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Formulating a strategic plan for digital skills diffusion with a focus on BIM: The Diffusion of Innovation Theory application in the Italian AEC industry

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Abstract

The importance of digital skills diffusion to foster the Architecture, Engineering and Construction (AEC) industry has been highlighted for more than a decade. The extent to which this objective can be achieved depends on several factors. Many countries have developed (or have been developing) their own internal policies in order to promote or mandate digitalization, above all boosting the use of Building information modelling (BIM) in the design stage of public works.

Seemingly, an augmented BIM adoption stems from, but is not restricted to, governmental policies and initiatives, but the rate at which countries adopt such methodology varies from one case to another. This study aims to assess the diffusion of digital skills, specifically through BIM adoption, and to establish feasible policies and strategies for its adoption within the Italian construction industry, taking into account institutional, organizational, and project-related factors.

This purpose has been achieved through an initial investigation of the most recognized hurdles in BIM uptake according to policies adopted at international level. Moreover, a rigorous review of recent developments in Information Development Manual and digital diffusion's theories are presented. According to findings based on this literature review, an exploratory online survey was conducted, combining the experiences of various authors in digital skills diffusion and BIM-related researches in order to use the questionnaire results to further synthesize the initial findings. This study aims at supporting the public and private sector to have a better assessment and understanding of the current BIM preparation level and barriers, while the results of the findings can be applied to other digital innovations connected to the AEC industry.

Keywords: Digital skills diffusion, Digitalization, AEC industry, Diffusion of innovation theory, Building Information Modelling, BIM adoption, BIM barriers, Information Delivery Manual

Abstract

L'importanza della diffusione delle competenze digitali per promuovere il settore dell'architettura, dell'ingegneria e dell'edilizia (AEC) è stata evidenziata per oltre un decennio. La misura in cui questo obiettivo può essere raggiunto dipende da diversi fattori. Molti paesi hanno sviluppato (o stanno sviluppato) le proprie politiche interne al fine di promuovere o imporre la digitalizzazione, soprattutto promuovendo l'uso del Building information modeling (BIM) nella fase di progettazione di opere pubbliche.

Apparentemente, un'adozione BIM aumentata deriva, ma non si limita a, politiche e iniziative governative, ma il ritmo con cui i paesi adottano tale metodologia varia da un caso all'altro. Questo studio mira a valutare la diffusione delle competenze digitali, in particolare attraverso l'adozione del BIM, e a stabilire politiche e strategie realizzabili per la sua adozione nel settore edile italiano, tenendo conto dei fattori istituzionali, organizzativi e di progetto.

Questo scopo è stato raggiunto attraverso una prima indagine sugli ostacoli più riconosciuti nella diffusione del BIM secondo le politiche adottate a livello internazionale. Inoltre, viene presentata una revisione rigorosa dei recenti sviluppi nel Manuale di sviluppo delle informazioni e nelle teorie della diffusione digitale. Secondo i risultati basati su questa revisione della letteratura, è stato condotto un sondaggio online esplorativo, che combina le esperienze di vari autori nella diffusione delle competenze digitali e le ricerche relative al BIM al fine di utilizzare i risultati del questionario per sintetizzare ulteriormente i risultati iniziali. Questo studio mira a supportare il settore pubblico e privato per avere una migliore valutazione e comprensione dell'attuale livello di preparazione BIM e delle barriere, mentre i risultati dei risultati possono essere applicati ad altre innovazioni digitali connesse all'industria AEC.

Parole chiave: Diffusione delle competenze digitali, digitalizzazione, industria AEC, diffusione della teoria dell'innovazione, Building Information Modelling, adozione BIM, barriere BIM, Information Delivery Manual

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1 INTRODUCTION

1.1 Why digitalization

According to the new World Economic Forum report, 'adoption of advanced technologies at scale' and digitalization of the construction industry is necessary in order to meet the global needs in the future. The report maps three scenarios 'Building in a virtual world', 'Factories run the world', 'A green robot' for the construction industry to emphasize the importance of preparing for the emerging transformation trends in the future of the construction industry. Moreover, the report predicts full-scale digitalization of the construction industry can save up to $1.7 trillion globally within ten years.

The construction industry, as a whole, is slow at adopting new technologies (Ahmed, 2018; Cao, Li, Wang, & Huang, 2017). Thus, researchers emphasize the need for a greater probe of innovation spread within the construction industry (Azwani, Ya, Azli, Rahim, & Zainon, 2018; B. Gledson, 2017). Digital technologies have transcended being a mere tool to help improve the old processes to a transformation of how things are done. In spite of the AEC industry being well aware of the importance of the trend towards digitization, it still suffers from a "digital divide" (Ayinla & Adamu, 2018). There is still a dearth of inquiries in factors affecting the spread of innovation within the construction industry (Succar & Kassem, 2015). Therefore, those companies that fail to develop and implement their own digitization strategy will lose ground in terms of productivity improvement and business advancement (Schober, Hoff, & Sold, 2015). Challenges in innovation diffusion in the construction industry as a complex social system are derived not only from the distinct organizational and structural characteristics of construction firms (Haron, Alias, Muhammad, & Dorothy, 2018; Shibeika & Harty, 2015) but also from governmental supports (J. Rogers, Chong, & Preece, 2015).

In the UK, one of the leading countries in terms of exploitation of BIM technology and processes, the government emphasized the role of digital innovations in order to have a more efficient and technologically advanced industry by 2025. As a result, they set out strategies to “utilize global leadership in BIM exploitation to create growth for the UK market”(HM government, 2013). In 2012, National Building Specification (NBS, 2012) launched a national BIM library and have been publishing BIM national and international reports annually since 2011, which has become the main platform for evaluating the use of BIM in the UK.

Modular Building Institute (MBI) provided solutions to improve the efficiency and productivity of the U.S. construction industry (The Modular Building Institute, 2010). It argued that, among different challenges discussed, there is a consensus that there are major losses due to the lack of labour coordination and interoperability. Consequently, BIM was proposed as one of the five suggested interrelated activities to improve the efficiency in the construction industry and help meet other challenges, such as environmental sustainability.

1.2 BIM and the benefits of its use

BIM is a set of “interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle” (Succar, 2009).

(Khosrowshahi & Arayici, 2012) distinguishes between the perceived benefits of BIM adoption in the UK construction industry by defining the 3-stage maturity measurement criteria where (figure 1):

- BIM Stage 1 refers to migration from 2D to 3D object modelling and documentation
- BIM Stage 2 advances from mere modelling to collaboration and interoperability
- BIM Stage 3 reflects the shift from collaboration to integration among different stakeholders

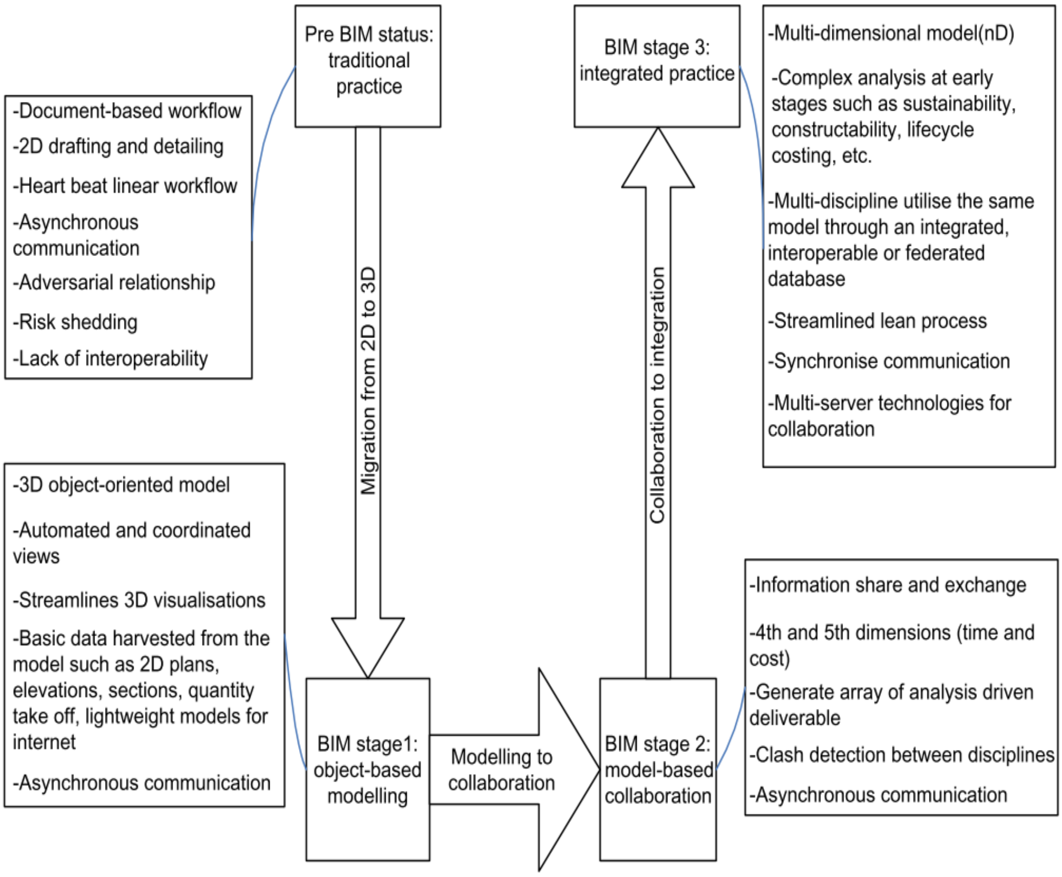

Figure 1. BIM maturity stages and their corresponding perceived benefits (Source: Khosrowshahi & Arayici, 2012)

Based on results obtained through a questionnaire surveyed in the UK construction industry, (Khosrowshahi & Arayici, 2012) categorizes the most prominent perceived benefits to BIM adoption in terms of BIM maturity stage as follows (table 1):

BIM maturity stage	Benefit
BIM Stage 1	3D walkthroughs, visualisation, quick analysis of alternatives
	Material supplier integration, better modelling
	Quick revisions to schemes
	Guidelines, implementation support and monitoring

	High-quality documentation
BIM Stage 2	Efficient collaboration among the stakeholders
	Common understanding of project costs schedules
BIM Stage 3	Reduced error, rework and waste for better sustainability for design and construction;
	Improved risk management
	Removal of waste from process, lean construction and design
	Whole lifecycle asset management, better facility management/asset management

Table 1.perceived BIM benefits in terms of BIM maturity stage according to (Khosrowshahi & Arayici, 2012)

(McGraw Hill Construction, 2015) argues that benefits emanated from the BIM adoption can be divided into three:

- Internal benefits: benefits accruing to the contractor
- Project benefits: benefits directly related to the project on which BIM is being deployed)
- Process benefits: benefits related to processes and workflows

Table 2 shows the most eminent perks of BIM adoption in terms of contractors' perception:

Type of benefit	Benefit
Internal benefits	Enhanced organizational image
	Increased profitability
	Maintaining repeat business
	Marketing new business
Project benefits	Reduced errors and omissions
	Reduced rework
	Reduced construction cost

Process benefits	Collaborate with owners/ design Firms
	Better cost control/predictability

Table 2. contractors' perceived perks of BIM implementation according to (McGraw Hill Construction, 2015)

(Mostafa, Moslem, & Saeed, 2018) define benefits of BIM application in construction projects in terms of specific key performance indicators where quality improvements, sustainable construction, construction cost reduction, constructability improvement (e.g. with prefabrication and clash detection), time efficient construction delivery (e.g. project schedule) were respectively perceived as the most important benefits. Furthermore, (Singh, Sawhney, & Borrmann, 2019) go one step forward and analyse the integration of "built-in rules of modular coordination" in BIM authoring tools which brings about, for instance, streamlined project process, reduced modelling errors, improved design quality which eventually guides the user through the modelling process and facilitate BIM adoption. Overall, these benefits made BIM the leading technological innovation tool in the construction industry (table 3).

Reference	Benefit
Advanced 3d simulation of building elements in an integrated data environment	(Azhar, 2011); (Bryde, Broquetas, & Volm, 2013); (McGraw Hill Construction, 2015)
Provide prefabrication and shop drawings for building systems	(Bryde et al., 2013); (Sherif, Pyung, Y, & Payam, 2018)
Built-in cost estimating features	(Bryde et al., 2013); (Azhar, 2011)
Construction sequencing to coordinate materials ordering, fabrication, delivery schedules	(Bryde et al., 2013); (Sherif et al., 2018);
Collision and clash detection to avoid possible interferences between different building systems	(Bryde et al., 2013); (Azhar, 2011); (Demian and Walters, 2014)
Improved Facility management (maintenance, renovation, space planning) through digitalizing building information record	(Bryde et al., 2013);(Azhar, 2011)

Table 3. Most envisaged BIM benefits according to different authors

2 METHODS

2.1 Information Delivery Manual (IDM)

As mentioned before, the benefits to BIM adoption is connected, but not restricted to, to the construction process. These benefits are also associated with managing the use of space within buildings, facilities. IDM helps to ensure that BIM is exploited to its maximum extent through guaranteeing that the required information is available and the quality of the information is adequate in the BIM. it is a “technical document (physical or digital) that describes the business needs, activities and transactions and information exchange requirements for a certain purpose”.

For this purpose, a common insight of the processes and data required within the entire life cycle of a project along with the required information for their execution and results need to be provided. The ISO 29481[1] “describes these required processes and data in the development or management of a construction facility”.

2.1.1 BIM and IDM

Building information modelling translate various sets of information used in the construction sector into a common information language. For this purpose, “there should be a common standard for the building processes and the information for their execution”. ISO 29481 sets out the requirements for the development of an information delivery manual.

In Building Information Modelling an overall information schema is used. As shown in figure 2, From different elements of an information Schema only some specific classes of information are required for a particular business process. Each class consists of multiple objects with unique identity and state. Consequently, “classes that support the business process form a unique and identifiable standard schema or model view” (ISO 29481, 2017).

[1] BS EN ISO 29481-1:2017 Building information models– Information delivery manual part 1: methodology and format

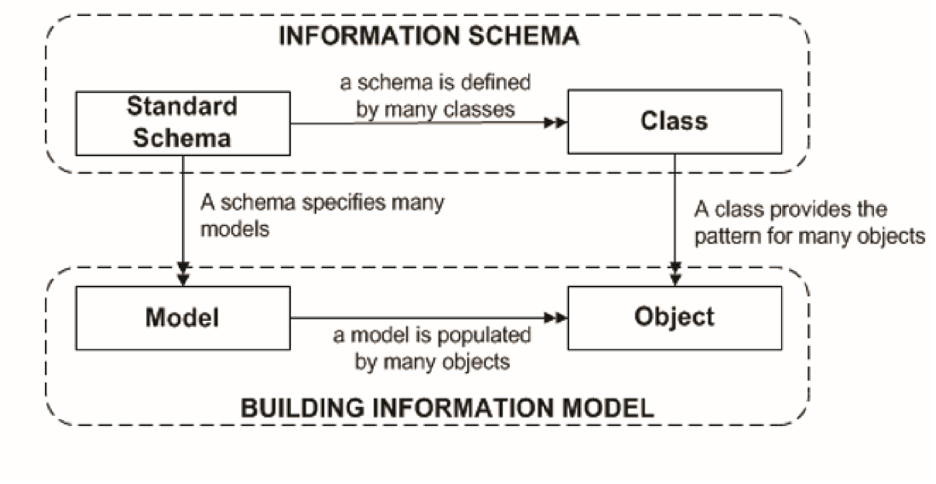

Figure 2. Supporting the BIM process (Source: ISO 29481, 2017)

2.1.2 Business context

Within different contexts, both client (Role 1) and the consultant (Role 2) need to standardize and formalize different aspects of their relationship both in terms of contractual aspects and the exchange of information (figure 3). “The IDM describes the information requirements associated with the transactions (both ways) associated with that relationship” (ISO 29481, 2017).

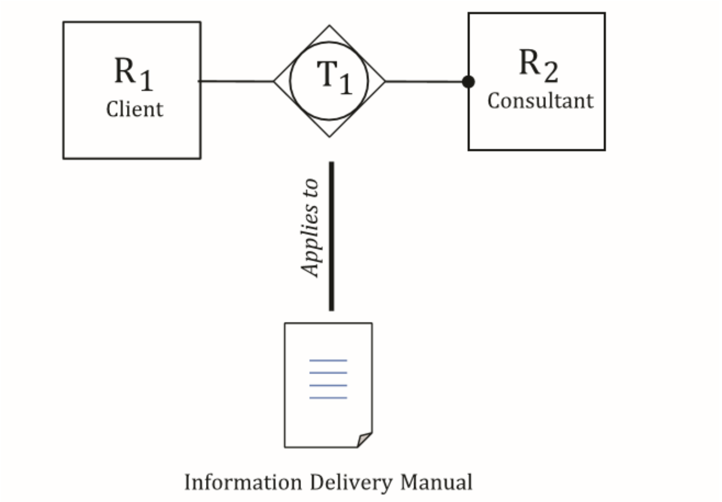

Figure 3. Example of a simple business context requiring an IDM (Source: ISO 29481, 2017)

2.1.3 Developing BIM Execution plans in a contract

A crucial part of implementing BIM processes in projects is to have a BEP (BIM execution plan). A BEP, in agreement with the client, through contractual obligations, "defines how, why, when and by whom the information modelling aspects of the contract will be carried out" (EFCA, 2018). ISO 19650 identifies different types of information requirements that denote specific needs of all supply chain members regarding a project or asset (figure 4):

- Organizational Information Requirements (OIR): they are generally the information required to answer to organizational high-level strategic objectives in terms of building, managing or operating assets.
- Asset Information Requirements (AIM): they are the required information for enabling Organizational Information Requirements delivery.
- Project Information Requirements (PIR): they are the information required to meet the client's Organizational strategic objective with regards to a specific built asset project.

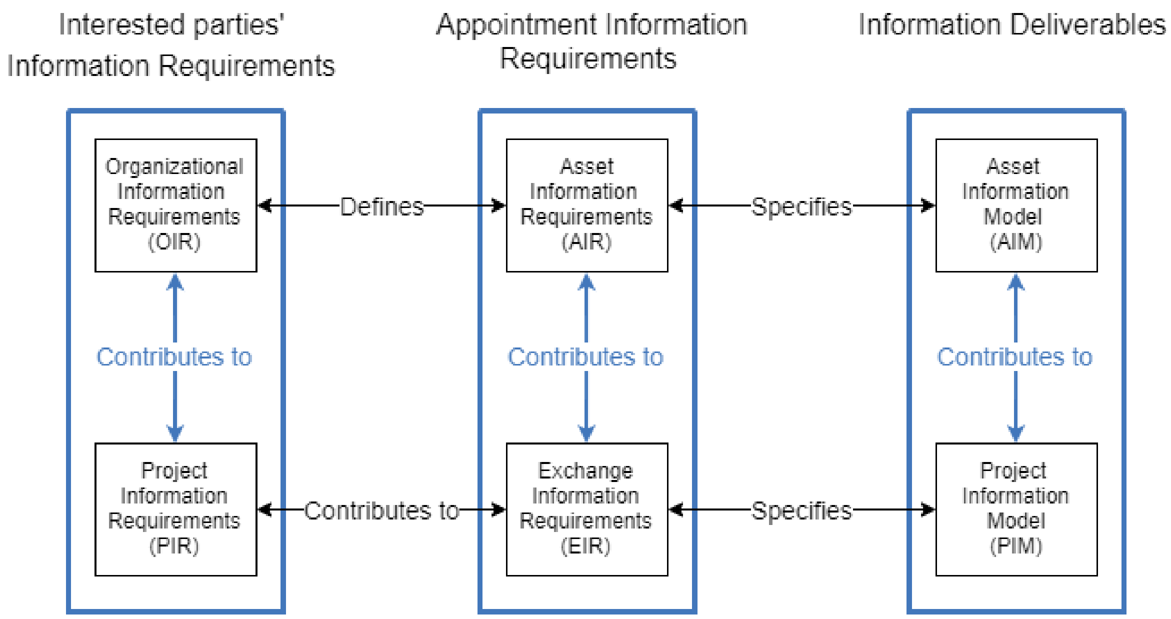

Figure 4. Different types of information requirements and information models and their relations according to ISO 19650

ISO 19650 explains the general information management life cycle in a project which revolves around AIM (Asset Information Model) and PIM (Project Information Model) and their relative relation (figure 5). 'A' is the start of the delivery phase and is the transfer of the relevant AIM to PIM. 'B' is the development of the design model into a virtual construction model. 'C' is the end of the delivery and the transfer of relevant information from PIM to AIM which is a handover from the construction phase to the operational phase. Based on These information requirements different use cases are formulated.

