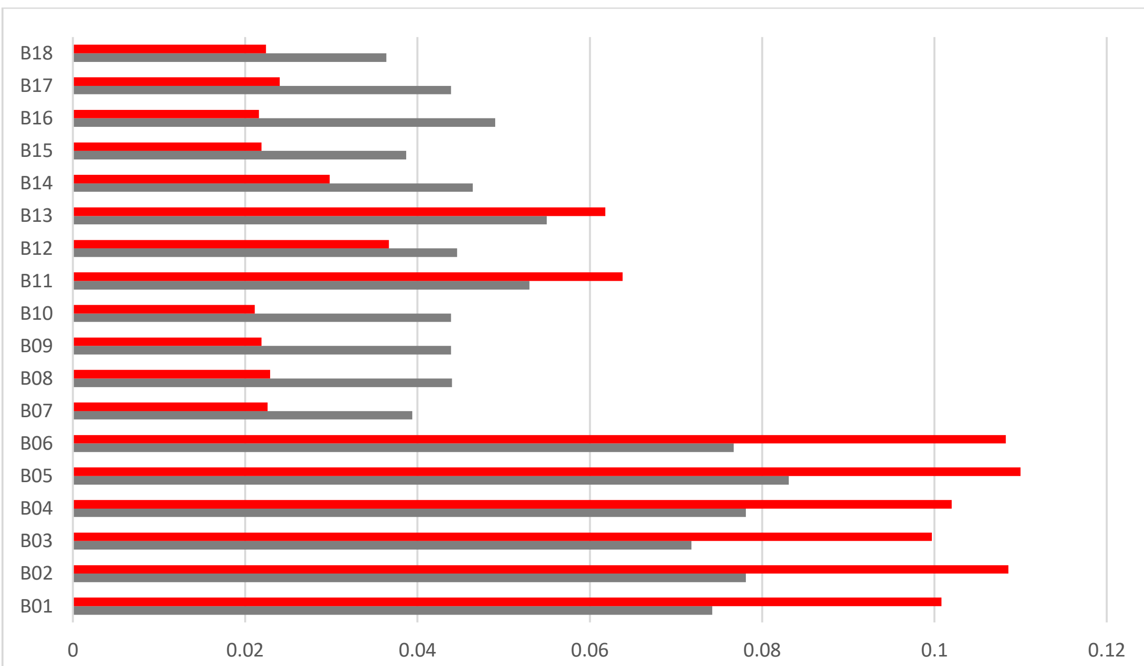


Figure 40: weight differences between the 2nd (grey) and 4th (red) survey rounds

The following Table 31 demonstrates the three levels of BIM barriers including the primary, secondary and tertiary levels, and their associated relative weights that are associated with the tertiary level's BIM barriers. The table shows two pair sets, the 1st pair includes relative weights from the 1st and 3rd survey rounds, and the 2nd pair includes relative weights from the 2nd and 4th survey rounds, the first weight column in each set represents the potential of the associated BIM barriers, and the second weight column represents the potential of the introduced application to overcome the associated BIM barriers. Hence, the percentages of increase or decrease from the 1st to the 3rd weight values will provide an accurate evaluation for the potential of the developed application in overcoming the associated BIM barriers. A nearly zero increase/decrease ratio between the compared weights will indicate more or less an equivalent effect for the developed application to overcome the associated barrier (the developed application has potential to overcome the associated barrier nearly equivalent to the barrier's potential in BIM adoption), meanwhile negative and very low decrease ratio between the compared weights will indicate negative effect for the developed application to overcome the associated barrier (the developed application has low potential to overcome the associated barrier, the potential of the barriers in BIM adoption is higher than the potential of the application to assist in overcoming that barrier), and a positive increase ratio between the compared weights will indicate a positive effect for the developed application to overcome the associated barrier (the developed application has high potential to overcome the associated barrier, the barrier's potential in BIM adoption is lower than the application's potential to overcome that barrier).

The 1st pair set includes relative weights from the 1st and 3rd survey rounds and the calculated increase/decrease ratios. The positive difference ratios between w_{i1} and w_{i3} are accomplished by the tertiary BIM barriers (B01-B06) that belong to the processes/uses (B01, B02, and B03) and legal/management (B04, B05, and B06) subgroups from the secondary level and methods/standards subgroup from the primary level. This means that the local Hungarian AE SMEs that are based in different regions across the country testify the high potential of the developed application to overcome defined key BIM barriers against the adoption of BIM workflows, with relative evaluation weights at the highest quarter (> 0.0750) and increasing difference ratio with 18.269%, 21.198%, 7.658%, 26.421%, 19.484%, and 15.858%, representing the following key BIM barriers: B01 (lack of BIM adoption definition methods/workflows), B02 (lack of BIM Uses definitions and objectives), B03 (lack of BIM-based project parties' collaboration), B04 (undefined security, legal liability, and responsibility), B05 (management/contractual BIM processes, e.g., BEP), and B06 (undefined related business standards for BIM adoption), respectively.

Table 31: paired comparison between the relative weights from the conducted survey rounds, and their associated increase/decrease ratios

Barriers levels			**1st pair weights and ± ratio**			**2nd pair weights and ± ratio**			**Merged**
P	**S**	**T**	w_{i1}	w_{i3}	**Dif. ratio**	w_{i2}	w_{i4}	**Dif. ratio**	**∑ dif. r.**
1st	**1**	**B01**	0.0832	0.0984	+18.269 %	0.0742	0.1008	+35.849 %	+54.12%
		B02	0.0835	0.1012	+21.198 %	0.0781	0.1086	+39.052 %	+60.25%
		B03	0.0666	0.0717	+7.658 %	0.0718	0.0997	+38.858 %	+46.52%
	2	**B04**	0.0651	0.0823	+26.421 %	0.0781	0.1020	+30.602 %	+57.02%
		B05	0.0852	0.1018	+19.484 %	0.0831	0.1100	+32.371 %	+51.86%
		B06	0.0845	0.0979	+15.858 %	0.0767	0.1083	+41.199 %	+57.06%
2nd	**3**	**B07**	0.0434	0.0306	-29.493 %	0.0394	0.0226	-42.640 %	-72.13%
		B08	0.0422	0.0302	-28.436 %	0.0440	0.0229	-47.955 %	-76.39%
	4	**B09**	0.0357	0.0309	-13.445 %	0.0439	0.0219	-50.114 %	-63.56%
		B10	0.0422	0.0312	-26.066 %	0.0439	0.0211	-51.936 %	-78.00%
3rd	**5**	**B11**	0.0512	0.0479	-6.445 %	0.0530	0.0638	+20.377 %	+13.93%
		B12	0.0506	0.0452	-10.672 %	0.0446	0.0367	-17.713 %	-28.39%
4th	**6**	**B13**	0.0504	0.0449	-10.913 %	0.0550	0.0618	+12.364 %	+1.45%
		B14	0.0504	0.0411	-18.452 %	0.0464	0.0298	-35.776 %	-54.23%
	7	**B15**	0.0368	0.0324	-11.957 %	0.0387	0.0219	-43.411 %	-55.37%
5th	**8**	**B16**	0.0414	0.0353	-14.734 %	0.0490	0.0216	-55.918 %	-70.65%

		B17	0.0486	0.0402	-17.284 %	0.0439	0.0240	-45.330 %	-62.61%
		B18	0.0391	0.0368	-5.882 %	0.0364	0.0224	-38.462 %	-44.34%

On the other hand, the 2nd pair set includes relative weights from the 2nd and 4th survey rounds and the calculated increase/decrease ratios. The positive difference ratios between w_{i2} and w_{i4} are accomplished by the tertiary BIM barriers (B01-B06, B11, and B13) that belong to the processes/uses (B01, B02, and B03), legal/management (B04, B05, and B06), conservative culture (B11), and awareness/skills (B13) subgroups from the secondary level, and methods/standards, cultural, and abilities/capabilities subgroups from the primary level, respectively. This means that the local potential Hungarian AE SMEs that are based in the ST region testify the high potential of the developed application to overcome defined key BIM barriers (B01-B06) for the adoption of BIM workflows. Accounting for relative evaluation weights at the highest quarter (> 0.0750) for key BIM barriers (B01-B06), and the second highest quarter (0.0500-0.0750) for (B11 and B13). With increasing difference ratios accounting for 35.849%, 39.052%, 38.858%, 30.602%, 32.371%, 41.199%, 20.377%, and 12.364%, representing the following BIM barriers: B01 (lack of BIM adoption definition methods/workflows), B02 (lack of BIM Uses definitions and objectives), B03 (lack of BIM-based project parties' collaboration), B04 (undefined security, legal liability, and responsibility), B05 (management/contractual BIM processes, e.g., BEP), B06 (undefined related business standards for BIM adoption), B11 (industry resistance and difficulty to change processes), and B13 (lack of BIM knowledge, awareness, and research), respectively.

6. Results and discussion

This chapter is dedicated to listing all concluded results and outcomes from the conducted research work during the duration of the related study program. The results are going to be listed based on the research's timeline sequence, meaning that the results are going to be listed respectively based on the obtaining time starting with the earlier and finishing with later concluded results.

6.1. Direct results and their potential applications

- Based on the analyzed data regarding construction outcomes for small regions in Hungary by the location of the building industry firms, the ST region has the lowest value of CP compared to other small regions in the country. The study presents the percentage of construction production of building industry enterprises based on the ST region and compares it with the percentages for other small regions in Hungary for five years (between 2016 and 2020). The results show that building industry companies in the ST region suffer from severe low values of CP (6%) compared to same value from the country's other small regions that reach up to 9%, 9%, 9%, 10%, 13%, 14%, and 30%, for Central Transdanubia, Western Transdanubia, Northern Hungary, Norther Great Plain, Pest, Southern Great Plain, and Budapest, respectively.
- Based on the introduced size-based nomination method, which is supported by a statistical measure of spread among the set of values for related size indicators, the research reveals that the majority of the collected building industry firms in the ST region are small size firms or SMEs accounting for 93% (158 firms) of the total collected 169 building industry firms. Including the following NACE (Statistical Classification of Economic Activities in the European Community) business classes: 25.11, 28.99, 35.30, 41.10, 41.20, 42.13, 42.21, 42.91, 43.21, 43.22, 43.34, 43.99, 45.21, 47.52, 68.10, 68.20, 68.31, 70.22, 71.11, 71.12, 74.90, and 80.20, representing the following main activities: manufacture of metal

structures and parts of structures, manufacture of other special-purpose machinery, steam and air conditioning supply, development of building projects, constructions of residential and non-residential buildings, constructions of bridges and tunnels, construction of utility projects for fluids, construction of water projects, electrical installation, plumbing, heat, and air-conditioning installation, painting and glazing, other specialized construction activities, general construction of buildings and civil engineering works, retail sale of hardware, paints, and glass in specialized stores, buying and selling of own real estate, renting and operating of own or leased real estate, real estate agencies, business and other management consultancy activities, architectural activities, engineering activities and related technical consultancy, other professional, scientific, and technical activities, and security systems service activities, respectively.

- Based on the introduced size-based nomination method, which is supported by a statistical measure of spread among the set of values for related size indicators, the research reveals that minor group (13 firms) of the collected building industry firms in the ST region are considered large firms, accounting for 7% of the total collected 169 building industry firms, including the following NACE business classes: 16.22, 23.61, 25.21, 5x41.20, 2x42.21, 43.22, 71.11, and 71.12, that represent the following main activities: manufacture of assembled parquet floors, manufacture of concrete products for construction purposes, manufacture of central heating radiators and boilers, constructions of residential and non-residential buildings, construction of utility projects for fluids, and plumbing, heat, air-conditioning installation, architectural activities, and engineering activities and related technical consultancy, respectively.
- The research reveals the high potential firms from the defined target group small-size (SMEs) building industry firms. According to the results of the conducted comparison study between all target group firms and based on the values of their key indicators, the highest potential firms are AE firms with the following NACE business classes: 71.11 and 71.12, and main activities: architectural activities and engineering activities & related technical consultancies, respectively. The potential AE firms in the ST region account for 62.82%, 38.39%, and 28.57%, of the total share for the available main three indicators: number of firms, number of employees, and net revenue, respectively.
- The level of BIM adoption among local AE SMEs that are based in different Hungarian regions and surveyed according to a convenience sampling method is lagging behind the industry, the percentage of the firms that adopt BIM processes (minimum NBS BIM Level 02) is significantly low, accounting for 21.74% at the optimal case.
- The level of ISO 19650 standards adoption among local AE SMEs that are based in different Hungarian regions and surveyed according to a convenience sampling method is lagging behind the industry, the percentage of the firms that adopt ISO 19650 standards is significantly low, accounting for 9%.
- The level of BIM adoption among the potential AE SMEs that are based in the ST region and surveyed according to a purposive sampling method is lagging behind the industry, the percentage of the firms that adopt BIM processes (minimum NBS BIM Level 02) is considered low, accounting for 21.74% at the optimal case. and goes down to 13.04% at the inadequate case.
- The level of ISO 19650 standards adoption among the potential AE SMEs that are based in the ST region and surveyed according to a purposive sampling method is lagging behind the industry, the percentage of the firms that adopt ISO 19650 standards is considered low, accounting for 13.04%.
- The research reveals key BIM barriers for local AE SMEs based on scored relative weights derived from two survey rounds. Local AE professionals share similar concerns regarding

BIM adoption barriers, which assist in developing a research mission to overcome defined key barriers.