Figure 5. Information management life cycle (Source: EFCA, 2018)

Neither The role of BIM manager nor the BIM champion have not been yet addressed in the previous standards which leaves a wide gap in the industry in terms of understanding the specifics of the role. At an organizational level, the solution lies in identifying information management and clarification of delegated roles, responsibilities and tasks among different individuals involved in a project. This would differ from one project to another depending on organization traits, size and also market sector. ISO 19650 maps the process of information management and delivery in eight stages of a project (figure 6):

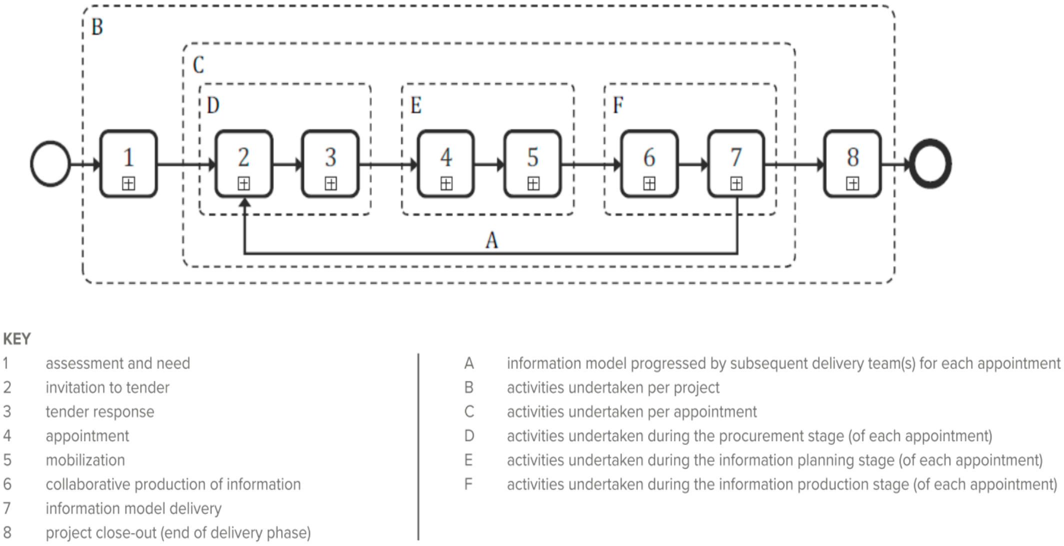

Figure 6. Process of information delivery in eight stages of a project (Source: EFCA, 2018)

Furthermore ISO 19650 underlines the relationships among the client, consultant engineer and the contractor in establishing information delivery requirements during the tender process (figure 7). “the BEP is prepared during the bidding process in order to have a clear understanding between the appointing and appointed party, before the commencement of the project” (EFCA, 2018).

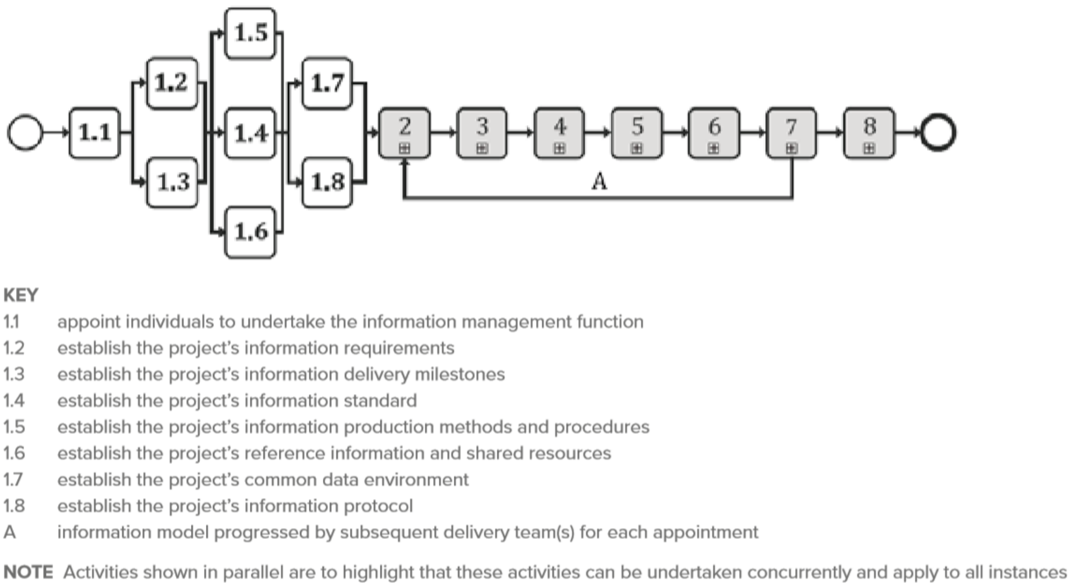

Figure 7. identifying Information Delivery requirements in the assessment stage (Source: EFCA, 2018)

2.1.4 Developing an IDM

According to ISO 29481, an IDM comprises, in detail, the following contents:

- Describe the need for information exchange for the purpose of achieving business objectives
- Identifying specifically the actors involved and their relative roles in exchanging information
- Describing in depth the information exchanged, in a transpicuous way, at different stages in order to satisfy the requirements
- The specifics of information requirements need to be applicable to different actors

IDM has three main elements supplied by the strategic objectives, as shown in figure 8, and it is developed Based on the context of the information that is exchanged among different roles. Use cases are used to translate the strategic objectives Into a specific model and map the ideal scenario for the information exchange. In simple terms IDM, enables the stakeholders across the supply chain to identify their information requirements, processes and transactions and eventually the exchange requirements in order to satisfy their demands. "The business needs are defined by Use cases while activities and transactions are outlined with Process maps and/or Interaction maps" (Guidance for understanding and using EN/ISO 29481-1, in preparation). IDM aligns and standardize use cases so that they can be used on international, national and organizational level. The standardized IDM will benefit all actors involved by improving information exchange with reduced errors so that IDM can be used in tenders, contracts and different projects.

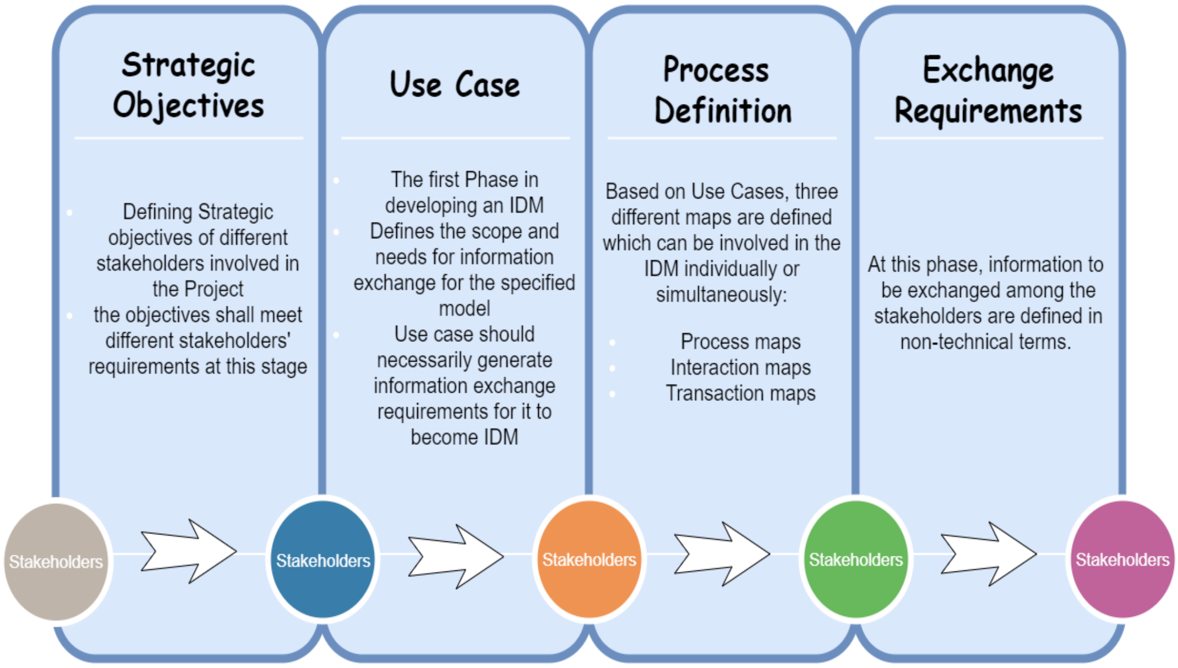

Figure 8. Elements of IDM (author's elaboration)

2.1.4.1 Use cases

"Use cases define the business needs for information exchange" and they are the initial step in developing an IDM. Use cases do not necessarily lead to developing an IDM and they can be solely used to define the use of existing information for use cases which do not generate any information exchange requirements. Use cases contain information about:

- The actors and their roles and interests
- How to develop and manage information exchange
- Whether the existing contracts, documents, standards are in line with the information exchange

According to (Guidance for understanding and using EN/ISO 29481-1, in preparation) certain Regulation Information Requirements need to be set out in order to enable standardized use of information requirements within national and state territory.

As shown in figure 9, Regulation Information requirements establishes common information requirements on national/state level and therefore will shape and regulate the Organizational Information Requirements which by the same token defines the Information Requirements at asset and project specifics. All of the abovementioned information requirements contribute to Exchange Information Requirements (EIR) which alongside Use Cases build IDM.

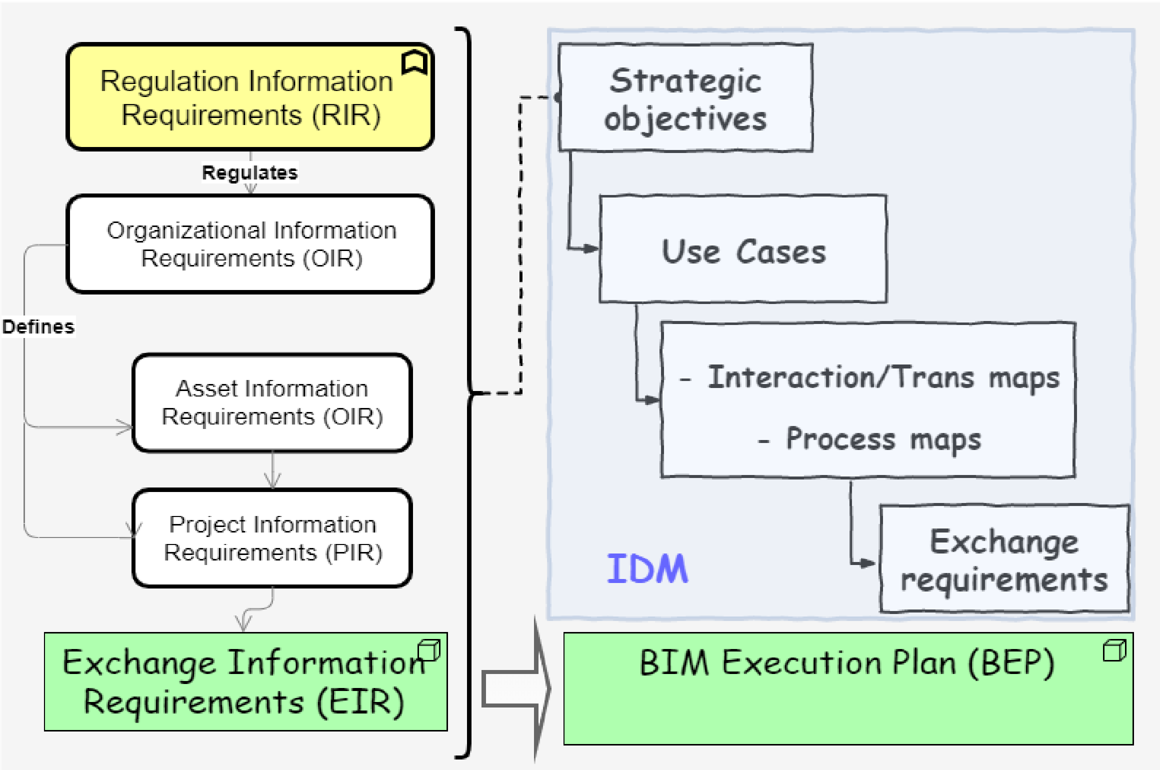

Figure 9. the Relationship between different information requirement types and IDM

2.1.4.2 Activities and transactions

Activities and transactions describe the process of information exchange and production based on the selected use case. These processes assign tasks and responsibilities to actors to achieve the scope of use cases. The three following types of mapping can be used individually or concurrently:

- **Process maps:** when the focus of the IDM is on the "flow of activities within the boundary of a particular business process, roles played by actors" that lead to information exchange. The process boundary is set according to the contents of exchange requirements. In Process maps the boundary of the information exchanged is initially formulated subsequently the activities within the process are identified along with a logical sequence (figure 10)

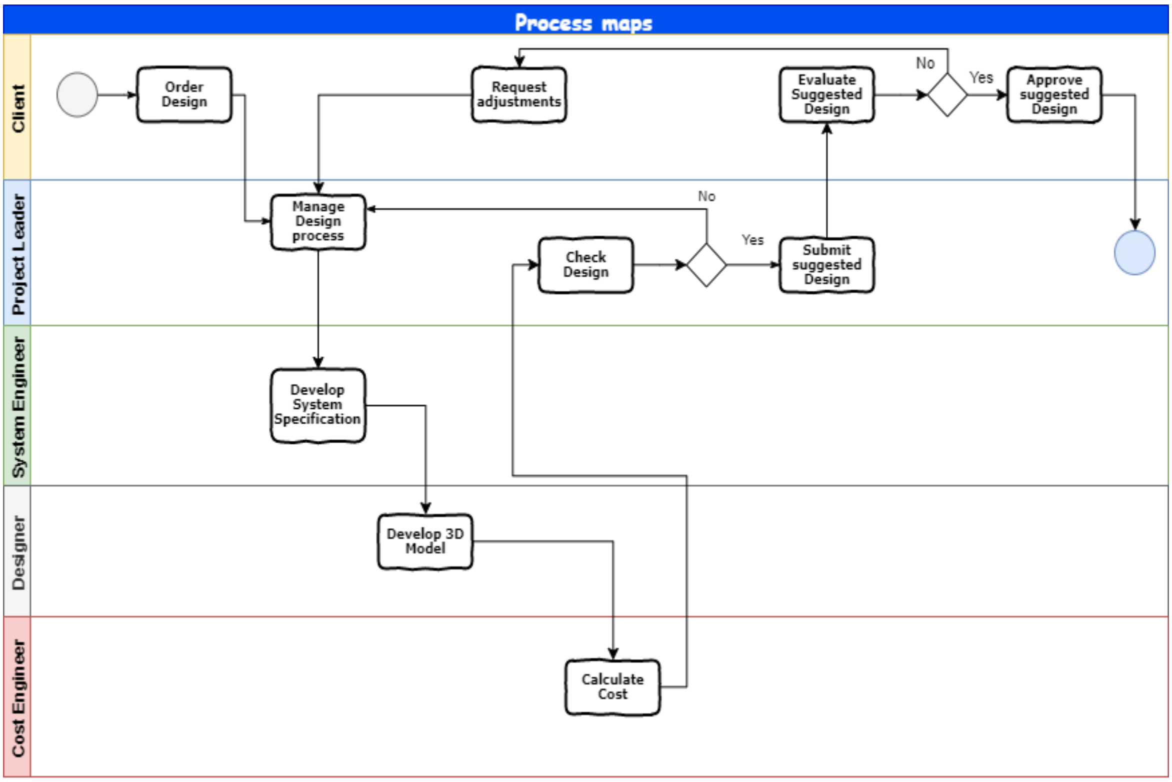

Figure 10. Example of a process map according to ISO 29481

- **Interaction maps**: Interaction maps set out the relevant roles and the relative transactions for achieving project tasks. Interaction maps enable Different roles' contribution to BIM within business contexts through definition of required transactions. A transaction occurs when there is a communication between an initiator (the role that makes the request for information) and an executor (the role that executes in response to the request). it demonstrates all the possible interactions among actors deriving from responsibilities assigned to them. the issue is to “ensure that agreed communication protocols are in place to ensure that the project goals are achieved” (ISO 29481, 2017) (figure 11).

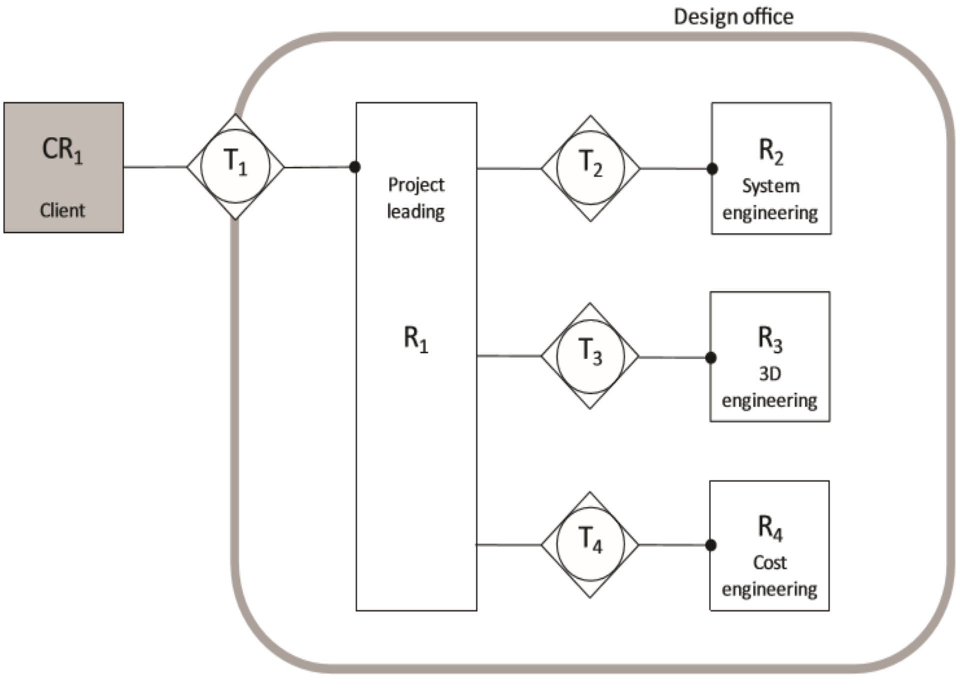

Figure 11. Example of an interaction map (Source: ISO 29481, 2017)

- **Transaction maps:** Focuses on message exchanges and the respective results derived from a transaction between two participating roles. “The handling of a request appears to occur in a particular pattern called the transaction” (ISO 29481). The messages contain required information models for the fulfilment of the process and It is through the transactions and relative communications that different roles’ contribution to BIM is ensured (figure 12). For this purpose along with transaction specifics, other contents may be attached to messages: exchange requirement; information package (a set of object data as information delivery in response to the exchange requirement); window of authorization explaining each roles’ access to BIM software application.

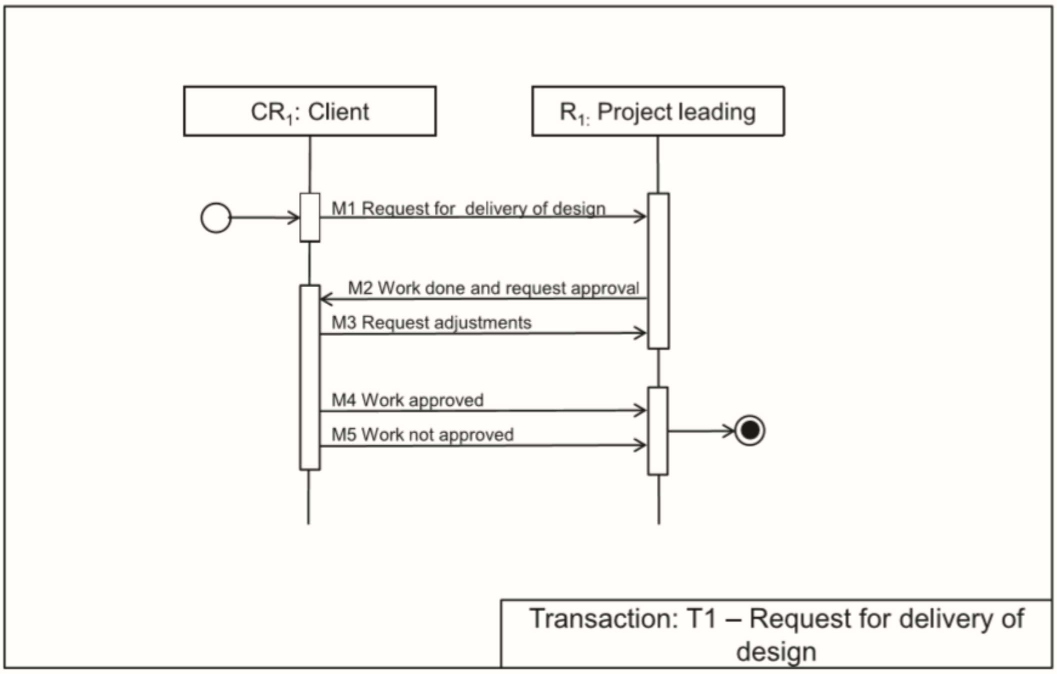

Figure 12. Example of a Transaction map (Source: ISO 29481, 2017)

2.1.4.3 Exchange Requirements

Exchange requirements provides non-technical information that needs to be exchanged to support a specific business process during in life-cycle stages of the project. This information therefore will be comprehensible for all end-users (architects, engineers, constructors, etc). An exchange requirement represents the connection between process and data (Guidance for understanding and using EN/ISO 29481-1, in preparation). It describes the information for the process performed by an initiator which triggers a downstream process to be performed by an executer. The information is derived from the needs of the downstream actor (executer):

- **Information Units:** They are the prerequisites for information exchange that are necessary for the execution of the current exchange requirement and they are provided in sets of information units. Each information unit contains unambiguous description on a specific project, entity along with their attributes.
- **Information Constraints:** Information constraints specify the data types of information units furthermore it provides rules, restrictions for each specific information units.