- The research prioritizes BIM barriers based on their relevant weights according to local AE SMEs, it is concluded that processes, uses, legal, and management barriers account for the highest and almost double the priorities of other barriers. Followed by the business culture, client culture, knowledge, experience, policy, and time related BIM barriers with medium priority level compared to key barriers. Lastly, the low priority barriers include tools cost, expertise cost, return, benefit, ICT, and efficiency related barriers.
- The research formulates an objective BIM adoption mission, which is derived from key BIM barriers defined by local AE SMEs. The main intention of the mission is to develop a method for overcoming associated BIM barriers and assisting in BIM implementation at prospective AE SMEs, and other building industry firms with similar challenges.
- By studying and reviewing a collection of particular and comprehensive academic sources, the research derives an academic-based roadmap to pinpoint objective BUs on a multi-level functional-based manner, representing the academic component of the developed method.
- By studying and reviewing the ISO 19650-1/2 BIM-related standards, the research derives a set of practice potential points to be embedded in the practice component of the developed method, including information requirements, phases, parties, and information delivery plan.
- The study connects the academic and practice components by matching BUs and IRs, and suggests a code syntax to classify and arrange defined specific BUs from the academic component with the corresponding IRs and their practice related details from the practice component.
- The research develops a methodology to pinpoint objective BUs for BIM-based projects aligned with business standards to facilitate the development of the BEP document by the management team. The method is based on developing a BUs' roadmap based on academic sources and aligning it with the BEP's essential details according to the practice business standards.
- The research designs and develops a windows-based application that automates the previously introduced methodology. The application facilitates workability, applicability, and testability of the introduced method. The developed application reduces the complexity of the introduced method, enhances the user experience, and supports customizability to match the company's scope. The application intends to assist in overcoming key BIM barriers against the adoption of BIM workflows by prospective building industry firms.
- A convenience sample of local AE SMEs testified the high potential of the developed application to overcome defined key BIM barriers against the adoption of BIM workflows. By scoring high potential weights (> 0.0750) and increased difference ratios (based on paired comparison) that account for 18.269%, 21.198%, 7.658%, 26.421%, 19.484%, and 15.858%, representing the following key BIM barriers: B01 (lack of BIM adoption definition methods/workflows), B02 (lack of BIM Uses definitions and objectives), B03 (lack of BIM-based project parties' collaboration), B04 (undefined security, legal liability, and responsibility), B05 (management/contractual BIM processes, e.g., BEP), and B06 (undefined related business standards for BIM adoption), respectively.
- A purposive sample of local potential AE SMEs that are based in the ST region testified the high potential of the developed application to overcome defined key BIM barriers (B01-B06) and other barriers (B11 and B13) against the adoption of BIM workflows. By scoring high potential weights (> 0.0750) for key BIM barriers and relatively high potential weights (0.0500-0.0750) for the other two barriers. In addition, the research reports an increased difference ratios (based on paired comparison) accounting for 35.849%, 39.052%,

38.858%, 30.602%, 32.371%, 41.199%, 20.377%, and 12.364%, representing the following BIM barriers: B01 (lack of BIM adoption definition methods/workflows), B02 (lack of BIM Uses definitions and objectives), B03 (lack of BIM-based project parties' collaboration), B04 (undefined security, legal liability, and responsibility), B05 (management/contractual BIM processes, e.g., BEP), B06 (undefined related business standards for BIM adoption), B11 (industry resistance and difficulty to change processes), and B13 (lack of BIM knowledge, awareness, and research), respectively.

- Based on the results of the response rank analysis and comparative studies between the conducted paired samples survey rounds, the developed application supports accomplishing the objective BIM adoption mission by assisting prospective AE SMEs in overcoming the defined key (B01-B06) and other (B11 and B13) adoption barriers with a total potential of 62.94% and 12.56%, respectively.

6.2. Discussion

The following discussion points include notes, highlights, and insights that have been concluded from the research work. These points may be very useful for researchers who intend to conduct similar research work or have related studies and interests in the dissertation's topics. This discussion subchapter will focus on limitation and restriction points that have been faced during the research work. In addition, this subchapter will highlight some recommendation and suggestion points that may have high value for future research work projects.

- The research highly recommends repeating similar research study (regarding BIM implementation and its barriers) among the construction firms with the following NACE business classes: 41.10 and 41.20, and main activities: development of building projects and constructions of residential & non-residential buildings, respectively, due to the relatively high potential of these firms in the total share for the main three building industry indicators: number of firms, number of employees, and net revenue, at the ST region, accounting for 20.51%, 29.88%, and 37.14%, respectively.
- The research highly recommends researchers in related fields to perform region-based studies for local building industry firms based in other Hungarian small regions (e.g., Central Transdanubia, Western Transdanubia, Northern Hungary, Norther Great Plain, Southern Great Plain, Budapest, and Pest) and gather related size, count, and activity information to create a database for building industry firms on the country level, and assist in: a) setting comprehensive size classification scale for the domestic Hungarian building industry market, b) defining potential building industry firms (business classes) based on the main three indicators: number of firms, number of employees, and net revenue, respectively, c) supporting comparative and research studies within the sector by forming a scientific base for building industry indicators, and encouraging the development of the sector, and d) supporting comparative and research studies with other sectors on the domestic level, by forming a scientific base for building industry indicators and their counterparts from other sectors and industries.
- The research suggests investigating the defined medium priority barriers including business culture, client culture, knowledge, experience, policy, and time related BIM barriers that have intermediate and upper-intermediate relative weights for local AE firms. The investigation may include deriving a second BIM mission that can be developed and tested to overcome relevant barriers and assist in BIM employment.
- Similarly to the previous discussion point, this point suggests investigating the defined low priority barriers including tools cost, expertise cost, return, benefit, ICT, and efficiency related barriers that have under-intermediate relative weights for local AE

firms. The investigation may include deriving a third BIM mission that can be developed and tested to overcome relevant barriers and assist in BIM employment.