2.1.4.4 IDM framework

Figure 13 shows how different elements of IDM are connected. It should be noted that the choice of maps depends on the business context and therefore both Process maps and Interaction/Transaction maps can be utilized concurrently or individually. As mentioned earlier, Interaction maps specify the roles and responsibilities while transaction maps deliver the messages derived from transactions among the roles and it also regulates the execution outcome. Instead in Process maps for each role a swim lane is defined, according to the process boundary, within which sequence of activities to be followed by each role is identified. The fulfilment of these activities may require information exchange among roles that will consequently trigger a transaction and a subsequent message.

Some messages may give rise to a package of BIM information which necessitate the definition of exchange requirement. This would involve collaboration among different roles, library requirements, information constraints, units and guidance to their use for delivering the specific message.

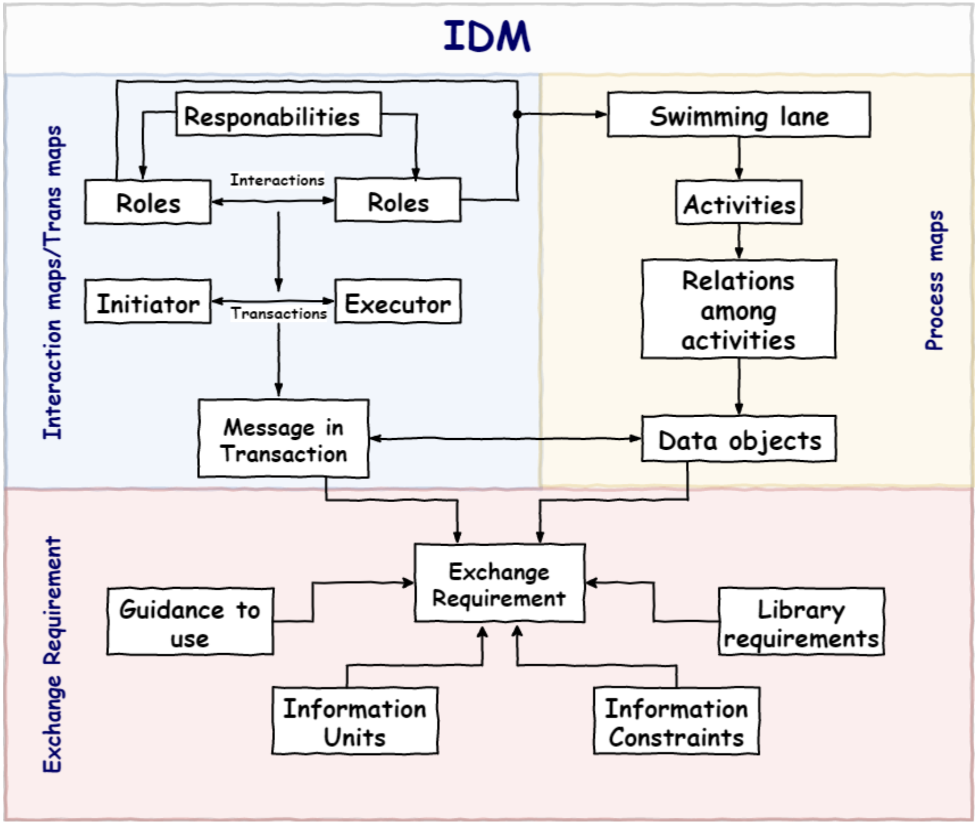

Figure 13. IDM framework according to ISO 29481

2.2 Barriers to BIM adoption

(Kassem, Brogden, & Dawood, 2012) stresses that the identification of barriers to BIM adoption can serve as an overture to BIM adoption. Essentially, it is clear that the discrepancy in adoption differs from SMEs (Small or Medium size Enterprises) to large-scale firms (Hosseini et al., 2016). (Park & Kim, 2014) argue that the problems for BIM adoption need to be addressed on three grounds: "business and legal barriers, technical barriers, human or organizational barriers". (Gu & London, 2010) classify the issues in BIM adoption under two areas: technical tool functional and non-technical strategic issues. (Ahuja, Sawhney, Jain, Arif, & Rakshit, 2018) categorize the significant drivers to BIM adoption into technical, organizational, environmental factors and discuss different significant hurdles in each category in the Indian construction sector; BIM implementation process complexity, perceived cost of BIM, lack of a BIM expertise (technical knowledge), lack of government incentive and standardization for process of implementation just to mention some. Thus, to have a better perception of the barriers to BIM adoption, we need to differentiate between the challenges derived from the organizational and structural characteristics of companies, governmental attributes of the country in which the firm is based as well as human factors. (J. Rogers et al., 2015) view the lack of well-trained staff as the biggest challenge in BIM adoption. The shortage of BIM professionals and the importance of BIM education frameworks are discussed by (Rodriguez, Suresh, Heesom, & Suresh, 2017; Silverio, Suresh, Heesom, & Renukappa, 2017). (NBS, 2018) identifies lack of in-house staff, no client demand and lack of training and costs as the main challenges to be addressed for a higher BIM adoption in the UK construction industry. (Zakaria et al., 2013) argue that the most arduous challenge for BIM adoption in the Malaysian construction industry is the lack of a BIM-use mandate and National BIM standards. (Sherif et al., 2018) find the most significant challenges to BIM integration in the prefabrication industry in Australia to be: changes in business practices to support BIM, investment required for software, training and hardware and challenges derived from project team members' collaboration and communication and furthermore indicate that the Australian government needs to mandate full collaborative BIM to facilitate information exchange. (Matarneh & Hamed, 2017) identify the absence of governmental support and lack of BIM standards along with lack of awareness as the most challenging issues of BIM adoption in the Jordanian construction industry. The cost of software, the steep learning curve and incompatibility hindering the BIM adoption in the Indian construction industry is highlighted by (Nanajkar & Gao, 2014). (Chan, 2014) ranks in order of importance: lack of qualified in-house staff, lack of training/education, lack of standards, and lack of client demand and lack of government's lead/direction as the primary challenges for BIM adoption in China. In Table 4, the different hurdles for BIM adoption according to different references are further discussed and classified into three categories (some barriers belong to different categories):

- institutional barriers,
- organizational/human-centred barriers
- technological/project-based barriers

Barrier	Type	References
Lack of support and incentives from governments	Institutional	(Matarneh & Hamed, 2017); (Ayinla & Adamu, 2018); (Hosseini et al., 2016); (Zakaria et al., 2013); (Nanajkar & Gao, 2014); (Ahuja et al., 2018); (Sherif et al., 2018)
Absence of standards and guidelines	Institutional	(Hosseini et al., 2016); (NBS, 2018); (Matarneh & Hamed, 2017); (Burgess et al. 2018); (Chan, 2014)
Lack of knowledge and awareness	Institutional / organizational, human-centred	(Gu & London, 2010) ; (Kassem et al., 2012) , (Matarneh & Hamed, 2017); (Hosseini et al., 2016); (Zakaria et al., 2013); (Khosrowshahi & Arayici, 2012)
No client demand	Institutional/ Project-related and technological	(NBS, 2018); (J. Rogers et al., 2015); (Chan, 2014); (Matarneh & Hamed, 2017); (Ayinla & Adamu, 2018); (Khosrowshahi & Arayici, 2012); (Hosseini et al., 2016); (Ahuja et al., 2018)
Lack of in-house expertise	Organizational, human-centred	(NBS, 2018); (J. Rogers et al., 2015); (Chan, 2014); (Ayinla & Adamu, 2018); (Matarneh & Hamed, 2017); (Hosseini et al., 2016); (Ahuja et al., 2018)
Resistance to change, culture-centred	Organizational, human-centred	(J. Rogers et al., 2015); (Matarneh & Hamed, 2017); (Ayinla & Adamu, 2018); (Hosseini et al., 2016); (Khosrowshahi & Arayici, 2012)

Technology and interoperability	Project-related and technological	(J. Rogers et al., 2015); (Matarneh & Hamed, 2017); (Ayinla & Adamu, 2018); (Hosseini et al., 2016); (Ahuja et al., 2018); (Sherif et al., 2018)
Lack of training/education	Organizational, human-centred	(NBS, 2018); (J. Rogers et al., 2015); (Chan, 2014); (Burgess et al., 2018); (Matarneh & Hamed, 2017); (Hosseini et al., 2016); (Ahuja et al., 2018)
Costs (software, training, time, suitable technology), risks of adoption	Organizational, human-centred / Project-related and technological	(NBS, 2018); (J. Rogers et al., 2015); (Matarneh & Hamed, 2017); (Ayinla & Adamu, 2018); (Hosseini et al., 2016); (Khosrowshahi & Arayici, 2012); (Ahuja et al., 2018); (Sherif et al., 2018)

Table 4. The most significant barriers to BIM adoption according to different authors

2.3 The roles of governments and global strategies

Many governments have already established BIM implementation policies, USA (Wong, Wong, & Nadeem, 2009) and UK (HM government, 2016) among the major pioneers, or went as far as planning BIM education frameworks addressed to academia and the AEC industry for a better BIM education (Rodriguez et al., 2017). In spite of their recent rise in the global construction industry market, BIM related technologies have attracted little attention in the AEC industry, and the current lack of knowledge and understanding in BIM adoption can pose a serious threat in a near future to the market itself (Schober et al., 2015).

Several researches have specifically reviewed different initiatives towards BIM adoption in various countries and linked them to direct and indirect benefits generated. (Wong et al. 2011) classify governmental BIM initiatives for BIM usage in terms of policy, process and technology, whereas (Cheng & Lu, 2015) categorize the efforts of public sectors into BIM goal and promises, BIM implementation, BIM standards and guidelines around the world. This paper does not intend to elaborate the different policies conducted in various countries, as it rather examines their relative approaches towards BIM adoption and results.

The World Economic Forum has developed a "Networked Readiness Index" for different countries, ranking them in order of their respective readiness towards information and communication technology and digitization in general. Italy is ranked 45th, whilst Singapore and Finland are leading the chart and, interestingly, leading countries in BIM usage are ranked among the top 15 on the list. Hence, it is perceived that there is a link between BIM adoption and a country's readiness to digitization (World Economic forum, 2016).

How governments in different countries have contributed to BIM adoption varies from one to another . (Cheng & Lu, 2015) illustrates the main roles a public sector can assume in facilitating BIM adoption (figure 14). As follows, this study compares different actions undertaken by governments based on the undermentioned roles.

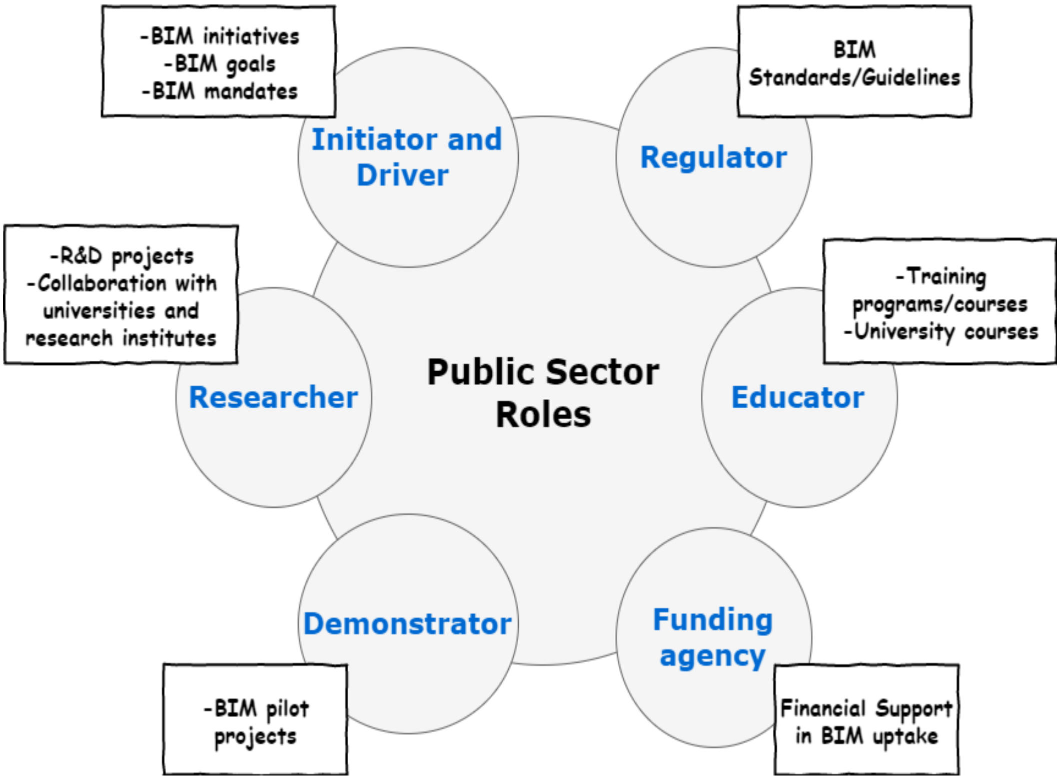

Figure 14. The Roles of public sector in BIM adoption according to Cheng & Lu, 2015

2.3.1 U.S.A.

What makes the USA one of the pioneering countries in BIM use is because that public sector has contributed to BIM implementation at different levels (Cheng & Lu, 2015). As early as 2007, The government has embraced collaboration and among different partners to foster BIM adoption.

2.3.1.1 The government's role as an initiator and driver

Not only at national organizations' level but also at state's and universities' level, goals and targets were set to promote BIM implementation. In 2003, The US General Services Administration (GSA) established the national 3D-4D-BIM program that required BIM adoption for public building service. They have developed eight Guide series to BIM implementation so far in the last few years with the help of industry tech leaders. By the same token in 2007, The GSA mandated BIM use in validation of projects under their control which led to a nation-wide BIM obligation for governmental projects in 2008. In 2006, United States Army Corps of Engineers (USACE) released a Roadmap to BIM implementation by articulating six goals. This program mandated BIM adoption for all Public Buildings Service projects in 2007. In 2009, the United States Department of Veterans Affairs (VA) mandated BIM implementation for renovation and construction projects over $10M. Equally the same determination was found at the states' and universities' level where, the state of Wisconsin and Indiana University required BIM for construction projects totalling more than $5M, just to name a few. Although in 2007 no national BIM standard existed, the government's initiatives and especially BIM promotion within governmental projects certainly supported BIM adoption in private organizations later on.

2.3.1.2 The government's role as an educator and funding agency

Furthermore in 2012, the USACE also funded a CAD/BIM technology center that also provided training within the United States Department of Defence (DoD). National Institute of Building Sciences (NIBS) assigned a committee to develop national BIM standards and to incorporate BIM into college curricula (Cheng & Lu, 2015).

2.3.1.3 The government's role as a regulator

According to (Cheng & Lu, 2015) As of 2015, a total of 47 BIM standards were released at different National, City and State and University levels to facilitate BIM adoption (figure 15). On national level a total of 24 standards/guidelines were developed by different public bodies:

- From 2007 to 2011 the United States General Services Administration (GSA) issued eight guide series incorporating topics such as engaging GSA stakeholders in BIM practices, required tools and process to use BIM, benefits of 4D modelling (use of time-related data), energy performance in construction, design and operations' modelling, Facility management in BIM implementation.
- From 2007 to 2015 The United State National Institute of Building Sciences (NBIMS-US) published three versions of standards covering basic topics regarding methodologies of use and development to more complex ones such as BIM implementation in building's full life-cycle from the planning, designing, construction to operations.
- From 2007 to 2013, The American Institute of Architects (AIA) published guides on digital data protocol and an extension on procedures regarding digital data exchange.
- Furthermore from 2007 to 2015, other public non-profit organizations such as The Department of Veterans Affairs (VA), National Institute of Standards and Technology (NIST) and The Association of General Contractors (AGC) released guidelines separately.

Region	Country/ Organization	Year Range	Quantity		
			Gov. Body	Non-profit Org.	Total
The United States	Nation-wide	2007-2015	9	15	24
	State-wide and city-wide	2009-2013	8		8
	University-wide	2009-2013		15	15
	Sub-Total		17	30	47

Figure 15. Number of different guidelines/standards in The USA (Source: Cheng & Lu, 2015)

On State's and City's level, a total of 8 public bodies issued standards/guidelines for BIM implementation:

- In 2009 The state of Wisconsin issued BIM standard and guidelines for architects and engineers requiring BIM use for most of projects. Later on in 2011, following their footsteps the state of Ohio released a BIM protocol for its implementation and in 2013, the state of Tennessee provided BIM requirements for designers and contractors for state building projects.
- In 2012, the NYC department of construction and design published a BIM guide which triggered a series of BIM guidelines to be released by different public organizations in the New York city. In 2013, Seattle Public utilities and Seattle Department of Transportation jointly published a CAD-Standard to make AUTOCAD and GIS compatible files as projects' final outcome.

On universities' level between 2009 and 2015, 15 BIM standards have been published:

- Since 2009, Pennsylvania State University has published and drafted various BIM standards and BIM Project Execution Planning guides. The Los Angeles Community College District by means of Information modelling standards in 2010, the University of Connecticut through their CAD guidelines in 2011 and Indiana University with BIM standards and guidelines in 2012 are some examples of the public universities who have contributed to BIM implementation.

2.3.1.4 Results of BIM Adoption in the USA

Consequently, levels of BIM adoption in North America rose from 28% to 71% between 2007 and 2012 (Construction McGraw-Hill, 2012). Moreover, in 2014, according to (McGraw Hill Construction, 2015), the USA was leading in terms of years of BIM experience (28% between 6 to 10 years of BIM experience), BIM expertise (35% advanced BIM levels), and BIM implementation level (79% high/very high BIM implementation levels as shown in figure 16). The report also reveals that they have the fewest low-level users (21%) and the highest/very high-level users (22%), which could be a result of policy in place for seven years, post-policy active adoption of BIM, and widespread use and rapid growth or higher acknowledgement of BIM use among other stakeholders apart from designers (Edirisinghe & London, 2015).

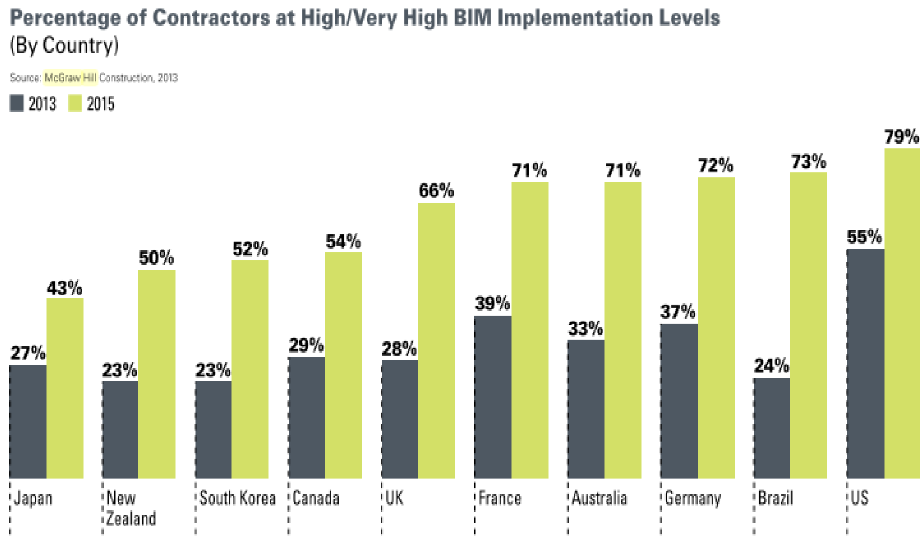

Figure 16. Contractors at high/very high BIM implementation levels per country (Source: McGraw Hill Construction, 2015)

2.3.2 UK

The United Kingdom set out 12 action plans to utilize its position as the leader in BIM exploitation to create growth for the UK market (HM government, 2013). As a consequence of a 5-year initial program in 2016, the UK government mandated BIM level 2 implementation in public sector projects. Moreover the UK government "established the UK BIM Task group in order to assist clients and supply chain through an intensive collaboration between governmental departments, industry, academia and estate clients" (Sielker & Allmendinger, 2018), which is why the UK government has stimulated BIM use in its client role as well. In general, BIM adoption has been led by larger firms, particularly contractors that operate on a design-and-build service (Davies et al., 2015). Furthermore, UK keeps track of the rate of BIM adoption within the country through continuous annual reports published by National BIM Library (NBS) which gives them an edge over the other pioneering BIM adopting countries.

2.3.2.1 The government's role as an initiator and driver

As early as 2011, the Government Construction Strategy targeted BIM level 2 adoption within all governmental departments by 2016. For this purpose, a BIM task group was formed in 2011 which brings together different stakeholders: the government departments, industry, academia, estate clients (Sielker & Allmendinger, 2018). Through various work packages also the possibility of Construction Operations Building Information Exchange (COBie), which denotes requirements for information exchange, implementation in public infrastructure projects was discussed. Other public bodies have also contributed to level 2 BIM implementation through different BIM protocol drafts and standards since (Cheng & Lu, 2015). In the Government Construction Strategy 2016-2020 report, the importance of BIM appliance was reiterated and led to the BIM level 2 mandate from 2016. "The announcement of the budget in March 2016 marks the start of the Digital Built Britain strategy. "The goal is to deliver reductions in whole-life costs, develop a low-carbon industry and improve productivity by using intelligent building models and commit to Level 3 BIM" (Sielker & Allmendinger, 2018).