- The downside of the introduced methodology is its workflow relative complexity, since it requires multi-level engagement from the user in order to define BUs according to the academic roadmap and then fill-in practice related details for the defined BUs, both levels combined will form the base for the related BEP document by generating a table-form document that contains the project's or appointment's title, BIM dimension, defined BUs and their associated codes, grouped BUs based on their code syntax, and major practice details for each BU (table row). Hence, manual development of this method is extremely difficult bearing in mind the necessity to develop an ID code for each defined BU based on the pre-chosen parent levels, and before filling in the practice related details, the defined BUs should be grouped into sets based on their codes. Hence manual application of this method is considered inefficient since it requires time and effort from the user with high probability of mistake due to the necessity for multi-level engagement.
- Based on the previously explained discussion point, the research highly recommends the potential of using automation or automatic approach to apply the introduced method. Automation will definitely guide the user in the proper way, save time and effort, reduce the chances for making mistakes, and enhance the user experience. Hence, the research is going to take this discussion point into account to develop an application for the introduce method that can be used by the intended AE professionals to carry out BIM-based project.
- The research highly recommends developing web-based application with. This will increase the potential, target users, accessed users, and applicability of the introduced application.
- Due to the variety and complexity of BIM-based projects within the industry, it is impossible to collect all specific BUs in one database. Hence, the research highly recommends an adaptable "specific BU description from level 04" that is based on the information typed in by the user. This will allow the user to insert any specific BU based on the exact need of the intended project by simply typing it down, instead of limiting the user with a certain number of listed specific BUs or asking the user to access the database sheet to customize the list of BUs (that he can choose from) based on the project's scope and needs.

7. Summary

The overall objective of the research is to support BIM adoption in prospective local building industry Small and Medium-sized Enterprises (SMEs). The research develops an application-based method that assists professionals to pinpoint required objective specific BIM Uses (BUs) and align them with business standards and BIM Execution Plan (BEP) details to facilitate carrying out and executing BIM-based projects. The method is developed based on an extensive review of academic and practice sources, and with respect to the aspects of an objective BIM adoption mission, which was derived based on the defined key BIM adoption barriers according to prospective local Architecture and Engineering (AE) SMEs, which suffer from low BIM adoption levels. Generally, the developed method and its associated application are targeting any building industry firm that intends to carry out BIM-based projects and suffer from similar key adoption challenges. But on a specific level, the developed method and its application are targeting prospective local-based AE

SMEs, which have the highest potential among other collected and nominated building industry firms located within the South Transdanubia (ST) study region.

The research can be briefly summarized by four main milestones, including a) defining the study region and potential building industry SMEs, b) defining the BIM-adoption level and its key barriers for potential building SMEs, c) developing a methodology that intends to overcome defined key barriers and assist potential SMEs in BIM adoption, and d) automating the methodology by developing an application that facilitates the objective of the method and validates the leverage of the method to overcome key barriers by the same potential firms.

First, the research carefully selects the target study region and the building industry firms that are based within the borders of the region. Then, it collects and analyzes data for each included building industry firm, and it defines the target SMEs group by performing a size-based nomination supported by a statistical measure of spread among the set of values for related size indicators. Further, and based on a comparison between the available key indicators for all nominated building industry SMEs, the research defines the high potential of region-based *AE SMEs* that will take part in the upcoming research steps.

Second, the research collects and analyzes BIM adoption barriers, then it defines the level of BIM implementation and its key barriers for local AE SMEs, including the defined potential AE SMEs by performing two survey rounds. Then, the research merges the defined key BIM barriers and formulates a federated objective BIM adoption mission, which corresponds to overcome the referred key barriers and forms the base for upcoming research steps.

Third, the study breaks down the content of the objective BIM adoption mission and develops a methodology that corresponds to the mission's elements. The methodology has two main components, the academic and practice components. Each component is developed separately, then a linking point is introduced to connect both the academic and practice components. By aligning and connecting both components the research introduces a method to accurately define specific objective BUs and align them with business standards to facilitate the execution of BIM projects. At this stage of the research, and due to the intensity of the developed methodology, questions are raised regarding the applicability and testability of the method by the intended potential firms, leading to the main driver for the last step of this research work.

Fourth, the research automates the introduced method by developing a Windows-based application that corresponds with the academic and practice components of the method. The application facilitates the workability and testability of the introduced method by reducing the complexity, enhancing the user experience, and supporting customizability to match the firm's scope. The research performs another two survey rounds with paired samples to the former conducted ones, the results of the response rank analysis and comparative studies between the survey rounds successfully confirm the high potential of the introduced application-based method to accomplish the objective BIM adoption mission and overcome key BIM barriers. Hence, the research can assist local-based prospective AE SMEs and other building industry firms with similar BIM adoption challenges to kick-off BIM-based projects and carry out BIM-based workflows.

8. Attachments

8.1. Attached tables

Table 32: Statistical Classification of Economic Activities in the European Community (NACE) with its sections (S.), titles, and divisions (Divis.)

S.	Title	Divis.	S.	Title	Divis.
A	Agriculture, forestry, and fishing	01-03	L	Real estate activities	68
B	Mining and quarrying	05-09	M	Professional, scientific, and technical activities	69-75
C	Manufacturing	10-33	N	Administrative and support service activities	77-82
D	Electricity, gas, steam, and air conditioning supply	35	O	Public administration and defense; compulsory social security	84
E	Water supply; sewerage, waste management, and remediation activities	36-39	P	Education	85
F	Construction	41-43	Q	Human health and social work activities	86-88
G	Wholesale and retail trade	45-47	R	Arts, entertainment, and recreation	90-93
H	Transportation and storage	49-53	S	Other service activities	94-96
I	Accommodation & food service activities	55-56	T	Activities of households as employers undifferentiated goods & services producing activities of households for own use	97-98
J	Information & communication	58-63	U	Activities of extraterritorial organizations and bodies	99
K	Financial & insurance activities	64-66			

Table 33: allocation of collected ST's building industry firms based on NACE classification, including sections (S.), divisions (Div.), groups (Gro.), classes, and main activities, per each scanned county including Baranya (Ba.), Somogy (So.), and Tolna (To.)

S.	Div.	Gro.	Class	Main activity	Ba.	So.	To.	Σ
C	16	16.2	16.22	Manufacture of assembled parquet floors	0	1	0	1
	23	23.6	23.61	Manufacture of concrete products for construction purposes	1	0	0	1
	25	25.1	25.11	Construction of utility projects for fluids	0	1	0	1
		25.2	25.21	Manufacture of metal structures and parts of structures	0	0	1	1
	28	28.9	28.99	Manufacture of central heating radiators and boilers	1	0	0	1
D	35	35.3	35. 3	Steam and air conditioning supply	1	0	0	1
F	41	41.1	41.1	Development of building projects	3	1	0	4
		41.2	41.2	Construction of residential and non-residential buildings	15	8	10	33
	42	42.1	42.13	Constructions of bridges and tunnels	1	0	0	1

		42.2	42.21	Construction of utility projects for fluids	1	0	3	4
		42.9	42.91	Construction of water projects	1	0	0	1
	43	43.2	43.21	Electrical installation	1	0	0	1
			43.22	Plumbing, heat and air-conditioning installation	1	0	1	2
		43.3	43.34	Painting and glazing	1	0	0	1
		43.9	43.99	Other specialized construction activities	0	0	1	1
	45	45.2	45.21	General construction of buildings and civil engineering works	0	2	0	2
	47	47.5	47.52	Retail sale of hardware, paints and glass in specialized stores	1	0	1	2
L	68	68.1	68.1	Buying and selling of own real estate	3	0	1	4
		68.2	68.2	Renting and operating of own or leased real estate	2	0	0	2
		68.3	68.31	Real estate agencies	1	0	1	2
M	70	70.2	70.22	Business and other management consultancy activities	0	1	0	1
	71	71.1	71.11	Architectural activities	37	17	12	66
			71.12	Engineering activities and related technical consultancy	17	7	7	31
	74	74.9	74.9	Other professional, scientific and technical activities n.e.c.	1	0	0	1
N	80	80.2	80.2	Security systems service activities	1	0	0	1
Σ	8 sections, 15 divisions, 23 groups, 25 classes, and 25 main activities				90	38	38	166

Table 34: List of BUs based on objectives according to the mentioned comprehensive source (potential source)

Listing BUs based on objective according to “BIM Use Definitions Standard 2023”					
Capture conditions	Author design	Analyze design	Visualize construction sequencing	Coordinate design and construction	Review design
Produce construction documentation	Generate estimates	Generate fabrication details	Author temporary work	Layout construction work	Compile record deliverable
Manage assets	Manage space	Monitor facility performance			

Table 35: List of BUs based on potential or phase according to the mentioned comprehensive source (potential source)

Listing BUs based on potential or phase according to the „National BIM Guide for Owners 2017”					
Classifying BUs based on **potential**:					
Essential BUs	Existing conditions	Design authoring	Design review	Coordination	Record modeling
Enhanced BUs	Cost estimating	Phase and 4D planning	Site analysis	Site utilization	Digital fabrication

<table>
<tr><td></td><td>3D location and layout</td><td>Engineering analysis</td><td>Sustainability analysis</td><td>Codes and standards compliance</td><td>Construction systems design</td></tr>
<tr><td>Owner BUs</td><td>Asset management</td><td>Disaster planning</td><td>Space management</td><td></td><td></td></tr>
<tr><td colspan="6">Classifying essential BUs based on phase:</td></tr>
<tr><td>Plan</td><td>Design</td><td colspan="2">Construct</td><td colspan="2">Operate & maintain</td></tr>
<tr><td colspan="2">Existing condition</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="3">Design author</td><td></td><td></td></tr>
<tr><td></td><td colspan="2">Design review</td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="3">Coordination</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="2">Record model</td><td></td></tr>
</table>

Table 36: List of BUs based on purpose and characteristics according to the mentioned comprehensive sources (potential sources)

<table>
<tr><td colspan="6">Listing BUs based on purpose and characteristic according to „The Uses of BIM, Classifying and Selecting BIM Uses - Version 0.9, September 2013” and “The National BIM Standard - United States® Version 3, Chapter: The Uses of BIM: Classifying and Selecting BIM Uses, Version 0.91 – October 2013”</td></tr>
<tr><td colspan="5">Purposes</td><td rowspan="2">Characteristics</td></tr>
<tr><td>Gather</td><td>Generate</td><td>Analyze</td><td>Communicate</td><td>Realize</td></tr>
<tr><td>Qualify</td><td>Prescribe</td><td>Coordinate</td><td>Visualize</td><td>Fabricate</td><td>Facility element</td></tr>
<tr><td>Monitor</td><td>Size</td><td>Forecast</td><td>Draw</td><td>Assemble</td><td>Facility phase</td></tr>
<tr><td>Capture</td><td>Arrange</td><td>Validate</td><td>Transform</td><td>Control</td><td>Discipline</td></tr>
<tr><td>Quantify</td><td></td><td></td><td>Document</td><td>Regulate</td><td>LOD</td></tr>
</table>

Table 37: List of BUs based on phase and potential according to the mentioned comprehensive sources (potential sources)

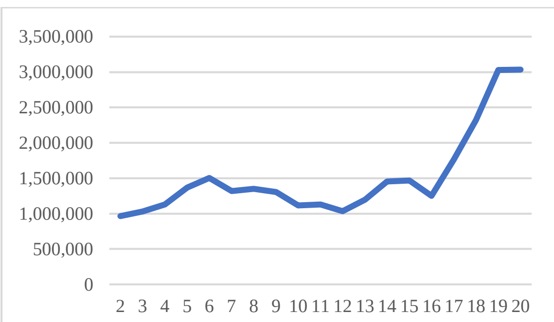
<table>
<tr><td colspan="8">Listing BUs based on phase and potential according to „BIM Project Execution Planning Guide - Version 2.2, 2019” and „The New Zealand BIM Handbook, Appendix D, 2023”</td></tr>
<tr><td colspan="2">Plan</td><td colspan="2">Design</td><td colspan="2">Construct</td><td colspan="2">Operate</td></tr>
<tr><td colspan="8">Existing conditions modeling</td></tr>
<tr><td colspan="8">Cost estimation</td></tr>
<tr><td colspan="6">Phase planning</td><td></td><td></td></tr>
<tr><td colspan="3">Programming</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">Site analysis</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="3">Design reviews</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="2">Design authoring</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="2">Energy analysis</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="2">Structural analysis</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="2">Lighting analysis</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="2">Mechanical analysis</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="2">Other eng. analysis</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="2">LEED evaluation</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="2">Code validation</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="3">3D coordination</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="2">Site utilization plan</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="2">Con. system design</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="2">Digital fabrication</td><td></td><td></td></tr>
</table>

				3D control & plan			
					Record model		
						Maintenance sche.	
						Building systems	
						Asset management	
	Primary BUs					Space Mgmt/track	
	Secondary BUs					Disaster planning	

Table 38: parties of interest at BIM-based project

Parties of interest		
Project team		
	Delivery team	
		Task team
Appointing party	Lead appointed party	Appointed party

8.2. Attached Figures



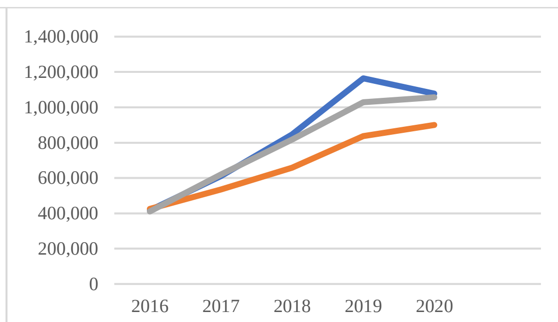


Figure 41: (to the left) values of construction production of Hungary by the location of construction (inside the Hungarian borders) from 2002-2020 (values are in million HUF)

Figure 42: (to the right) values of construction production by location of building industry firms according to the three large regions (blue: Central Hungary, grey: Great Plain and North, and orange: Transdanubia) from 2016-2020 (values are in million HUF)