2.3.2.2 The government's role as a regulator

Prior to 2015, 18 standards were published in UK. Construction Industry Council (CIC) along with BIM task group have also co-produced different guidelines in response to the government's statement regarding BIM in 2016 mainly touching on topics about BIM requirements in construction contracts. Furthermore from 2007 onwards, various non-profit organizations have issued standards (Cheng & Lu, 2015):

- Between 2007 and 2015 British Standards Institution (BSI) regarding life-cycle information exchange and digital definition and Building information management and data and procedures standards
- AEC UK committee on BIM standards and BIM protocols

2.3.2.3 Results of BIM Adoption in the UK

BIM usage and awareness has risen substantially from 48% in 2015 to 74% in 2018, while BIM knowledge and skills enjoyed a 13% boost from 2015 to 2018 (currently at 58 %) (NBS, 2018) (figure 17). In the 2016-2020 Government Construction Strategy report, the importance of developing a BIM-based construction sector is reiterated to cut down on whole-life costs, create a low-carbon industry and improve productivity by using intelligent building models and committing to level 3 BIM (HM government, 2016). As shown in figure 18, according to (NBS, 2018) the majority of users in the UK have reached the level 2 BIM (70%) which concerns the collaboration among the stakeholders.

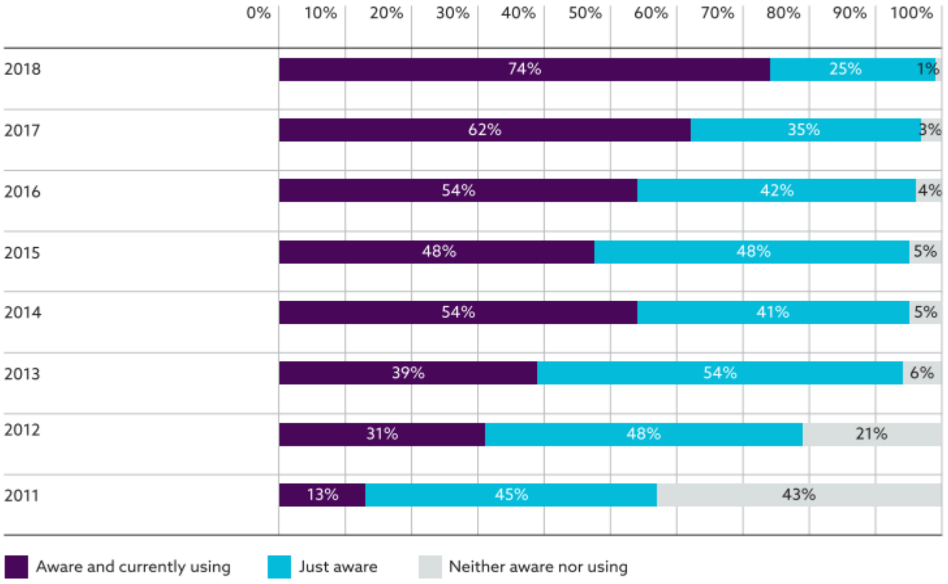

Figure 17. BIM adoption over time (Source: NBS, 2018)

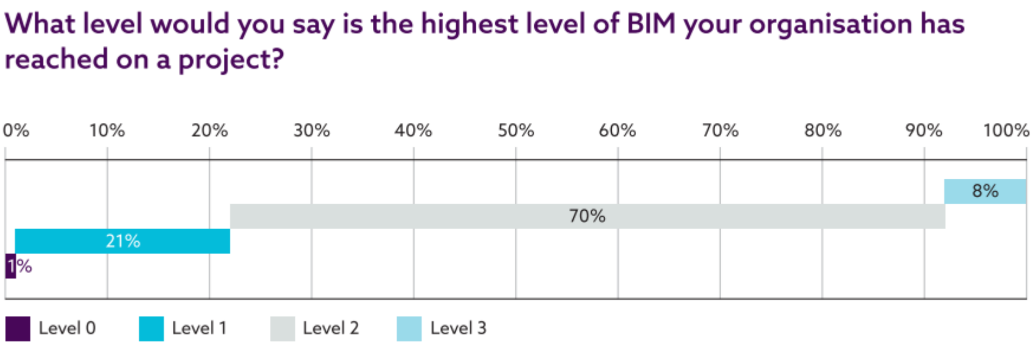

Figure 18. Percentage of use per different levels of BIM (Source: NBS, 2018)

2.3.3 Scandinavian countries

2.3.3.1 Denmark

2.3.3.1.1 The government's role as an initiator and driver and regulator and demosntrator

In Denmark, the use of IFC (Industry Foundation Classes) certification initially set the proper background for using BIM. With their leading role in developing BIM classification standards, they promoted the BIM implementation in Europe (Anker Jensen & Ingi Jóhannesson, 2013). The Danish government initiated the Digital Construction Project in 2007, which mandated the use of BIM in all public construction projects (Wong et al., 2009). The Digital Construction Project induced different state clients such as The Palaces & Properties Agency, The Danish University Property Agency, The Defence Construction Service to pilot BIM in their projects. Following suit of The Digital Construction Project, the National Agency for Enterprise and Construction issued four guidelines revolving around 3D CAD/BIM applications (Cheng & Lu, 2015). "As of 2013, projects that are fully or partly financed by the government and exceed the amount of DKK 5 million need to adopt BIM" (Sielker & Allmendinger, 2018).

2.3.3.1.2 Results of BIM adoption in Denmark

As of 2016, they had a 81% BIM usage(figure 20), which was higher than the UK (50%) furthermore Denmark has the highest application of IFC standards among other countries (NBS International BIM report, 2016) (figure 19).

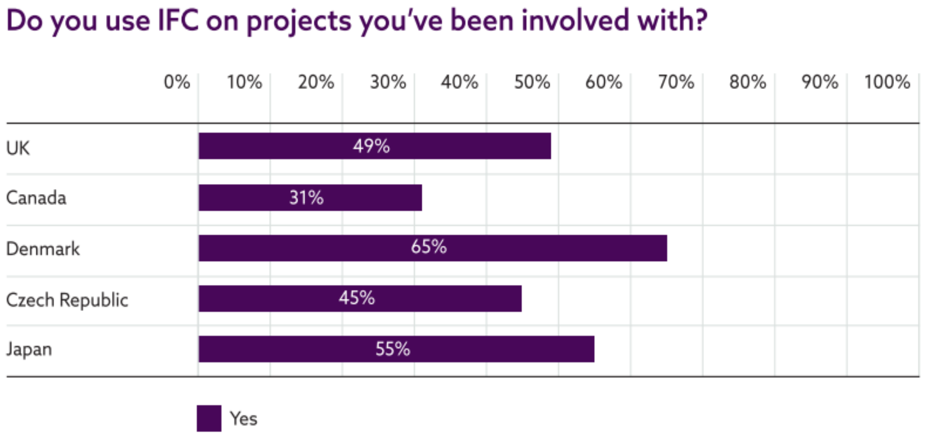

Figure 19. IFC application within different countries (Source: NBS International BIM report, 2016)

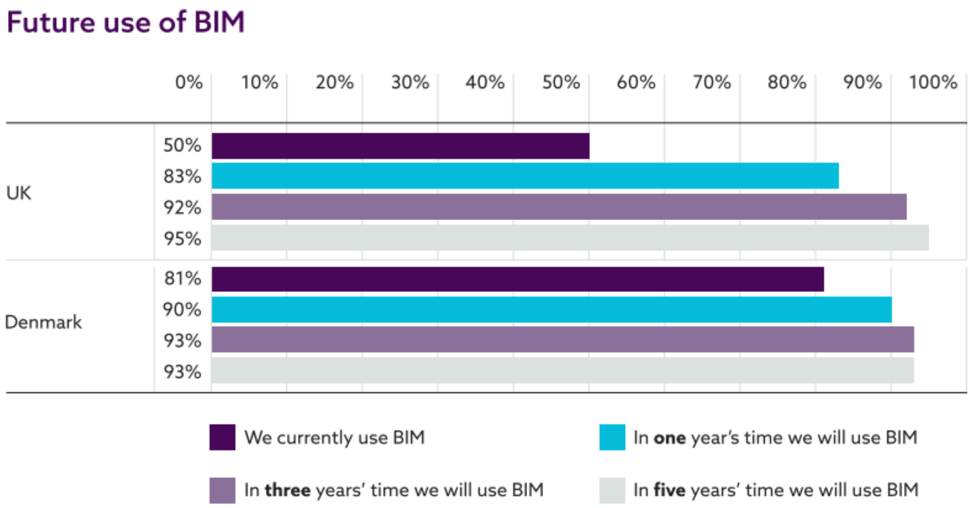

Figure 20. Future use of BIM (Source: NBS International BIM report, 2016)

2.3.3.2 Finland

2.3.3.2.1 The government's role as an initiator and driver, Regulator and Researcher and funding agency

According to World Economic Forum Finland is the second readiest country in the world in terms of digitalization. the first Country to adopt BIM building standards (Sielker &

Allmendinger, 2018). Senate Properties (the largest government enterprise under the Finnish ministry of finance) have mandated IFC-compliant BIM modelling since 2007 (BuildingSmart Australasia, 2012). Since 1970, the Finnish government has invested massively in IT research in the construction industry (Smith, 2014). Senate properties also established Common BIM requirements (COBIM) in 2012, which were developed with the help of several construction and consultant companies making them very practical (Cheng & Lu, 2015). Several private organizations and universities have also been conducting R&D work in BIM, and according to the (NBS, 2012) survey, Finland marked 65% of its respondents aware of and users of BIM (which was two times higher than the UK).

2.3.3.3 Norway

2.3.3.3.1 The government's role as an initiator and driver, Regulator and Researcher and demonstrator

In Norway, after the government expressed its commitment to BIM adoption in 2010, many public sectors (e.g. Norwegian Defence Estate Agency) launched programs and pilot projects in its support to require BIM application. Also In 2010 Statsbygg, a public administration company and Norwegian key advisor mandated the use of BIM for its projects based on IFC and IFD (Cheng & Lu, 2015). Norway's government has played an important role both as a researcher and a regulator as well. Statsbygg has been involved in many R&D projects focusing on BIM-related critical topics such as efficient buildings. Likewise in order to accommodate the abovementioned mandates, as of 2013, 4 BIM standards by Norwegian public bodies and 2 BIM standards by non-profit organizations were released (Cheng & Lu, 2015). Among different BIM manuals released, Statsbygg Building Information Modelling Manual (SBM), containing requirements for BIM application in projects, is mandatory for all state projects and is deemed to be the most influential one. A leading organization called SINTEF is also undertaking research in BIM and at the same time conducting several internal and cross-department studies under the BuildingSMART initiative (Wong et al., 2009). Although they are not exact information available on the current BIM usage percentage in Norway, it is deemed to be one of main the BIM leaders in the AEC industry.

2.3.4 Other Countries around the World

2.3.5 Singapore

2.3.5.1 The government's role as an initiator and driver, Regulator and Researcher and funding agency

The first strategic initiative supporting the use of information technology in the construction industry was established in 2000 through the Real Estate (CORENET) program. The CORENET e-Plan check system was later applied to further encourage the use of BIM (Smith, 2014): "the system uses IFC specifications as the core model for e-plan and enables architects and engineers to check their BIM-designed buildings for regulatory compliance through an online gateway" (BuildingSmart Australasia, 2012). In 2010, a major governmental agency called the Building and Construction Authority (BCA) implemented the BIM roadmap "with the goal that 80% of the Singaporean construction industry would use BIM and e-submissions for all new building projects of a size exceeding 5,000 square meters by 2015"(Cheng & Lu, 2015). in 2012, The BCA also released a BIM guideline to further clarify the requirements to BIM usage which was complemented with a BIM execution plan guide the year after. The government has furthermore encouraged BIM use through BIM funding, in support of trainings, development and higher collaboration among different participants and BIM awards for organizations and projects (Sielker & Allmendinger, 2018). In 2011 the government also developed a BIM specialist program diploma and it was aiming at a BIM level 3 specialized industry in 2015.

2.3.6 Australia

2.3.6.1 The government's role as an initiator and driver and Regulator

In 2012 buildingSMART Australia supported by the Built Environment Industry Innovation Council (BEIIC) developed the National BIM Initiative report, touching on mainly: mandating full 3D collaborative BIM in all government procurements; stimulating open BIM requirement on state level; developing a National BIM initiative

Plan. In 2016, a report by the Australian government's Standing Committee on Infrastructure, Transport and Cities exhorted the creation of a smart infrastructure task force (just like the UK task group). The Australian government has so far opted not to mandate BIM and settle instead for a gradual and voluntary approach. Nevertheless, from 2009 onwards many initiatives have been developed to inform project stakeholders about the potential productivity gains and gaining competitive advantages (Smith, 2014). "National BIM Guide" by the National Specifications (NATSPEC)in 2011, "National Guide for Digital Modelling" by Australia Cooperative Research Center (CRC) in 2009 and Australian and New Zealand Revit Standards (ANZRS) in 2009, addressing inconsistency issues among different Revit-related software, are among the most important BIM Guides developed in Australia (Cheng & Lu, 2015). Furthermore, BuildingSMART, as a key player in the BIM development and implementation, established the "Open BIM Alliance of Australia", which is an alliance between various software vendors to promote the concept of "Open BIM" (Smith, 2014). In 2014, the McGraw Hills report displayed Australia's exceptional leadership in external collaborative processes (50%), while arguing that 50% of contractors in Australia and New Zealand had been using BIM for three to five years by then (figure 21), so they were newer BIM users with lower engagement level (figure 22). Notwithstanding that, within 2 years a 38% boost in the percentage of contractors implementing BIM at a high/very high level is predicted, which implies that BIM adoption will be on an upward trend in the coming years.

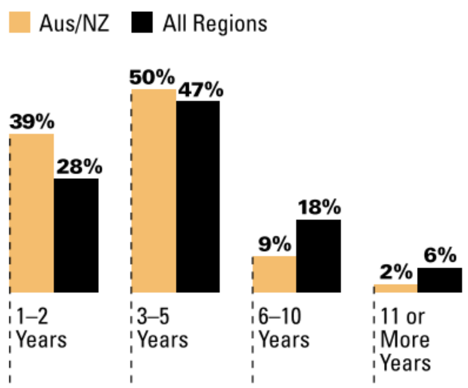

Figure 21.Length of time using BIM (Source: McGraw Hill Construction, 2015)

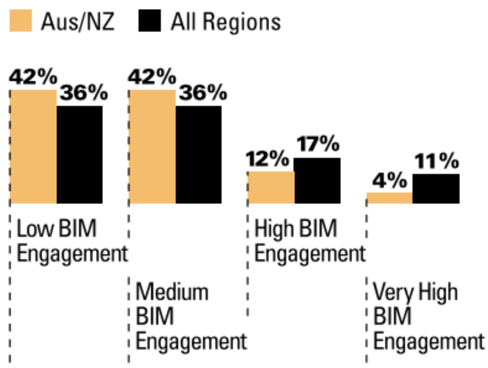

Figure 22. BIM engagement level (Source: McGraw Hill Construction, 2015)

2.3.7 Italy

2.3.7.1 The government's role as an initiator, driver and regulator and funding agency

In Italy under the law in 2013, IBIMI, an association that incentivize the diffusion of digital innovation in the Construction industry, was established and at the moment it is operating under the buildingSMART Italy which was founded a priori in 2004. Furthermore in 2014 government supported and funded a three year project called "INNovance" aiming at developing a standardized national BIM library which involved some of Italy's primary construction companies, three universities and associations of manufacturers of building components (Pasini, Caffi, Daniotti, Lupica Spagnolo, & Pavan, 2017). the first governmental action to support BIM implementation was triggered as a result of the "BIM decree" in December 2017, in which the contracting authorities mandated the use of "digital tools and methods". The decree requires BIM implementation in various phases as follows with the scope of having a fully digitized BIM using industry for projects amounting less than one million euro by 2025:

- Until 2019 for complex works exceeding 100 million euros
- From 2019 to 2021, the attention of the mandate will be on the matter of complexity rather than project's amount.
- From 2022 the mandate will require all ordinary works as well as complex works to use BIM

2.3.8 Comparison among different countries per roles played in BIM adoption

The government strategies vary considerably from one to another and the degree of success regarding each strategy should be viewed alongside the characteristics of different countries when it comes down to AEC industry. Singapore is stepping closer to a fully diffused level 3 BIM; the USA is distinguished among other countries for public body's contributes to BIM implementation from national level to university level; the UK has reached level 2 BIM mainly thanks to the government mandates; Denmark has very high rates of BIM-users currently and has the appropriate base to achieve a level 3 BIM. Table 5 compares different strategies undertaken in fostering BIM adoption in different countries with their relative roles:

Countries	Initiator and Driver	Regulator, Researcher and Funding Agency	Focus	Distinguishing feature and Main enablers
USA	Requiring BIM for government projects from 2008	Numerous standards by both public bodies and non-profit organizations triggered by the GSA series of guidelines in BIM implementation from 2007 onwards	Requiring BIM use for public service buildings in government projects through public bodies from 2007	The contribution to BIM up-take on different levels: university, national, state, public bodies
UK	Mandating level 2 BIM in 2016 as a result of a initial 5-year	Numerous standards by public bodies and non-profit organizations in response to the government initiative	Public service buildings and infrastructure	The government role is highlighted also as a client; establishing a BIM task group to link industry, academia, clients; delivering annual reports on BIM
Denmark	Digital Construction Project required BIM in public projects in 2007; Mandating BIM from 2013 for projects exceeding 5DKK,	Various standards released in early stages,	Public infrastructure	Implementing a Digital construction project in 2007 is deemed to be the turning point in BIM adoption; many state clients followed the initiative

Finland	The Senate, a major public enterprise, required IFC-compliant BIM modelling in 2007.	Major investments in IT-related research in construction industry. many R&D projects with the help of universities and private organizations were funded.	Public infrastructure	First country to adopt BIM standards and to require IFC-compliant BIM.
Norway	In 2010 Statsbygg, a public mandated IFC-IFD compliant BIM modelling,	Various standards developed by both public bodies and non-profit organizations, the SBM the most influential one within the industry as it is mandated in state projects. many R&D projects funded by the Statsbygg	Public infrastructure	Statsbygg as a key government advisor, has contributed in developing standards, manuals, funding research projects and mandating IFC-IFD compliant modelling
Singapore	Level 3 BIM mandate from 2015 for buildings above 5000sqm; mandating e-submissions for construction projects	Developing BIM execution plans in support of the mandate, BIM funding promoting higher collaboration among different stakeholders and BIM awards at organizational and project levels	All types of Projects above 5000sqm	The CORENET program enabled an IFC compliant BIM modelling industry; the first e-submission platform in construction industry
Australia	No government mandate	Various National BIM guides; Different initiatives and guidelines in promoting BIM use; Australian and New Zealand Revit Standards (ANZRS) in 2009, addressing inconsistency issues among different Revit-related software; "Open BIM Alliance of Australia"an alliance between various software vendors	No mandate	Government does not mandate BIM and is targeting gradual adoption through higher perception of its productivity; National BIM guidelines and initiatives; strong presence in addressing software related issues
Italy	BIM mandate from 2019	No national standard	For complex works exceeding 100 million euro	Funding a project to develop a national BIM library

Table 5. Comparison among different countries' strategies in fostering BIM

2.4 The Diffusion of Innovation (DOI) theory

2.4.1 Definitions and the main elements

(E. M. Rogers, 2003) describes technology as “a design for instrumental action that reduces the uncertainty in the cause-effect relationships involved in achieving a desired outcome”. It consists of two parts: hardware and software. hardware is “the tool that embodies the technology in the form of a material or physical object,” software is “the information base for the tool” while software is believed to have slower rate of adoption since it has lower level of observability (Sahin, 2006).

(E. M. Rogers, 2003) explains adoption as a type of decision that requires “full use of an innovation as the best course of action available” ,rejection as a decision “not to adopt an innovation” while diffusion is defined as “the process in which an innovation is communicated thorough certain channels over time among the members of a social system”.

These definitions necessitate the better explaining of the four main elements of diffusion of innovation process: Innovation, Communication Channels, Time, Social system

2.4.1.1 Innovation

(E. M. Rogers, 2003) explains innovation as “an idea, practice, or project that is perceived as new by an individual or other unit of adoption” this means that even if the innovation itself has been around for a long time, it could be perceived new for some individuals. (E. M. Rogers, 2003) relates the newness of an innovation, to be adopted, to the three steps of the innovation-decision process (knowledge, persuasion, decision) which is explained later on.

Uncertainty is considered a major obstacle in adopting innovations, which is emanated from the innovation’s consequences. (E. M. Rogers, 2003) define consequences as “the changes that occur in an individual or a social system as a result of the adoption or rejection of an innovation” and classifies them into “desirable versus undesirable (functional or dysfunctional), direct versus indirect (immediate result or result of the immediate result) and anticipated versus unanticipated (recognized and intended or not)" (Sahin, 2006). To reduce the uncertainty linked to an innovation adoption, individuals need to be informed about its advantages and disadvantages.