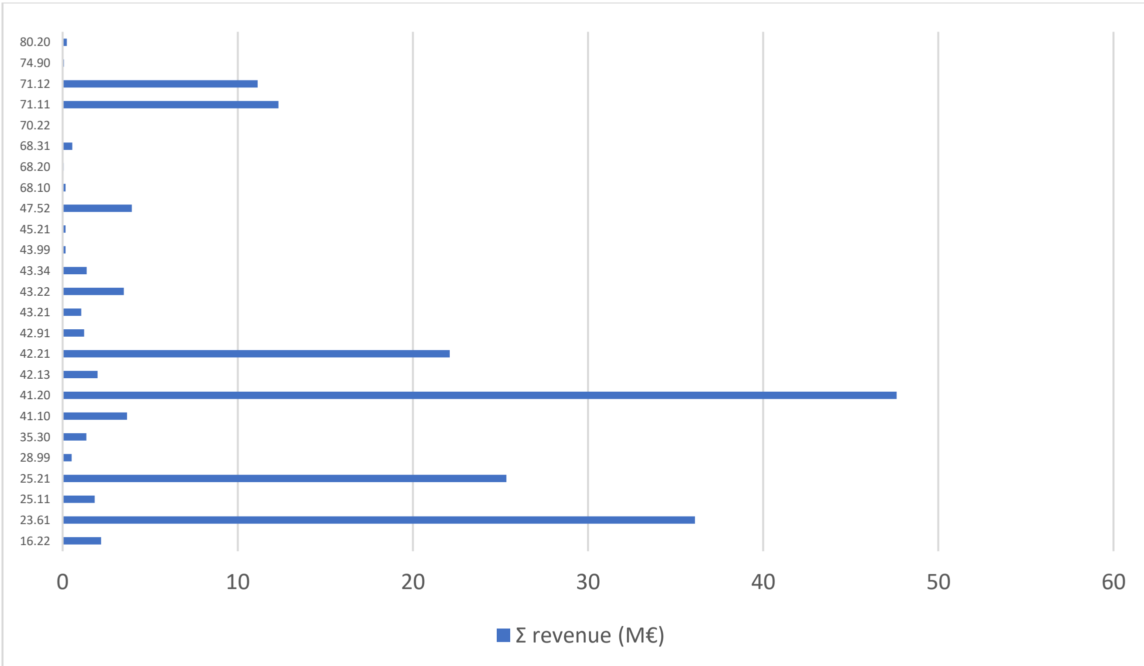


Figure 43: net revenue in million € as an essential key indicator for the size of collected building industry firms based on NACE classes

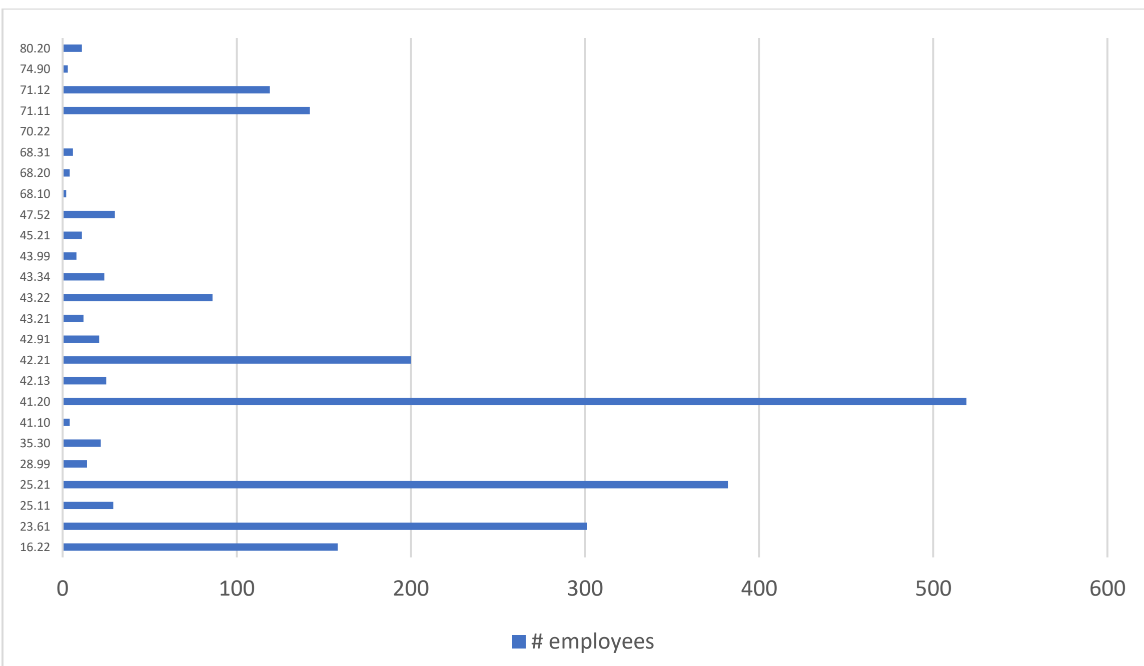


Figure 44: number of employees as an essential key indicator for the size of collected building industry firms based on NACE classes

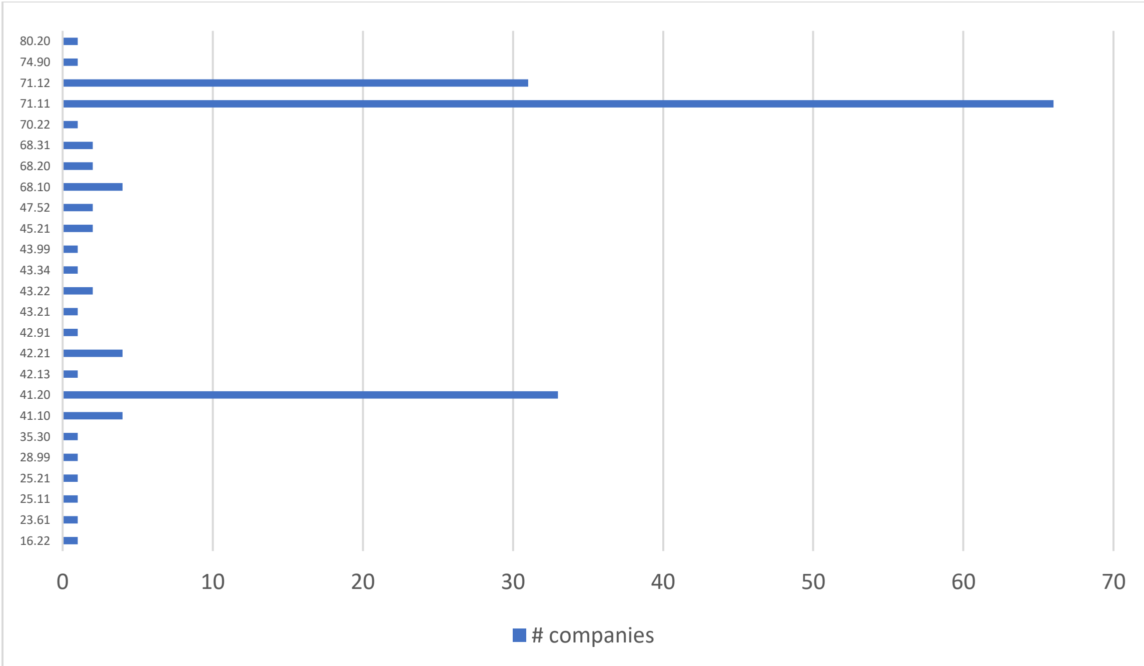


Figure 45: number of companies as an essential key indicator for the size of collected building industry firms based on NACE classes