2.4.1.2 Communication Channels

(E. M. Rogers, 2003) defines communication as "a process in which participants create and share information with one another in order to reach a mutual understanding" and explain that the receiver gets a message through different channels from an individual or an institution that originates the message (source). Rogers, considers the diffusion to be a specific kind of communication that involves different elements: an innovation, individuals and units of adoption, communication channels. Furthermore, Rogers classifies communication channels into two: Mass media including all communications happening by means of TV, radio, newspaper; Interpersonal communication which consist of communications between individuals. The interpersonal communication channel is deemed to be more effective and powerful in affecting individuals' behaviours.

Rogers explain "one of the most distinctive problems in the diffusion of innovations is that the participants are usually quite heterophilous" which translates into different individuals to be different in certain attributes.

The Communication Channels can be categorized also in Localite channels and Cosmopolite channels. While almost all mass media channels are cosmopolite, interpersonal channels consist of both which is the reason why the former is more effective in the Knowledge stage and the later in the Persuasion stage of innovation-decision process.

2.4.1.3 Time

Rogers stresses the importance of considering the time aspect in evaluating diffusion studies. For this purpose, both the innovation-diffusion process and the rate of adoption all possess a time dimension to their evaluations.

2.4.1.4 Social system

According to Rogers the innovation diffusion takes place in a social system and is defined as "a set of interrelated units engaged in joint problem solving to accomplish a common goal". Rogers furthermore, stresses that the structure of the social system affects the individuals' innovativeness and is the main criterion for categorizing the adopters.

2.4.2 The innovation-decision process

(E. M. Rogers, 2003) described the innovation-decision process as "an information-seeking and information-processing activity, where an individual is motivated to reduce uncertainty about the advantages and disadvantages of an innovation". The innovation-decision process consists of five stages: (1) knowledge (2) persuasion (3) decision (4) implementation (5) confirmation as shown in figure 23:

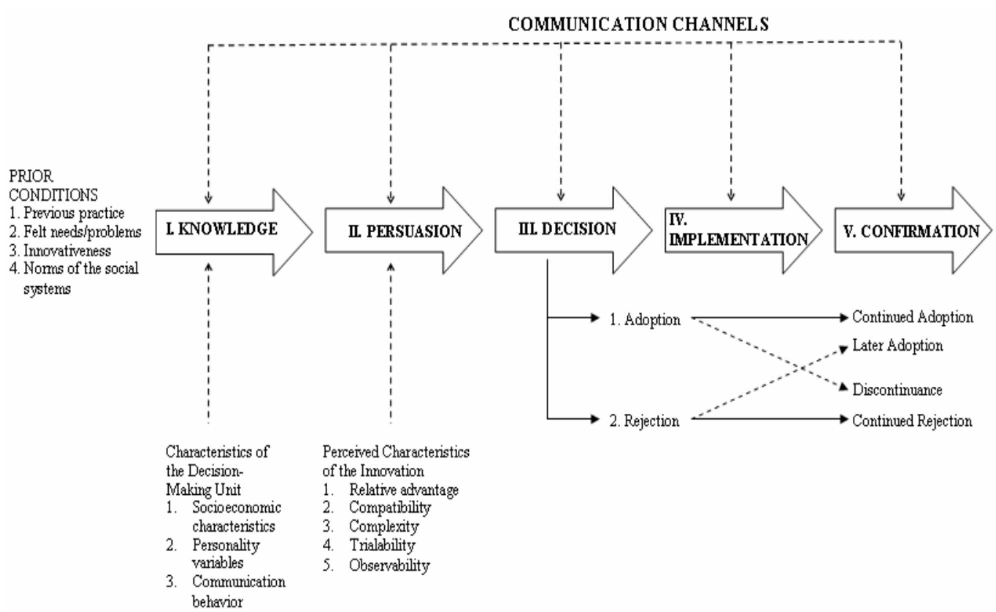

Figure 23. The five stages of the Innovation-Decision process (source: E. M. Rogers, 2003)

2.4.2.1 The knowledge stage

The innovation-decision process starts with this stage where individuals within the social system try to disclose information about the innovation and discover "what the innovation is and how and why it works" (E. M. Rogers, 2003). Rogers identifies three types of knowledge which seek to answer the above question: (1) awareness-knowledge (2) how-to-knowledge (3) principles-knowledge

2.4.2.1.1 Awareness-knowledge

This type of knowledge responds to questions regarding the innovation's existence. This type of knowledge can prompt the individual to seek other two types of knowledge and to eventually adopt it

2.4.2.1.2 How-to-knowledge

This type of knowledge contains information on how to use the innovation correctly (Sahin, 2006). Rogers considers this knowledge to be crucial in increasing the chances of adoption since a sufficient level of knowledge on how to use the innovation prior to its trial is inevitable.

2.4.2.1.3 Principles-knowledge

This type of knowledge explains how and why an innovation works although an individual does not have to necessary possess this type of knowledge to adopt it but lack of this knowledge might cause use discontinuation. "In fact, an individual may have all the necessary knowledge, but this does not mean that the individual will adopt the innovation because the individual's attitudes also shape the adoption or rejection of the innovation". (Sahin, 2006)

2.4.2.2 The Persuasion stage

Once the individual acquires knowledge about an innovation and shapes its attitudes accordingly, the next step in the innovation-decision process is persuasion stage. Rogers argues that while the knowledge stage is more cognitive (knowing) centred, the persuasion stage is more affective centred (feeling) (Sahin, 2006). This stage takes place when the individual forms a negative or positive attitude towards the innovation however Rogers affirms that this formation does not necessarily lead directly or indirectly to an adoption or rejection. the individual’s view of an innovation is affected by both the degree of uncertainty connected to the innovation’s functioning and the feedback it receives from its social context (colleagues, peers, …). Opinions from colleagues and trusted friends about an innovation are deemed to be more conceivable and convincing to individuals.

2.4.2.3 The Decision stage

At this stage of the innovation-decision process individuals decide whether to reject or adopt the innovation. Rogers describe adoption as “full use of an innovation as the best course of action available” while rejection is “not to adopt an innovation” (E. M. Rogers, 2003). If the innovation has a trial option, the adoption usually occurs more quickly however the rejection may happen at any stage of the innovation-decision process. Rogers classifies rejections in two: Active rejection and passive rejection. a rejection is active when the individual contemplates adopting an innovation after trying it but decides not to. A discontinuance rejection, which is rejection after adopting an innovation earlier, can be considered an active rejection also. in Passive rejection the individual does not think about adopting the innovation. Rogers argues that the order of the Knowledge-persuasion-decision can change into Knowledge-decision-persuasion in cases of collectivistic cultures where the decision to adopt an innovation is transformed from an personal decision into an collective one (E. M. Rogers, 2003).

2.4.2.4 The Implementation stage

At this stage the innovation is put into effect. Uncertainty about the innovation still exist to some degrees therefore the individual may need technical assistance to diminish the degree of uncertainty about the consequences. An essential part of this stage is Reinvention since the innovation loses its “the innovation loses its distinctive quality as the separate identity of the new idea disappears” (E. M. Rogers, 2003). Rogers describe Reinvention as “the degree to which an innovation is changed or modified by a user in the process of its adoption and implementation” whereas the adoption of an innovation “is the process of using an existing idea” (E. M. Rogers, 2003). Rogers argues the more reinvention is exploited, the more the innovation will be subject to rapid adoption and diffusion.

2.4.2.5 The Confirmation stage

At this stage, the individual assumes permanent attitudes towards the innovation based on the support it receives regarding the adoption (decision to adopt an innovation). “Rogers argues that this decision can be reversed if the individual is exposed to conflicting messages about the innovation” (Sahin, 2006). The individual can assume two attitudes at this stage: to further adopt the innovation or discontinue adopting.

There are two types of discontinuance decisions. when the individual replaces the old innovation with a new one and refuses to adopt the old one, the discontinuance decision is called replacement discontinuance while disenchantment discontinuance occurs when the individual rejects the innovation due to unsatisfactory performance level of the innovation.

2.4.3 Rate of adoption

Rogers describe the rate of adoption as “the relative speed with which an innovation is adopted by members of a social system” (E. M. Rogers, 2003). Rogers links an innovation’s rate of adoption with its most significant perceived attributes and argues that 49-87% of the variance an innovation’s rate of adoption is explained by five attributes that are discussed later. Other than these perceived attributes, other factors such as the “innovation decision type (optional, collective, authority), communication channels (mass media, interpersonal channels), social system (norms or network interconnectedness) and change agents” (Sahin, 2006) affect the rate at which an innovation is adopted. Rogers finds the relative advantage to an innovation to be the most significant predictor of its rate of adoption.

2.4.4 Most Significant perceived attributes

Rogers identifies five attributes as a measure to individuals' perception of an innovation. (E. M. Rogers, 2003) states "individuals' perceptions of these characteristics predict the rate of adoption of innovations". The attributes are as follows: (1) relative advantage (2) compatibility (3) complexity (4) trialability (5) observability

2.4.4.1 Relative advantage

(E. M. Rogers, 2003) describes relative advantage as "the degree to which an innovation is perceived as being better than the idea it supersedes". relative advantages to an innovation consist of cost and social status motivation aspects of an innovation (Sahin, 2006). Different perceptions of relative advantages affect the time of adoption for instance innovators, early adopter, early majority appreciate social status of an innovation while late majority and laggards value the status less. Rogers categorizes innovations into two groups in terms of the degree of uncertainty to their perceived relative advantages: preventive innovation, with rather highly uncertain relative advantages, described as "a new idea that an individual adopts now in order to lower the probability of some unwanted future event"(E. M. Rogers, 2003); incremental innovations, with lower level of uncertainty regarding relative advantages, which produce beneficial advantages in short period (Sahin, 2006).

2.4.4.2 Compatibility

Rogers distinguishes between relative advantages and compatibility to an innovation and describes the latter as "the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters". In other words, if the innovation is compatible/consistent with the individual's needs the rate of adoption should be increased since the uncertainty about the innovation diminishes.

2.4.4.3 Complexity

Rogers describes complexity as “the degree to which an innovation is perceived as relatively difficult to understand and use”. This attribute negatively impacts the innovation’s rate of adoption therefore, over-complex innovations are less likely to be adopted

2.4.4.4 Trialability

Rogers defines trialability as “the degree to which an innovation may be experimented with on a limited basis”. This attribute is positively correlated with the rate of adoption which means the more an individual experiments an innovation the faster its adoption. early adopters value the trialability attribute of an innovation more than the later adopters. As mentioned earlier, reinvention ,as an important factor to accelerate the rate of adoption, also occurs during the trial of an innovation in which the innovation can be modified to individuals’ needs (Sahin, 2006).

2.4.4.5 Observability

Rogers defines observability as “the degree to which the results of an innovation are visible to others”. This attribute is also positively correlated with an innovation’s rate of adoption.

Rogers argues that even though the availability of these attributes accelerate an innovation’s rate of adoption and the innovation-decision process, the decision to adopting a new innovation is difficult.

2.4.5 Adopters categories

Rogers classifies the adopters on the basis of their innovativeness. He describes the innovativeness as “the degree to which an individual or other unit of adoption is relatively earlier in adopting new ideas than other members of a system”. Non-adopters or incomplete adoptions are excluded from this classification. The curve forms a normal distribution where the respondents are divided by standardized percentages. This classification as shown in figure 8, include:

- Innovators: people who are willing to experience new ideas. They are the ones bringing the innovation from outside to the social system and they embrace the uncertainty connected to an innovation
- Early adopters: they are role models within the social system and are more confined to the limits of a social system and their evaluations about an innovation affect other members of the social system
- Early majority: they do not have the same role as early adopters within a social system, they are neither early nor late in adopting an innovation while they are half of their peers in the social system in adopting an innovation
- Late majority: they wait more than half of the social system to adopt an innovation before adopting it. They are more sceptical about the outcomes of innovations and their decision is triggered by economic rationale and peers' pressure.
- Laggards: they have the traditional view, more sceptical than the late majority about innovations. They have a very limited interpersonal network whom belong all to the same category of social system

Furthermore, Rogers categorizes the adopters in two groups: early adopters and late adopters. Earlier adopters include innovators, early adopters and early majority while later adopters comprise of late majority and laggards (figure 24).

Rogers compares these two groups in terms of "socioeconomic status, personality variables, and communication behaviors, which usually are positively related to innovativeness. For instance"(Sahin, 2006) and conclude that "the individuals or other units in a system who most need the benefits of a new idea (the less educated, less wealthy, and the like) are generally the last to adopt an innovation"(E. M. Rogers, 2003)

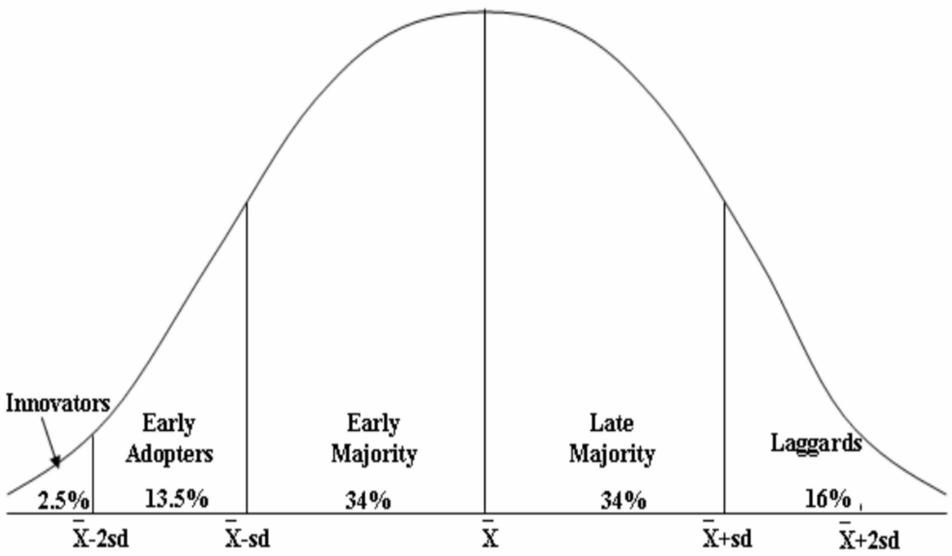

Figure 24. Classification of adopters on the basis of innovativeness (source: (E. M. Rogers, 2003))

2.5 The latest developments in the Diffusion of Innovation (DOI) theory

According to Rogers's DOI theory "innovation is an idea, practice, or project that is perceived as new by an individual or other unit of adoption" (E. M. Rogers, 2003). Such a theory scrutinizes how an idea spreads within specific homogeneous social systems. Early studies focused on personal innovation adoption behaviours and established five stages during which the diffusion of innovation takes place: knowledge, persuasion, decision, implementation, confirmation (E. M. Rogers, 2003). Consequently, studies extended the theory to discern the difference between the innovation adoption process in organizations, in other terms, assorted social systems, and in individuals (B. J. Gledson & Greenwood, 2017; Shibeika & Harty, 2015);. Founded on Rogers' innovation diffusion theory, (B. J. Gledson & Greenwood, 2017) discuss that the increase in the rate of adoption in the case of 4D BIM is mostly explained by its relative advantages in communicating the construction plan, its compatibility with existing planning practices and its capacity to be tested in a safe environment prior to use on a live construction project among other perceived attributes. (B. J. Gledson & Greenwood, 2017) argues that the most frequent decision type to adopt 4D BIM is the authority-type taken by the organization's upper management among other types (optional, collective). They also conclude that construction professionals prefer to obtain innovation information from within their own interpersonal networks, which is in contrast to one of Rogers's generalizations that considers mass media channel to be the most important communication channel. Furthermore, he correlates: the company size with the personal use of 4D BIM; organizational BIM maturity with the personal use of 4D BIM.

In accordance with the innovation diffusion theory (IDT), (Poirier, Staub-French, & Forgues, 2015) discuss four different reciprocal contexts of innovation adoption to explain key factors influencing the BIM adoption in SMEs: 1) industry 2) institutional 3) organizational 4) project contexts

Accordingly, (Hosseini et al., 2016) stress that industry and institutional factors affect the organizational factors and the latter manipulates the project level factors. Moreover, he merges the industry and institutional factors into one single embedded context named supply chain and summarizes the barriers in BIM adoption in three categories: 1) supply chain barriers 2) organizational barriers 3) project barriers. (Ahuja et al., 2018) use a TOE framework (technological, organizational, environmental) to categorize and analyse significant drivers to BIM adoption.

based on the IDT, (Shibeika & Harty, 2015) describe the process through which a firm spreads digital innovation, and the social system into which the digital innovation is introduced is described as neither stable nor static; instead, the project-based nature of the company has a great effect on diffusion. The communication channels do not appear in the classic form of the IDT, alternatively, the digital spread is explained through a change in the firm's structural organization and the key role of champions. (Shibeika & Harty, 2015) define three phases of diffusion: 1) Centralization of technology management: where a change in the organizational structure takes place; 2) Standardization of digital practices; 3) Globalization of project work.

Based therefore on the findings and recent developments of Innovation digital theory (IDT), this article groups the hindrances to BIM adoption into 3 categories (Figure 25):

- Institutional barriers;
- Organizational/human barriers;
- Project-related/technological barriers

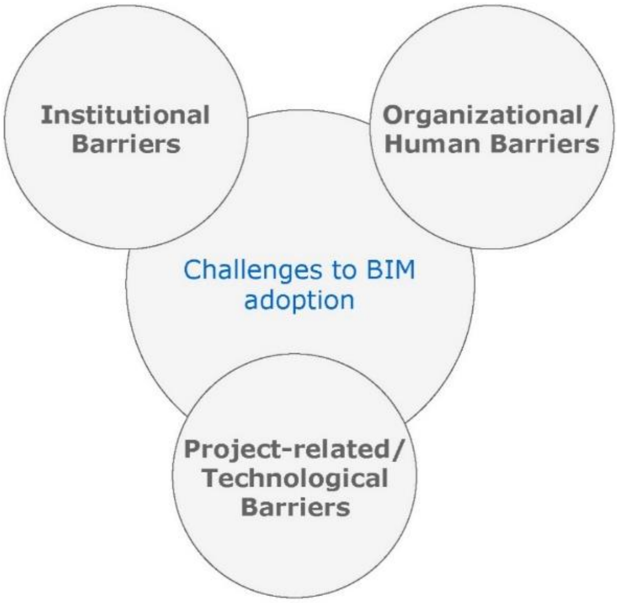

Figure 25. Three main categories of challenges to BIM adoption

2.6 Research Methodology:

An online web-hosted questionnaire survey was deployed in view of the barriers classification. The target population encompasses all of the construction-related companies across the Italian AEC (architecture, engineering, construction) industry. The online questionnaire was premised on previous questionnaires conducted by (NBS, 2018), (Hosseini et al., 2016), (Shibeika & Harty, 2015) and (B. J. Gledson & Greenwood, 2017), each of which covers a particular portion of the proposed classification of barriers to BIM adoption. The questionnaire was further bolstered by scrutinizing the literature review about hindrances to BIM adoption according to different authors. The first section of the questionnaire clarified the aims of the research study and sought to acquire the demographic factors of respondents. In the second section, the respondents who identified themselves as adopters were asked about their company organizational structure, their Level of BIM usage, the type of decision made to adopt BIM and how they found out about BIM (communication channels). This section of the questionnaire seeks to compare and inspect the prescribed conditions to BIM adoption according to (Shibeika & Harty, 2015) and (B. J. Gledson & Greenwood, 2017). Based on the literature review, the third section consisted of 12 barriers that asked the respondents to state their level of agreement regarding the challenges. The assessment is made through a five-point Likert-scale (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree). The barriers are classified into three super-categories as shown in Figure 26 (some barriers belong to more than one category).

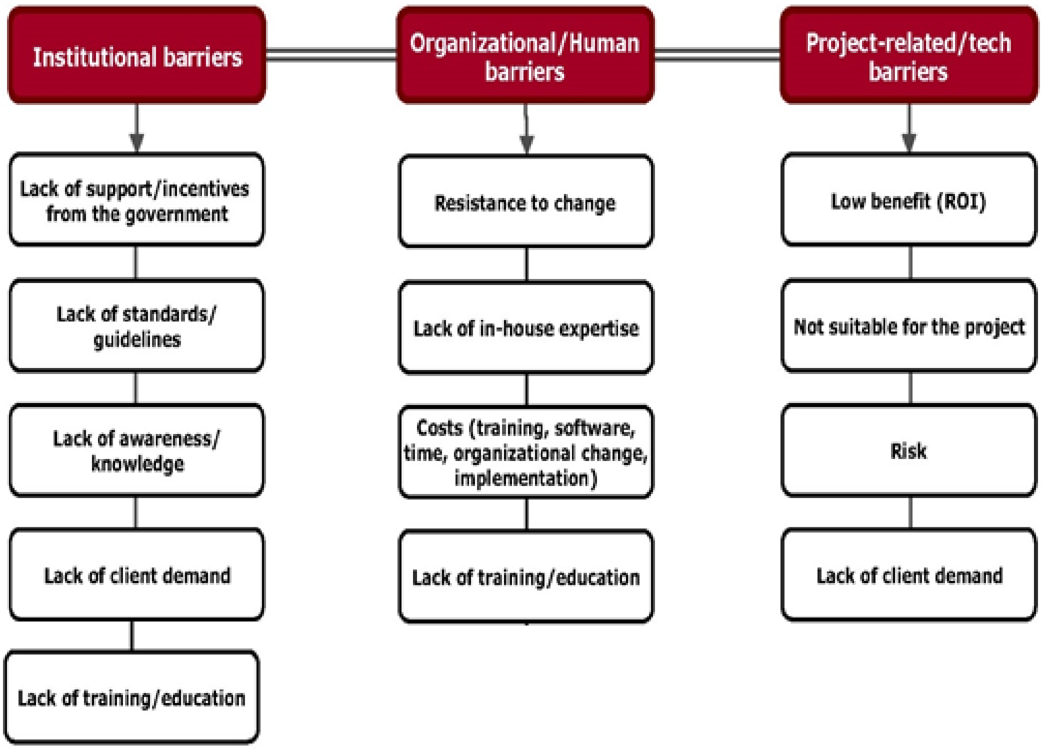

Figure 26. Classification of barriers to BIM adoption

2.7 Respondents' profile

The online questionnaire survey was conducted and disseminated among companies, individuals and entities connected to the AEC industry operating in Italy between December 5th, 2018 and February 5th, 2019, during which time a total number of 78 complete responses were recorded. The first part of the questionnaire sought to gather demographic information about the respondents as shown in Table 6:

Respondent Information	Categories	Percentage	Frequency
Gender	Male	79.5%	62
	Female	20.5%	16
Age	20-40	48.7%	38
	40-60	46.2%	36
	> 60	5.1%	4
Firm size by number of employees	Small (1-49)	51.2%	40
	Medium (50-249)	25.7%	20
	Large (> 250)	23.1%	18
Experience in AEC industry (in years)	1-10 years	48.8%	38
	11-20 years	25.6%	20
	> 20 years	25.6%	20
Company type	Contractor	5.1%	4
	Manufacturer	53.8%	42
	Construction Company	7.7%	6
	Architecture Company	15.4%	12
	Engineering Company	10.3%	8
	Consultant	7.7%	6
Specialization	Director	28.2%	22
	Designer	20.5%	16
	Project Manager	23.1%	18
	Engineer	2.6%	2
	Technicians	5.1%	4
	Consultant	17.9%	14
	Owner	2.6%	2
Job level	Upper management	35.9%	28
	Middle management	48.7%	38
	Lower management	15.4%	12
Primary clients of the company	Government	19.4%	24
	Individuals/Owners	19.4%	24
	Private Organizations	51.6%	64
	Public Organizations	9.7%	12

Table 6. Respondents' profile

As set out in Figure 27, 51% (n=40) of respondents identified themselves as working for small companies (1-49 employees); 25.7% (n=20) as working for medium companies (50-249 employees) and 23.1% (n=18) as working for Large companies (over 250 employees). As regards the type of companies (Figure 28), most of the respondents work for manufacturing companies (53.8% ; n=42), followed by Architecture (15.4% ; n=12) and engineering companies (10.3%; n=8), whereas in terms of their job position, the majority of respondents are directors (28.2% ; n=22) followed by Project managers (23.1% ; n=18) and designers (20.5% ; n=16) (Figure 29).

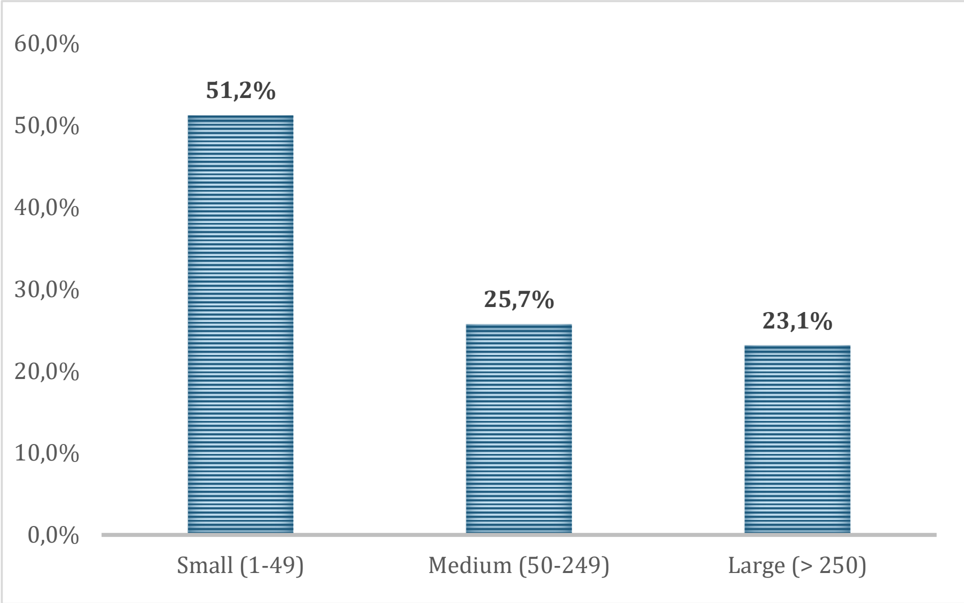

Figure 27. Firm size by number of employees

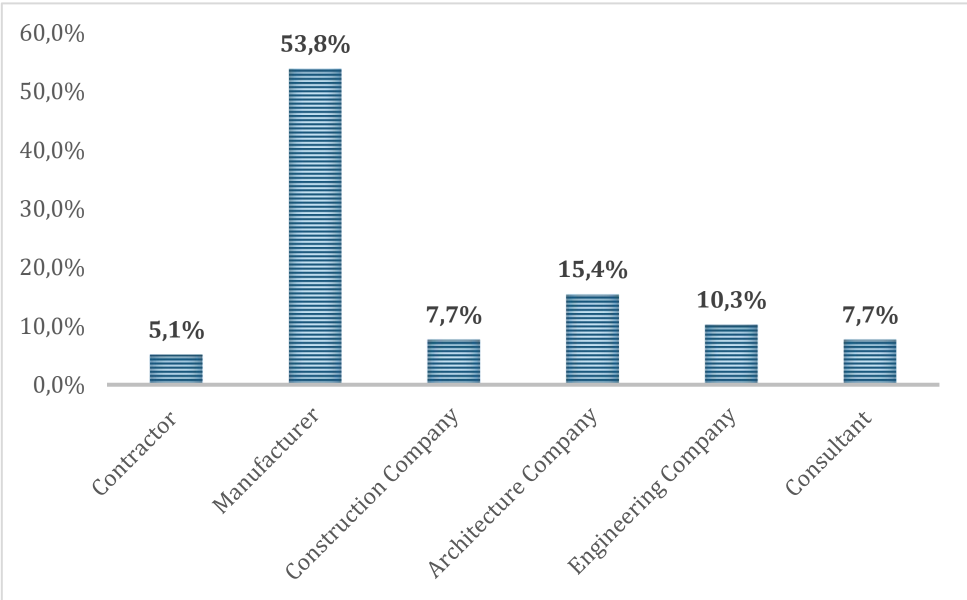

Figure 28. Company type

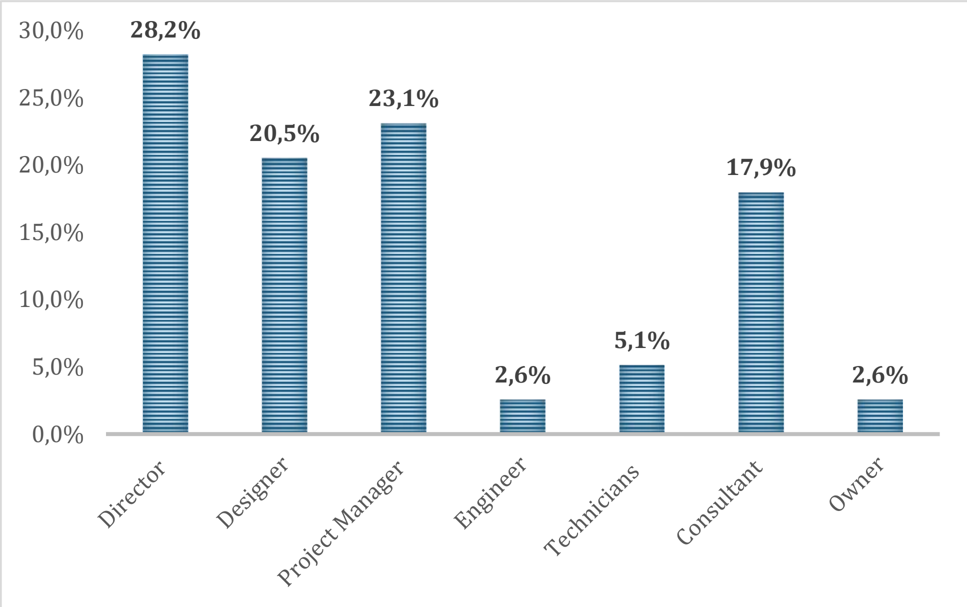

Figure 29. Respondent's specialization

Respondents also acknowledge that 51.6% (n=64) of their primary clients are private organizations, while each of individuals/owners and governments accounts for 19.4% (n=24) of their major clients (Figure 30).

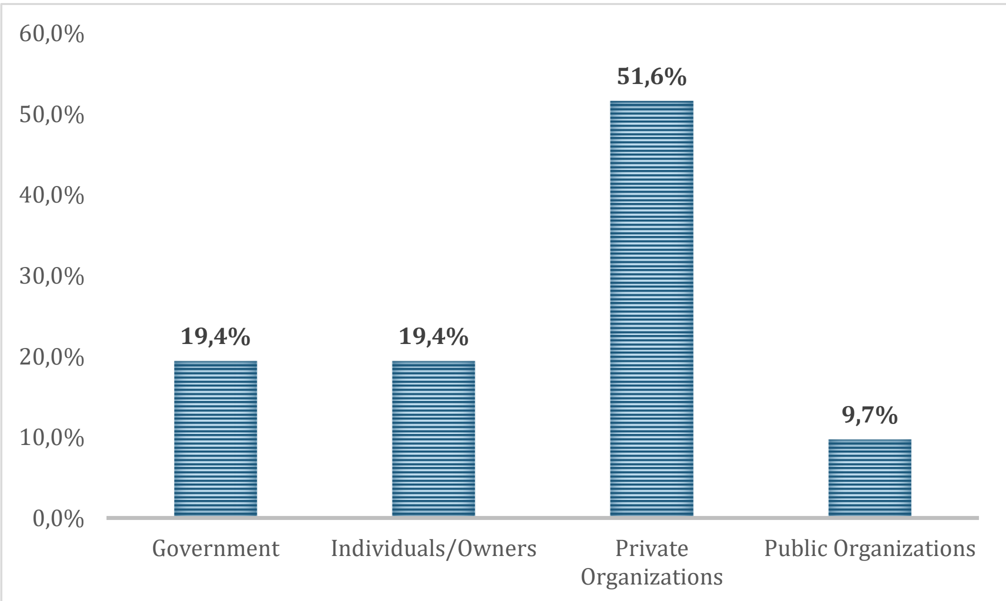

Figure 30. Primary clients of the company

Later on, the respondents were asked about their BIM awareness and usage:56% (n=44) confirmed their awareness and use of the BIM, while 36% were only aware (n=28) and 8% (n=6) were neither aware nor using the BIM (Figure 31). Furthermore, out of the 44%

(n=34) that do not use the BIM, 23% (n=18) expect to be using it in a year's time; 10% (n=8) in 3 years' time; 8% (n=6) in 5 years' time and 3% (n=2) think they will never use the BIM (Figure 32).

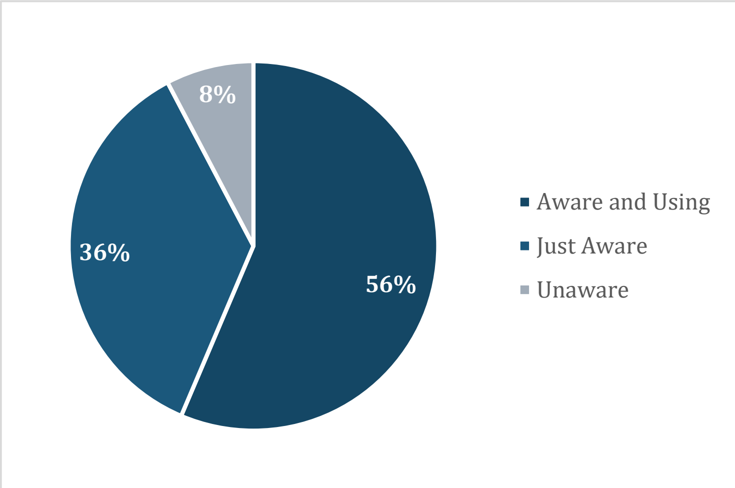

Figure 31. BIM usage and awareness

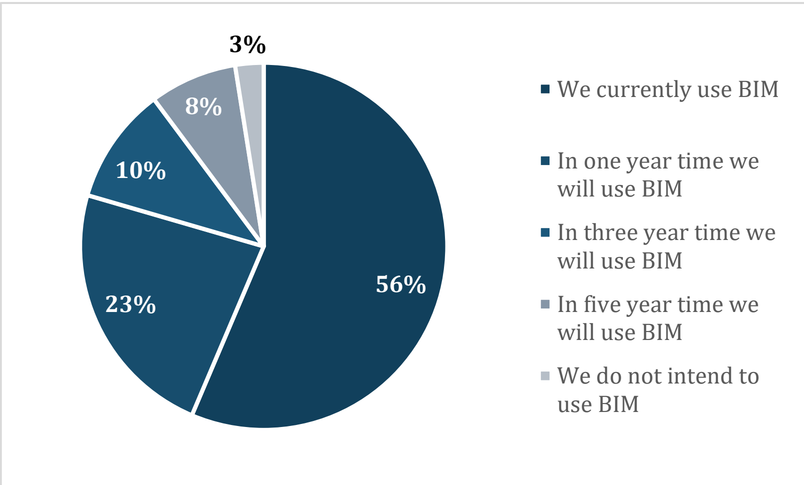

Figure 32. Future BIM use

By applying the (NBS, 2018) descriptions of different BIM levels, the adopters' perception of their organization's BIM maturity was appraised. As a result, 23% (n=10) identified their organization's BIM maturity as level 0; 27% (n=12) as level 1; 50% (n=12) as level 2 (Figure 33).

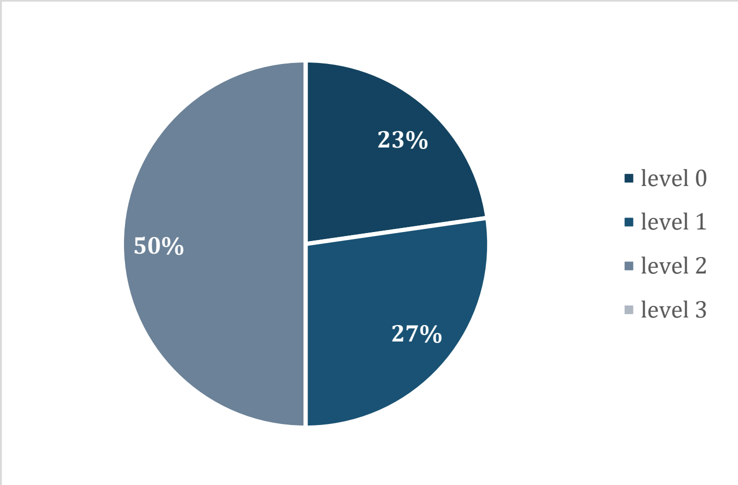

Figure 33. BIM maturity

The respondents identified as unaware or not using the BIM were directed straight to the third and last section of the questionnaire where they were asked to reflect on the challenges to BIM adoption. In the meantime, the rest of the respondents deemed to be adopters or aware of BIM were guided to answer questions regarding their organization's characteristics, type of decision and communication channel in BIM adoption, and eventually to give their thoughts on the barriers along with the others.

The Pearson's correlation coefficient method, also referred to as Pearson's r, was employed to investigate the correlations between different variables, as this method proves to be the best means of measuring linear relationships (Jan & Tomasz, 2011). The coefficient returns a value between -1 and +1 that represent the limits of correlation from a full negative correlation to a full positive correlation where 0 means no correlation between the variables (Bryman & Cramer, 2005). Fisher's exact test, an inferential statistics analysis method, was also exploited to examine the significance of statistical relationships between variables where the H_0 (null hypothesis) proves that the association between the variables occurs by chance, whereas, conversely, the H_1 (alternative hypothesis) proves the existence of an association between variables. This method was preferred to the Pearson's Chi-square test, since conditions for X^2 were mostly not met due to the fact that numerous cells during comparisons had observed and expected counts of less than 5.

2.8 Rate of adoption

Following the footsteps of (B. J. Gledson & Greenwood, 2017), the rate of adoption is assessed by comparing the first year of BIM awareness and the first year of BIM adoption; adopters are consequently asked to indicate the year in which they first became aware of BIM and the year they decided to first adopt BIM in their construction-related practices. The earliest year of awareness was 2003, while the latest was 2016, the mean is 2011 and the median 2012, where the majority of respondents asserted that they became aware of BIM between 2012 and 2016. The earliest year of adoption was 2005, while the latest adoption is in 2018, the mean is 2013 and the median 2015, and the majority of respondents adopted BIM between 2014 and 2018. Using Pearson's correlation coefficient method, a comparison was drawn between the first year of BIM awareness and the first year of BIM adoption. The coefficient for the variables is 0.843, which according to (Bryman & Cramer, 2005) is a strong positive relationship; moreover, the coefficient of determination (denoted by R^2) is 0.71, which implies the fact that 71% of the variance in the timing of the First adoption is explained by the linear model in Figure 10 (that is the timing of first awareness). Disregarding the outliers in the dataset (distinguished in Figure 34) would help us to identify the time lag to BIM adoption with more precision.

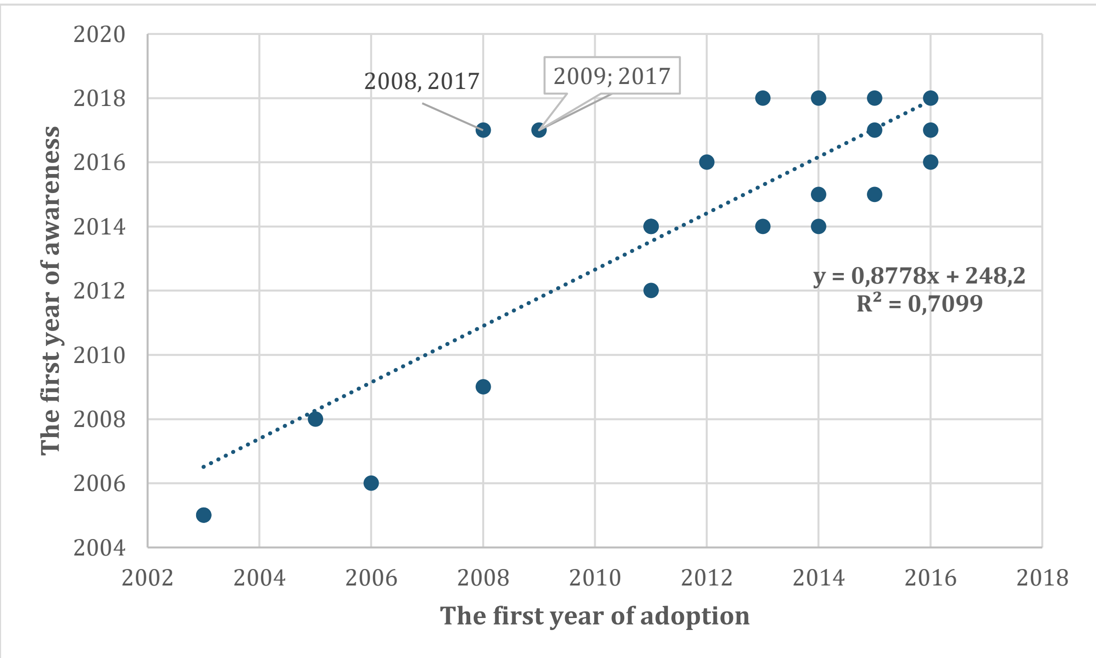

Figure 34. Correlation between the first year of BIM awareness and BIM adoption

One of the respondents became aware of BIM in 2008 but opted to adopt it only in 2017. The other outlier described the first year of awareness in 2009 but did not decide to adopt it until 2017; interestingly, both the outliers decided to adopt BIM due to a change in the organization's structure. Without considering the outliers, the data shows an average time lag of 1.9 years (around 23 months) between the first year of awareness and adoption.

(B. J. Gledson & Greenwood, 2017) relate higher personal use of BIM 4D with larger company size and higher organizational BIM maturity. Accordingly, a comparison between the size of the company and the personal BIM use was conducted formulating H_0 (Null hypothesis) and H_1 (alternative hypothesis) as follows:

- H_0. There is no relationship between company size and personal BIM use.
- H_1. There is a relationship between company size and personal BIM use.

All of the 78 respondents were deemed eligible for a Fisher's exact test. The resulting P-value of 0.477 rules out the H_1 in favour of H_0, which contradicts (B. J. Gledson & Greenwood, 2017) assumptions that higher BIM use happens within larger companies. It should be also noted that the definitions of company's size (in number of employees) was adopted from the (B. J. Gledson & Greenwood, 2017) in order to have the similar company size criteria.

A comparison between Organizational BIM maturity and personal BIM use was also made, formulating H_0 (Null hypothesis) and H_1 (alternative hypothesis) as follows:

- H_0. There is no relationship between Organizational BIM maturity and personal BIM use.
- H_1. There is a relationship between Organizational BIM maturity and personal BIM use.

The 72 respondents that identified themselves as adopters or aware of BIM were used for a Fisher's exact test. The resulting P-value of < 0.0001 rules out the H_0 in favour of H_1.Therefore, just as (B. J. Gledson & Greenwood, 2017) presumed, we can conclude that higher personal BIM use occurs within companies that are considered to have higher BIM maturity.

2.9 Organizational structure

The second section of the questionnaire focused on the organizational structure of the respondents in order to compare the classical form of communication channels and decision types introduced by the IDT with the organizational structure described by (Shibeika & Harty, 2015). Hence, the subset of 44 respondents that identified themselves as adopters were asked whether they had an organizational change within their companies leading to a centralization of technology management that affected their decision to adopt BIM. 82% (n=35) of respondents confirmed that an organizational change had taken place that reflected their BIM adoption, while 18% (n=4) did not relate their decisions to an organizational change. Similarly, 82% (n=35) also confirmed that their firms were operating outside Italy as well (Globalization), while 18% (n=4) stated that their organizations operated inside Italy only. In the meantime, only 64% (n=28) believed that standardization of digital practices existed within their organizations, whereas 36% denied its existence. As shown in Figure 35, the organizational structure of the adopters' firms is consistent with the processes described by (Shibeika & Harty, 2015) through which firms manage and spread digital innovations.

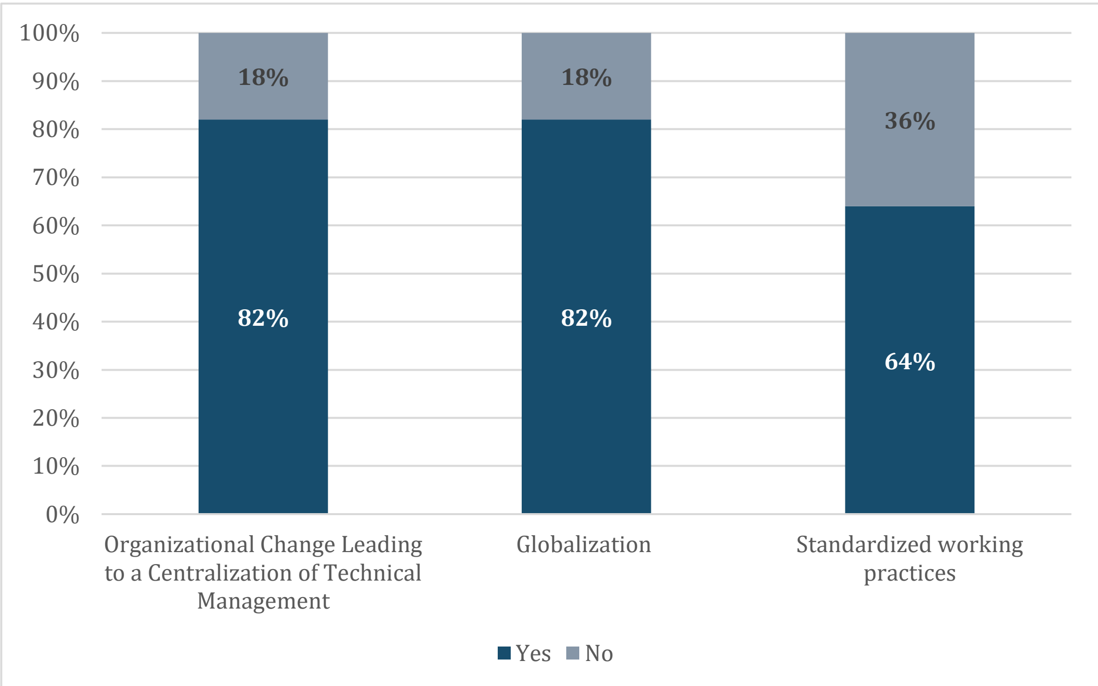

Figure 35. Firms' organizational structure

2.10 Decision types

The adopters were also asked about the type of decision they made to adopt BIM according to the IDT, where possible response options comprised: individual decision (optional), decision made consensually with others within the organization (collective) and decision imposed by a single person or a handful of people in charge of the organization (authority). The most frequent type of decision was the collective or authority one, each recording 36 % (n=16), followed by the optional decision that accounted for 28% (n=12) of the adopters. The implications contradict the results obtained by (B. J. Gledson & Greenwood, 2017), which indicated the superiority of the authority-type decision. This could be due to the fact that most of the respondents came from small companies (Figure 36).

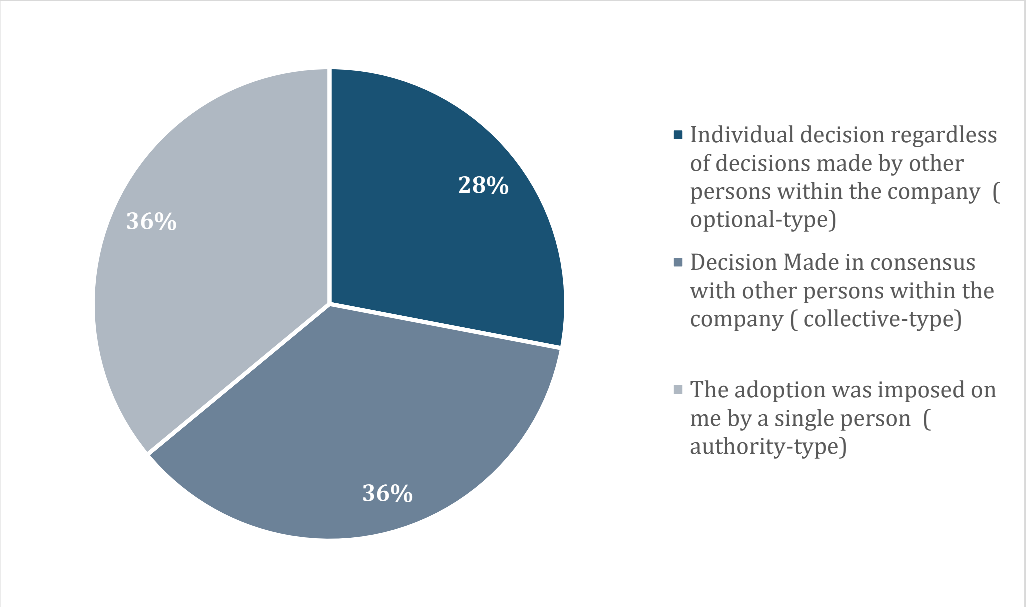

Figure 36. Decision type

2.11 Communication Channels

The 72 respondents identified as adopters or solely aware of BIM were asked about their communication channels with three possible response options: External sources i.e.: Mass Media, including internet, journals , government, social media; and Internal sources, i.e. : interpersonal connections, colleagues , suppliers); and Champions who are experts in BIM and act as innovations' promoters. For both adopters and respondents merely aware, Internal sources were recognized as the most common communication channel with 50%, but the big difference lay in the champions' proportion of communication channels where 36% of adopters marked champions as their communication channel while only 7% of those aware identified the champion as their communication channel. This is in line with (Shibeika & Harty, 2015) presumptions that stresses the important role of champions (Figure 37).

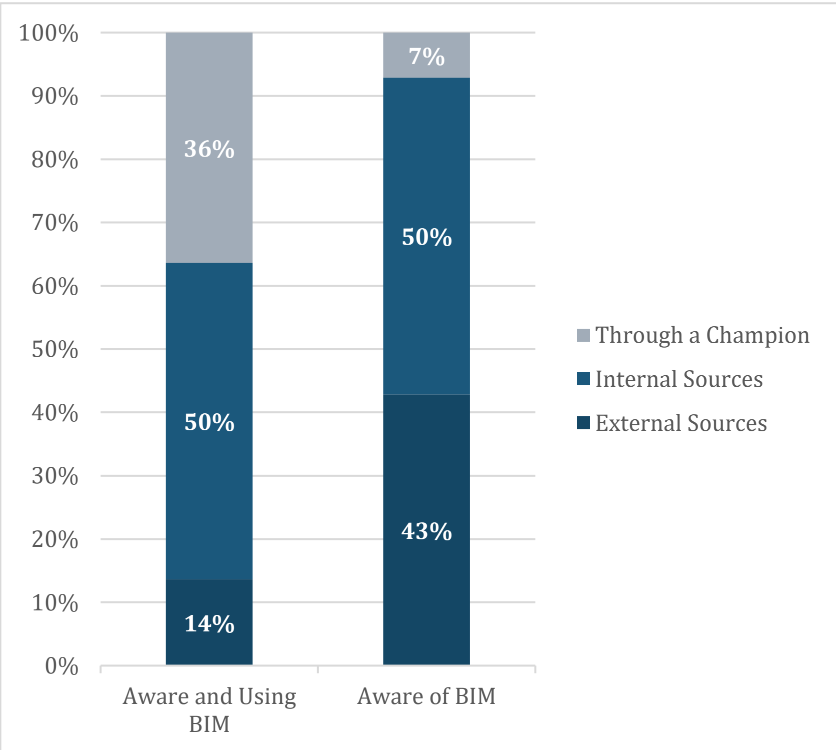

Figure 37. Communicational channels

2.12 Challenges to BIM adoption

In order to further examine the significance of the aforementioned challenges to BIM adoption in the literature review, all 78 respondents were asked to state their level of agreement with regard to the influence of each barrier in their decisions, using a five-point Likert-scale (1=Strongly agree, 2=Agree, 3=Neutral, 4=Disagree, 5=Strongly Disagree). After scrutinizing the literature review and reflecting on the main barriers suggested by (Hosseini et al., 2016), 12 main questions were formulated and reproduced (table 7), each belonging to one of the three abovementioned super-categories: Institutional barriers, Organizational and Human barriers, Project-related barriers.

Number	Question
Q1	Our clients are not interested in using BIM in their building projects
Q2	Our clients/Sub-contractors do not have sufficient knowledge about BIM and its benefits
Q3	There is no official standard for adopting and using BIM in building projects
Q4	There is no government support/initiative to use BIM
Q5	The current technologies we are using are enough, so we don't need BIM
Q6	Our firm is reluctant to adopt BIM because we don't have sufficient knowledge about it
Q7	Our firm does not have the skills and expertise for BIM adoption
Q8	There is a significant BIM implementation cost to our firm
Q9	There is insufficient training/education on how to use BIM
Q10	There is no or low benefit in adopting BIM in our building projects
Q11	BIM is not suitable for our building projects
Q12	the risks linked to adopting BIM is too high

Table 7. Survey's questions

For the purpose of evaluating different barriers and their corresponding significance, a Bar chart was produced to reveal the distribution of responses for each question (Figure 38).

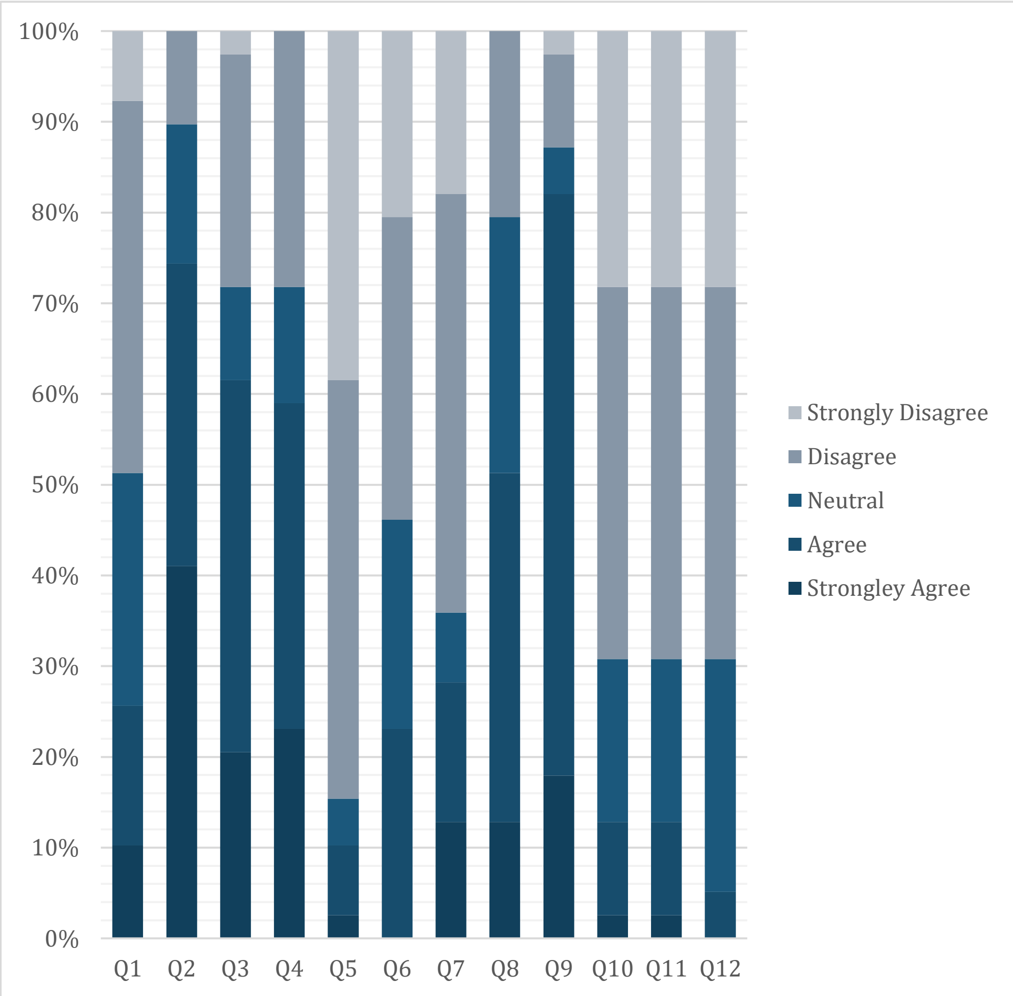

Figure 38. Distribution of responses related to each

In order to portray in a better manner the variability and the central tendency of responses and also identify the most common response in relation to each question, several statistical values were calculated. Since a Likert scale cannot define the distance between the data items, the mean value is of less importance. The Inter-Quartile range

(IQR), the median and the mode values of the responses on top of all other statistical values were analysed (Table 3). Another Bar chart was also produced where half of the "Neutral" responses were construed as "Agreeing" and the other half as "Disagreeing" to divide the responses to each question into simply "Disagree" or "Agree" responses (Figure 39).

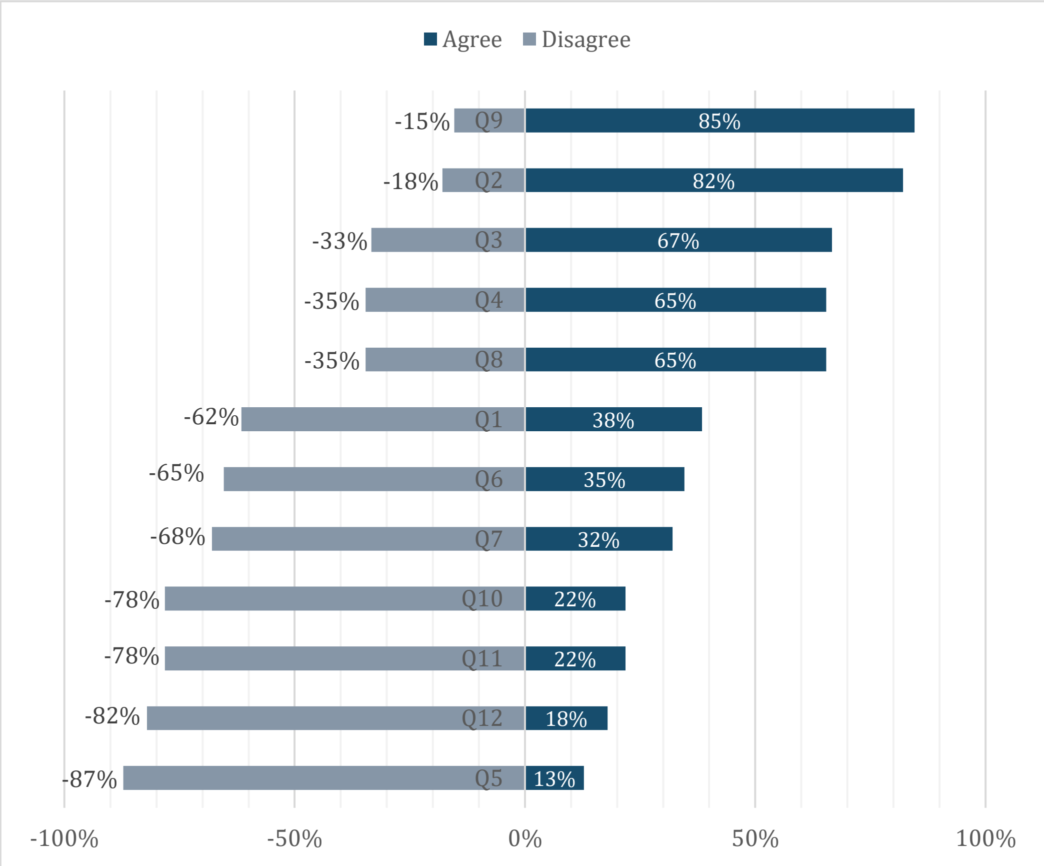

Figure 39. level of agreement in relation to each question

Q9, Q2, Q8, Q4, Q3 were selected respectively as the most significant challenges to BIM adoption, all of which have the median value of 2 (that implies "Agree") (table 8). 0.85% of respondents agreed that Q9 posed a great challenge to BIM adoption and, the IQR value of 0 and the mode value of 2 implies that the responses were highly clustered around the most common response "2=Agree". 82% of respondents recognized Q2 as the second most significant barrier that hinders BIM adoption, since the most frequent response was "1=Strongly Agree", while the IQR of 1.75 indicates that the responses were slightly more scattered than Q9; we can therefore assume Q9 and Q2 to be the most challenging barriers. Furthermore, 65% identified Q8 as the third most significant barrier to BIM adoption, and it was deemed more challenging than Q3 since it had a lower value of IQR, which suggests that the responses were more clustered and less variable around the most common response “2=Agree”. Q4 and Q3 were respectively the fourth and the fifth most significant barriers to BIM adoption. The questions were as follows: Q2 the clients do not possess sufficient knowledge about BIM and its benefit; Q9 lack of training/education on how to use BIM; Q8 BIM has a significant cost of implementation to the firm; Q4 Lack of governmental support/initiative; Q3 lack of official standards for BIM adoption .

Question	IQR	Median	Mode
Q1	1.75	3	4.0
Q2	1.75	2	1.0
Q3	2	2	2.0
Q4	2	2	2.0
Q5	1	4	4.0
Q6	1	4	4.0
Q7	2	4	4.0
Q8	1	2	2.0
Q9	0	2	2.0
Q10	2	4	4.0
Q11	2	4	4.0
Q12	2	4	4.0

Table 8. Statistical values of responses

3 Results

Solution to each of the aforementioned barriers depend vastly on the context in which BIM is being discussed and whether the focus of attention is on SMEs or public companies. Regardless the path to overcome the issues remain clear.

3.1 Establish BIM competences among all stakeholders

Evidently in Italy, there is a lack of BIM experts which is hindering BIM adoption in the AEC industry. Different stakeholders are involved in BIM education/trainings: Academia, Industry, Software companies, Local chapters of different associations, Government, Training institutions and BIM learners. Distinguishing between the BIM education and training is important (figure 40). while Academia provides the base for BIM education, the other stakeholders can build on the education by offering trainings to improve BIM knowledge(Rodriguez et al., 2017). Currently the most common types of trainings are focused on specific software competences, and therefore not BIM education, which are delivered through Diploma and Software courses therefore Integrating BIM into universities' curriculum with the support of the government and other stakeholders should disseminate BIM knowledge that will pave the way for future trainings. The current trend in promoting workshops/seminars revolving around OpenBIM concepts and BIM management should turn out to be fruitful and a complementary action prior to the existing trainings.

Education	Training
Broad scope	Limited field
Knowledge development	Specific skills
Theoretical method	Practical method
Stricter background	Hands-on experience
Mostly given in schools and higher education	Usually given on jobs

Figure 40. Differences between education and training (Source: Rodriguez et al., 2017)

For this purpose, (Rodriguez et al., 2017) proposes a collaborative BIM education framework for both academia and industry and divides the actions required in both domains into three: 'Strategy', 'Implementation', 'Revision'. In order for the collaboration to work out at the strategy stage, leadership is required at the academia's end since it involves numerous participants. The leadership's main role is to gather academics and people from industry, e.g. through an online platform, who have interests in BIM education. for the industry's side a BIM champion can put down the required strategies and the required actions are less complex. The (Rodriguez et al., 2017) maps out the required actions for each stage to be undertaken for every domain as shown in figure 41.

Academia			
Strategy stage	**Implementation stage**		**Revision stage**
	Actions	**Participants involved**	
• Creation of groups with members from Academia and the industry to lead the strategy • Identification of the BIM abilities needed per discipline from the educators • Identification of the BIM skills per discipline required from the students • Categorisation of these abilities by themes, according to the knowledge disciplines of the construction industry	Provision of education and training required for the educators.	• Academics • BIM education providers • Industry	Assessment of the programs created by getting feedback from: • BIM learners: to express their opinion about program and learning outcomes • Academics: by analysing the progress and performance of the students • Industry: by the evaluation of the BIM learners skills when practical implementation activities are programmed
	Elaboration of the learning modules: • To be embedded in current programs • For the creation of new programs	• Academics • Industry • BIM education providers • BIM learners • Researchers • Government (as support)	
	Creation of BIM learning materials for new modules inserted and programs modified.	• Academics • Industry • BIM providers • BIM learners • Researchers	
	Practical implementation of the knowledge acquired: • Knowledge transfer partnerships; • Internships; • Co-ops.	• Academics: for planning; • Industry: to provide opportunities to the BIM learners; • Government: to promote this practice in BIM education.	
	Diffusion of other BIM type of education and activities for knowledge boosting and acquisition of transferable skills through workshops, conferences, seminars, etc.	• Academics • BIM education providers • Industry • Government	
	Establishment of minimum knowledge requirements to undertake higher education degrees such as masters and research. That is to avoid teaching new things to students that have some gaps in knowledge.	• Academics • Industry: to identify problems in practice and propose research in the field	

Industry				
Strategy stage	**Implementation stage**			**Revision stage**
	Actions		**Participants involved**	•
• Designation of a BIM Champion to lead the strategy • Identification of the BIM scope of the company • Identification of the BIM abilities required per role in the organisation • Identification of the training to be taken by the staff depending on their role in the team and requirements of the type of projects: - Managerial levels; - Remainder staff; - The client, when needed	BIM Education for the staff	Higher education: Large funding needed. *Suitable for large companies with considerable budget dedicated to training*	Provided by: • Academia	• Evaluation of the performance of the staff and the client • Comparisons of project outcomes and performances before and after the strategy.
		Acquisition/upskill of software abilities:	Provided by: • Software developers; • Expert(s) hired by the organisation • Skilled staff from the company designated by the BIM champion.	
		Acquisition of different transferable skills: • CPD programs • Attend to workshops, conferences, seminars, etc.	Provided by: • Organisation • BIM education providers	
	BIM education to the client	To receive consultancy in the following areas: - Introduction to BIM - Establishment of BIM goals for the project - Documentation management	BIM consultant from: • The organisation • An independent BIM consultant	

Figure 41. Collaborative BIM education framwork proposed by (Rodriguez et al., 2017)

3.2 Raising knowledge about BIM benefits through greater collaboration among stakeholders including clients

One of the most challenging barriers hampering BIM adoption is the reluctancy and uncertainty on the clients' side. as a first step In order to tackle this hurdle, Different stakeholders including clients, have to perceive BIM as a value creator rather than extra costs. this would require higher levels of integration and open-data sharing among stakeholders at different stages of contracts and interactions. (World Economic Forum, 2018) suggests three elements to accelerate BIM adoption (figure 42):

- Motivation: Even though O&M (Operation and maintenance) accounts for most of an Asset's life cycle costs it is still not being utilized in BIM applications. BIM is still mostly perceived for its benefits in 3D Design and modelling but in order to reap its full potential asset operators could develop pilot use cases to apply BIM in O&M where building designers and engineers base their designs on Maintenance costs and optimized energy consumption criteria. This would also require government to finance Pilot use cases to use BIM in O&M operations for its public assets. Furthermore, different Cost-Benefit analysis should be undertaken to develop benchmarks in order to raise knowledge about BIM's benefits among clients.
- Collaboration: in order to enhance collaboration and communication among different stakeholders, different organizations' cultures, structures and processes need to change. Initially, This collaboration requires an acknowledgement of each party's needs and requirements. This can help to build up open-data sharing standards and standardizing BIM data exchange.
- Enablement: as discussed before, Establishing skills among all stakeholders requires attention to be made on different levels (Academia, Industry). The collaboration among these two will play a key role in training future BIM experts.

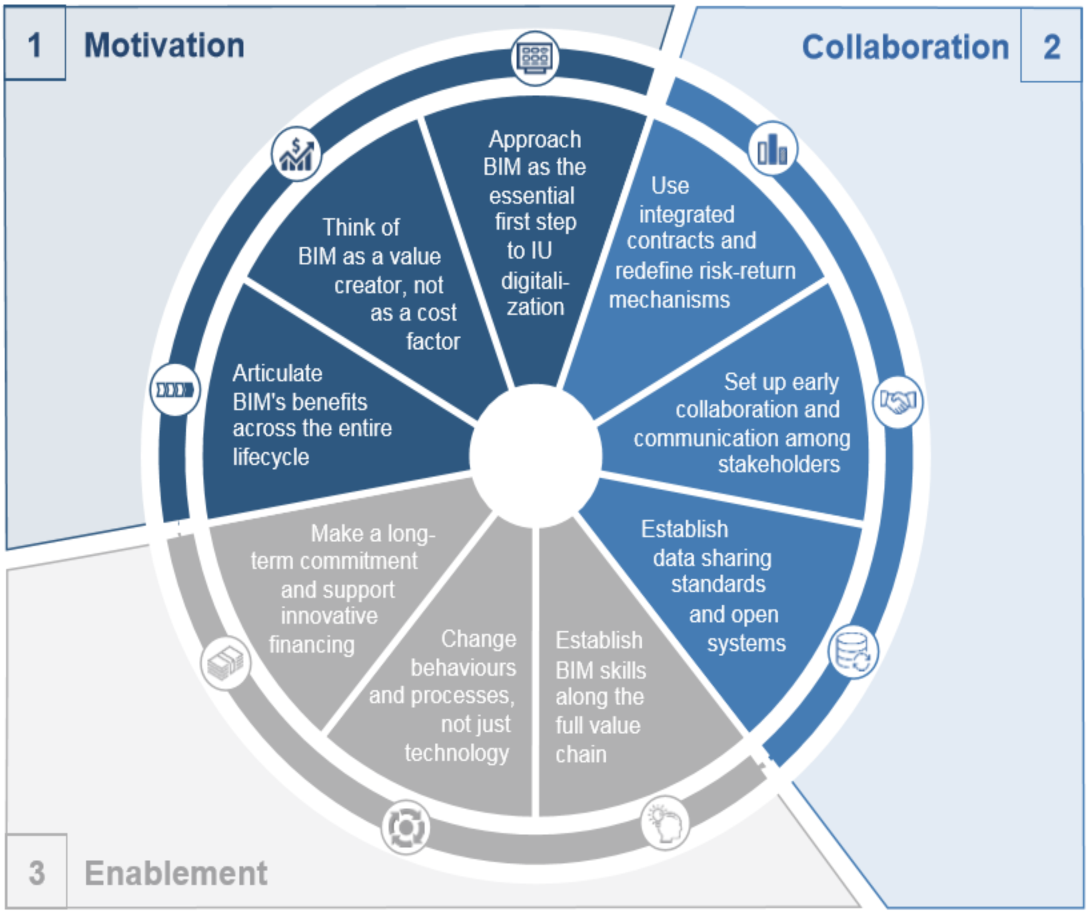

Figure 42. three steps to accelerate BIM adoption (Source: World Economic Forum, 2018)

3.3 The study's proposals

3.3.1 Standards and initiatives

Observing and comparing accurately the governments' roles in fostering BIM adoption help us in understanding the Impediment to BIM up-take in Italy. As discussed before, governments can assume different roles to accelerate BIM implementation within the AEC industry: Initiator and Driver; Regulator; Demonstrator; Funding Agency; Educator. It should be noted that the remedy to tackle BIM adoption barriers requires a precise study of the characteristics of the country under observation.

The diffusion of BIM implementation in the USA was triggered by a Public administration body mandate for its project and the release of relevant guidelines. In UK government set out ambitious initiatives and goals to rise as a BIM leader which resulted in a state-wide BIM level 2 mandate furthermore the government's role as a client as well as establishing a BIM task force to link the industry with the academia is noteworthy. Scandinavian countries such as Finland, Norway, Denmark are moving towards a BIM level 3 industry owing it to a far ahead mandate for IFC compliant BIM modelling. The hallmark of the Scandinavian countries was their prior development of standards and guidelines which enabled eager major public enterprises to apply them to mandate IFC compliant BIM modelling which highlights also their role as funding Agency and their engagement in R&D activities. Singapore is probably the most developed country in the world in terms of BIM implementation thanks to the pioneering e-submission initiative and its mandate. Among different countries discussed, Australia remains the only one to steer clear of BIM mandates. Their strategy is to foster BIM adoption through increasing all stakeholders' perception of BIM benefits through National BIM guidelines and initiatives and also tackling software-related issues. Thanks to this approach they are expected to have the highest level of contractors' engagement among other countries.

Figure 43 shows the suggested areas of improvement for Italy as a country with low level of government contribution to BIM strategies respectively. In view of the identified hurdles to BIM up-take in Italy and taking into account the characteristics of the industry in the country it is evident that the encouragement of the clients and their acknowledgement of the existing benefits alongside training BIM experts should be brought to attention. Contrary to the current government initiative that lays out gradually a BIM use mandate for ordinary projects before 2025, the following scheme proposes a number of prerequisites prior to mandating BIM use for ordinary projects which have proved to be essential in other countries. The prerequisites consist of five proposals:

- Developing national standards/guidelines through the INNovance project before 2025
- Piloting BIM use for public infrastructure projects which will increase the public perception about the benefits of BIM implementation, this can be carried out through major non-profit public organizations that are involved in providing public building services

- So far the government has not played its role as a client but as a sole enforcer of the strategy therefore the government should assert itself as an interested client in BIM implementation
- Establishing a BIM task group in charge of reinforcing the connection between the industry and academia
- The responsibilities of the abovementioned task group should involve also incorporating BIM courses and programs into university curricula (e.g. the graduated students would satisfy the demand for specific roles connected with BIM within organization roles)

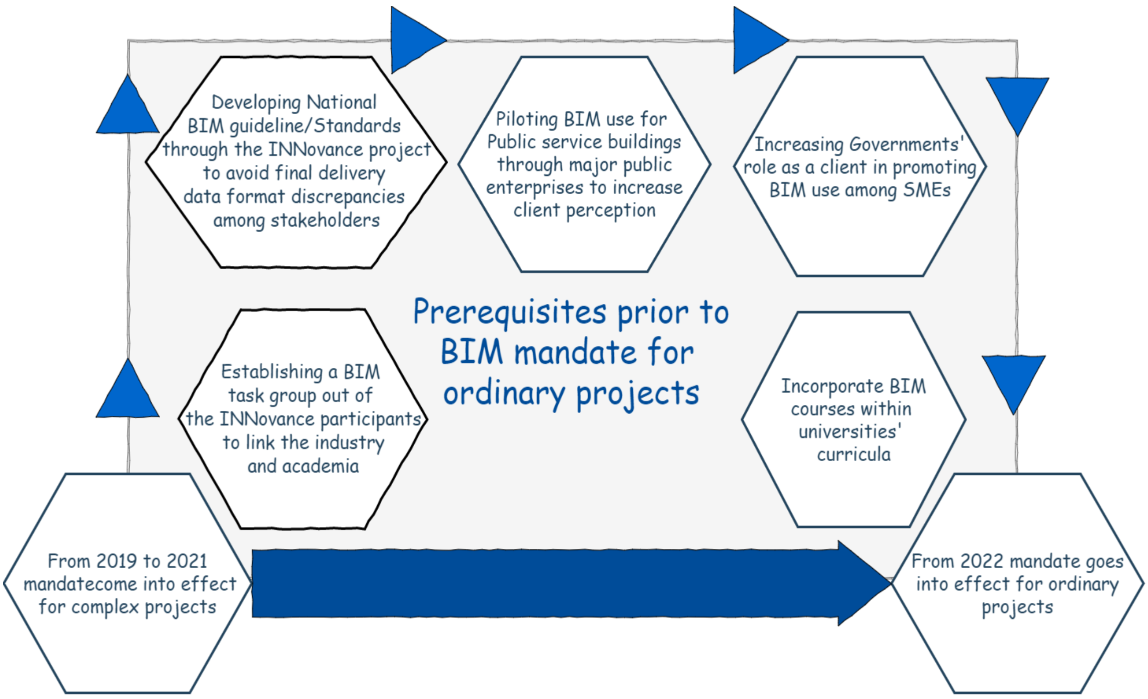

Figure 43. Suggested prerequisites prior to BIM mandate for ordinary projects in 2025

3.3.2 Proposed Information Development Manual (IDM) for tackling organizational obstacles

Following the results obtained through the questionnaire, the study proposes an Information development manual as a complementary element to government activities in order to align the organizational structures to achieve higher levels of BIM adoption. initially the survey revealed the statistical importance of the year of awareness and its positive correspondence with the year of adoption (around 23 months of gap). Subsequently the study stressed the important role of BIM champion alongside the internal communication channels as the main channels to BIM adoption. By the same token, collective and authority decision types were deemed to be more decisive than the optional choice to BIM adoption. Concerning the organizational structure and traits, the study considers both the globalization and the centralization of technological management within a company as essential factors in accelerating digital skills diffusion while the standardization of working practices can be provided by the government at national level. According to these findings the study provides different proposals for different components of an IDM in pursuit of integrating the government efforts and organizational efforts to facilitate digital skills adoption as follows:

- Interaction/Transaction maps: defining and integrating the role of BIM champion into current roles; establishing a permanent information management department within organizations in charge of centralization of technological management
- Process maps: aligning the activities and their relations with the new organizational structure taking into account the vital role of the information management department
- Exchange requirement: national guidelines, standards and library should be used to tackle interoperability issues for different stakeholders involved
- Establishing information models and archives after the fulfilments of projects in order to standardize organizational processes according to different projects

As shown in figure 44, companies need to establish an Information Management department to centralize their technological management. The tasks of the two divisions of the company (design team and Information management department) should be carried out simultaneously while the library, standards, guidelines requirements are provided at national level.

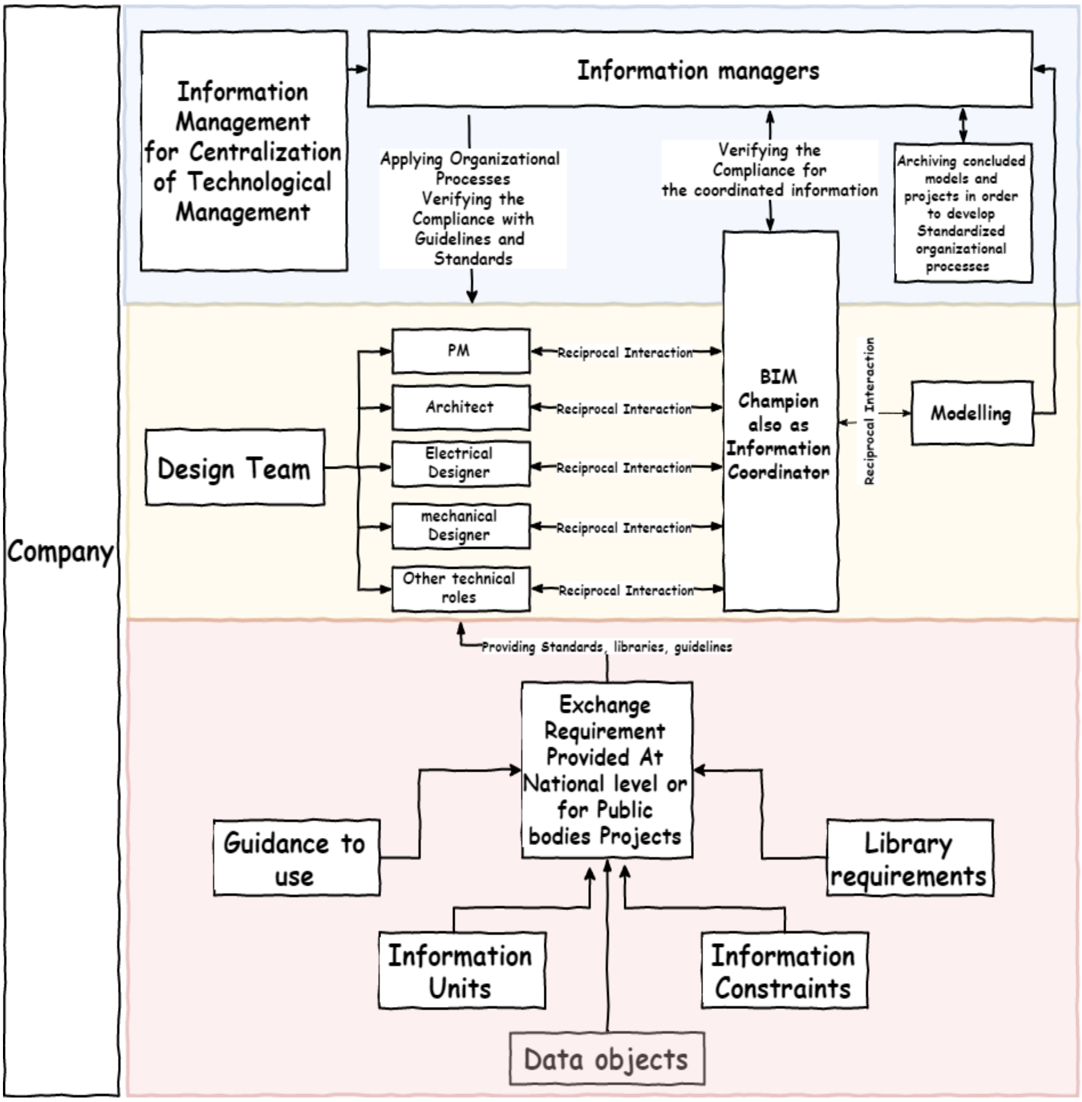

Figure 44. Proposed IDM for tackling organizational related issues in adopting BIM

The role of the BIM champion in this diagram is vital since he/she will be the bridge among the two teams. The information managers will initially verify the compliance with the exchange requirements as the technical members develop the initial design to prevent interoperability-related issues. In the next phase the BIM champion will coordinate the collected information from the design team and check the compliance with the exchange requirements with the help of information managers. The relationship among the BIM champion and other members of the company is reciprocal in that in case of modifications to the initial design it can be reverted. After the final modelling stage, the information managers should archive the concluded project alongside its specific processes in order to develop standardized organizational processes, specific to that company, that can be utilized for subsequent projects.

4 CONCLUSION

The aim was to provide a strategic plan to foster the diffusion and adoption of Building Information Modelling (BIM), as a digital skill, within the AEC Italian industry by detecting the most perceived challenges. This study has taken a different approach towards the issues of adoption and from the very beginning asserts the importance of integrating and associating issues stemming from the institutional context with the organizational and project traits. The current 56% rate of adoption compared to 74% in the UK (NBS, 2018) signals a low BIM-specialized industry comparatively. Reproducing the (B. J. Gledson & Greenwood, 2017) way of calculating the rate of adoption, the study also finds a correlation between the first year of awareness and the first year of adoption with an average time lag of 23 months between them; however, contrary to its presumptions, no association was detected between the company size and personal BIM use. It is noteworthy to mention that higher personal use happened within companies with a higher level of BIM maturity. The study compares and combines the Innovation Diffusion theory (IDT)'s postulations, by exploiting (B. J. Gledson & Greenwood, 2017)'s conclusions, with (Shibeika & Harty, 2015)'s described organizational processes through which an innovation diffusion takes places to investigate the organizational traits for adoption. Contrary to the IDT, authority-type and collective-type were both equally the most common decision type of adoption. given that the vast majority of respondents worked for small companies it can be argued that the authority-type could prove true only for larger companies. Likewise, the role of a champion, in spite of being neglected in the IDT, was highlighted among the communication channels where the IDT's internal sources still played the biggest role. The organizational processes explained by (Shibeika & Harty, 2015) for an innovation diffusion were deemed to be crucial where centralization of technical management in an organization's structure and its affiliation with foreign companies and operating projects abroad played a key role, although the existence of a standardized working practice proved not to be essential. As a startling revelation, the study denotes that the most critical hindrances to BIM adoption arise from lack of clients' knowledge about BIM benefits that are embedded within the institutional context and lack of BIM training/education within the organizational context. Furthermore, within the organizational and project-related contexts, small companies above all find the process of BIM adoption too risky, with high costs of implementation, and are reluctant to adopt it taking into account their narrow resources. This stresses the importance of BIM knowledge and education among different stakeholders involved, which has to be considered alongside the appropriate organizational structure of companies. Next thing, lack of governmental support/initiative and official standards for BIM linked to the institutional context were underlined, which in view of the recent government mandate should be ironed out in the coming years. The study furthermore provided different solutions to both organizational and governmental related issues in fostering BIM in Italy which highlighted the important role of BIM champion and necessitated National standards/guidelines releases before the BIM mandate for ordinary projects in 2025 is due.

Despite the findings, there are limitations to this study, that is, a larger sample and more distinct respondents in terms of organizational size and traits can help us separately determine the barriers to each organizational structure. Moreover, the connection between different contexts and their embedded barriers and their significances depend entirely on the type of organization involved, and thus, further studies should focus on these connections taking the organizational structures into account.

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