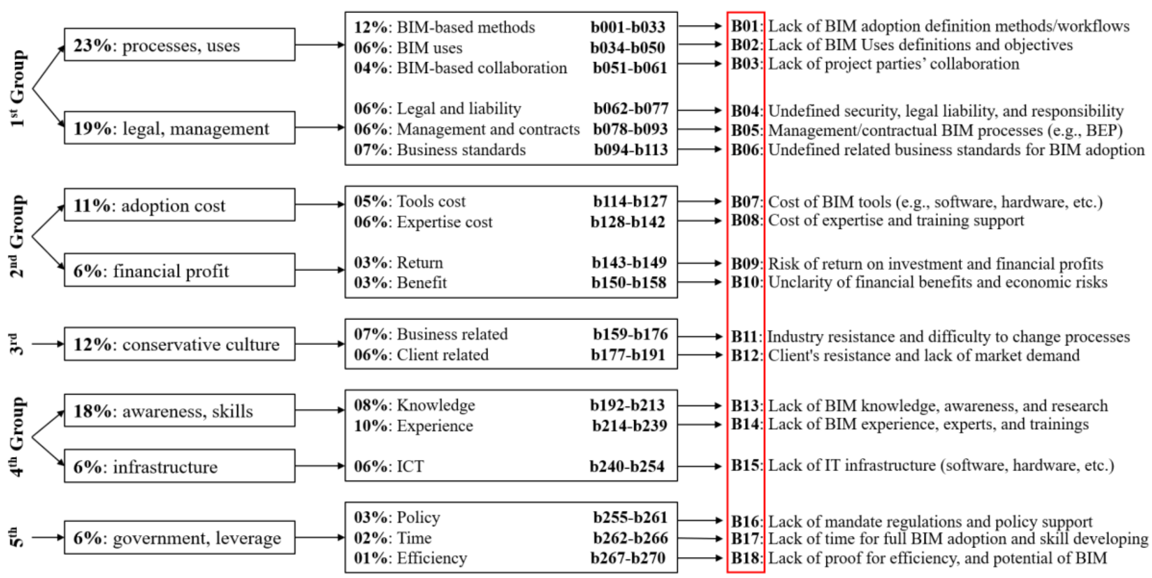


Figure 46: primary, secondary, and tertiary groups, and final 18 comprehensive BIM barriers

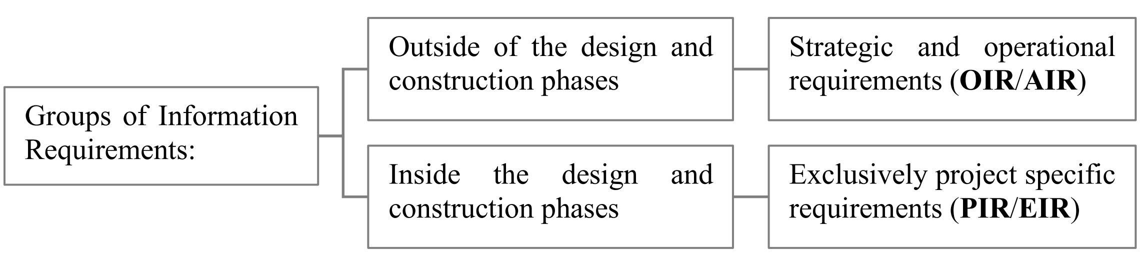


Figure 47: main groups of information requirements

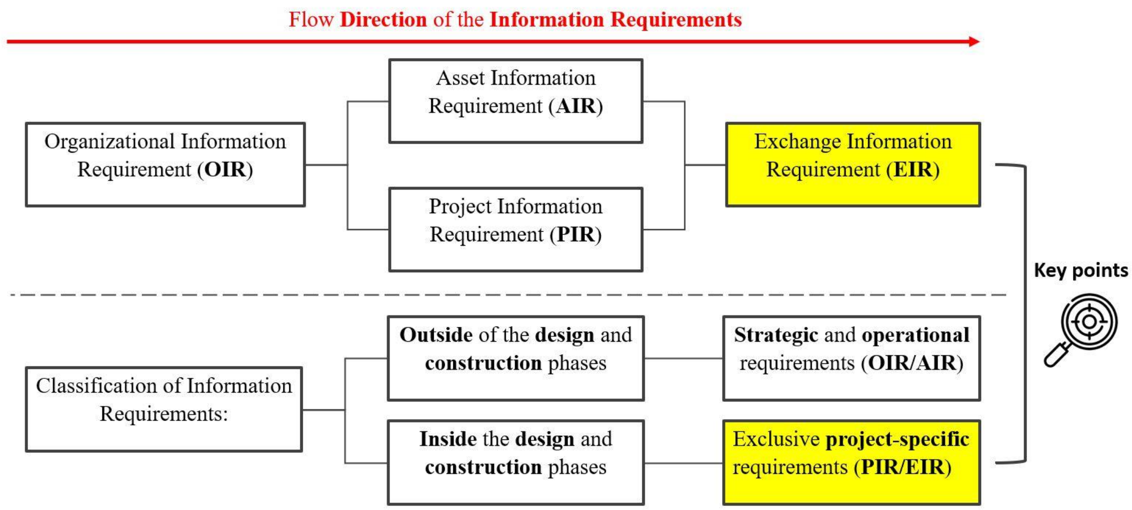


Figure 48: the flow direction of information requirements and focus key points

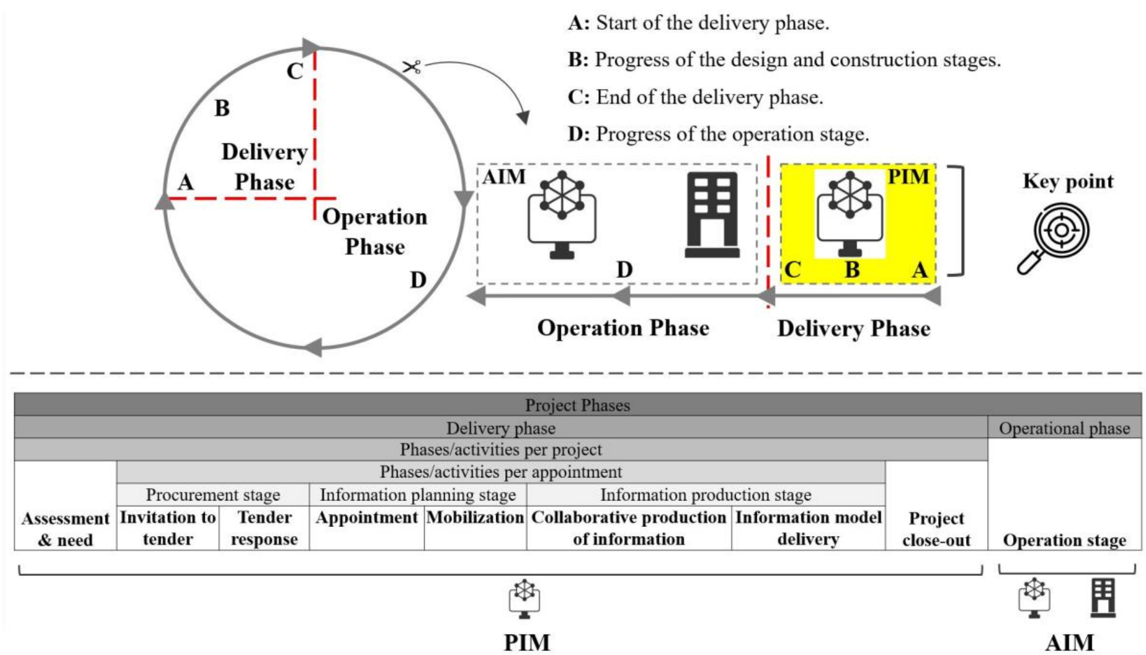


Figure 49: project phases and their associated information deliverables

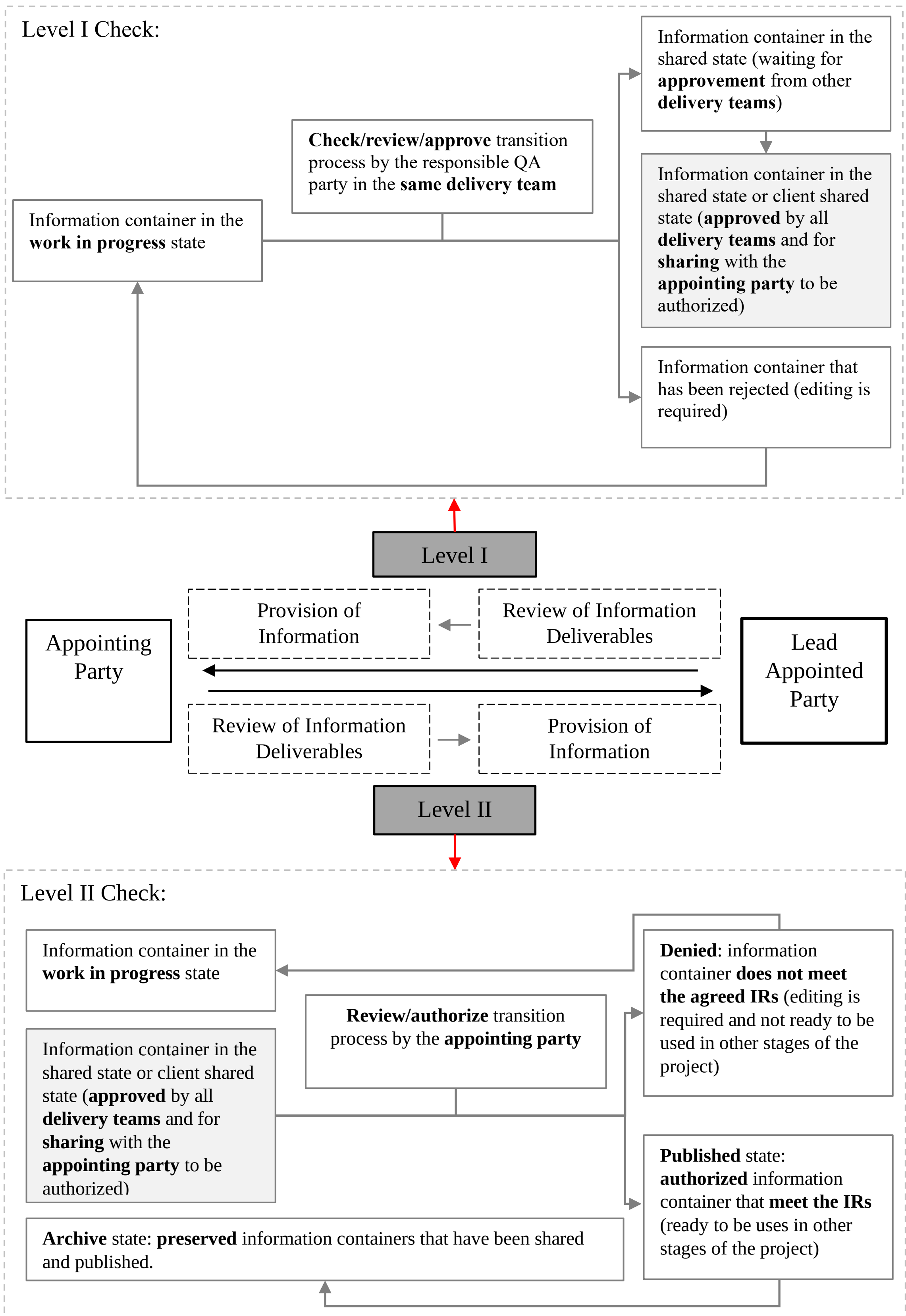


Figure 50: information check levels at the information exchange process between the appointing and appointed parties

Information Container-Based Collaborative Workflow	**Principles**	**Information** produced by different BIM authors is subject to **intellectual property**.
		Provide clear and specified **information requirements** by all participating parties.
		Provide suitable, secured, and accessible **CDE**.
		Develop information models based on the **ISO 19650 instructions**.
		Define information security procedures.

Figure 51: principles for information container-based collaborative workflow

Information Delivery Plan	**Components**	**How** the information will meet the **OIR, AIR, PIR,** and **EIR?**
		When the information will be **delivered**? (related project **phase** and **date**).
		What information and **how** the information will be **delivered**? (**type a**nd **format)**.
		How the delivered information will be **coordinated** by other generated information?
		Who is going to **deliver** the information and **who** is the intended **recipent?**

Figure 52: components of the information delivery plan

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10. List of publications

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11. List of tables, figures, and formulas

11.1. List of tables:

11.2. List of figures:

11.3. List of equations: