BIM implementation for infrastructure projects: Methods and tools for information modeling and management

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BIM implementation for infrastructure projects

Methods and tools for information modeling and management

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2020

Declaration

I hereby declare that, the contents and organisation of this dissertation constitute my own original work and does not compromise in any way the rights of third parties, including those relating to the security of personal data.

Niccolò Rapetti
2020

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I would like to dedicate this thesis to my mother, my father and Eleonora, only we know how hard the journey has been.

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Abstract

Nowadays, EU countries are adopting new strategies to improve efficiency and reduce costs in the Construction Industry. One of these strategies is Building Information Modelling (BIM). In fact, the European Parliament is also encouraging BIM adoption with the publication of European Directive No.24/25/26 relating to EU Members' Public Construction Procurement.

BIM is a collaborative methodology that can represent physical and functional facilities during the entire life cycle, combining set procedures and standards to produce, communicate and analyse building models. Although the concept of BIM has existed for more than 10 years, it still remains one of the most interesting innovations in the world of Architecture, Engineering, Construction and Operation (AECO). This methodology aims to improve the productivity and effectiveness of the construction industry, while at the same time reducing wastage of money, risks to projects, and should also contribute to reducing CO^{2} emission. many countries around the world are developing national initiatives to promote the spread of BIM (Singapore, USA, Canada, United Kingdom, Germany and so on), leading international BIM initiatives, and recognizing BIM as an incredible opportunity to innovate in the construction sector, to improve innovative technologies and to create new business models. In order to reach these goals, the process of standardization, towards national and international initiatives, plays a key role in the spread of BIM, especially into the sector of public works.

The aim of this research project is to investigate BIM implementation within a Public Administration such as ANAS S.p.A. Initially, under the terms of the New Contract Code D.gls. no. 50/2016 and following later publication of Ministerial Decree n.560/ 2017, the use of BIM for public works was set to become mandatory from 2019. This means that, in the future, ANAS

will have to request project development using BIM methodology. Thus, the organisation will be faced with several problems when dealing with this type of methodology. The problems may be divided into two main categories: firstly, problems related to BIM procurement implementation, defining tailored contract documentation, providing specific concepts about LODs, BIM Uses, Model Structure, Model Verification and Validation, Exchange data Format and so on. Secondly, problems related to the workflow structure for civil design, capable of mapping the process according to the different project stages thanks to the integration of a large number of BIM applications.

Currently, several noteworthy publications are available in international literature. Nevertheless, publications relating to BIM implementation in the public sector are few and are focused more on implementation in the private sector. The main barriers hindering the process of the introduction of BIM methodology, are technological, process and human factors.

The methodological approach adopted in this thesis is based on a literature review focused on several topics such as: BIM Implementation, BIM procurement, BIM modelling, Interoperability processes, and so on. The study goes on to propose a BIM point of adoption, by mapping the *As-is* process and defining a BIM-oriented *To-be* process. The new process establishes the authoritative process to be used to manage BIM information, identifying roles and responsibilities along with verification and validation methods. A new workflow is then proposed, tailored for infrastructure projects, attempting to organize the large number of disciplines involved, and by studying the characteristic elements of Civil engineering and relating them to other essential concepts such as LODs and BIM Uses.

IIn particular, the definition of Level of Development (LOD) plays a key role in determining what information should pass between the various disciplines at each work stage. An infrastructure project is characterized by its interaction with the environment. The integration of the BIM model with information deriving from geological, hydraulic, and environmental parameters together with many others factors, requires an integrated framework of databases that share information at different scales and work stages. Therefore, given the high level of complexity involved, it was important to define appropriate BIM Uses to determine modelling and information content.

Thanks to the development of several case studies, it was possible to test BIM workflow, processes, contractual documentation, interoperability processes and model authoring applications. The first BIM procurement *"Curva Carrai e Acquabona"* was useful for testing EIR, providing essential data to evaluate BIM requirements, BIM Uses and LOD's. This work produced the new public EIR, worth € 240 million in contracts for Engineering and Architecture support services and contract works. The *"Demonte Project"* was used to test different BIM tools, according to several BIM Uses, standard modelling, and BIM library and interoperability through the open exchange data format, to estimate the liability of data, during the design process.

The study shows that nowadays BIM implementation is a process involving not only software applications, but also technological, procedural and organizational aspects. The case study shows how the integration of BIM is essential to reach an appropriate BIM workflow, in particular for Civil design. In many cases, the use of Visual Programming Language was essential to avoid model handling and to improve information communication between one application and another.

In conclusion, the actions promoted by this study were tested to assess the maturity level of ANAS, through the use of the BIM Maturity Capability Model. Taking into account the fact that the models are not specifically created to assess Public Administration, they may provide important indicators for future actions to be taken to implement BIM policies

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Chapter 1

Introduction

This chapter aims to provide a brief introduction to the construction market sector, with particular attention to infrastructure in the European and Italian market. The European Construction Observatory underlines how the sector of AEC is somewhat behind in the digitalization process, especially in Italy, and identifies the BIM as a driver to reduce Construction and Demolition Waste (CDW) by up to 15% by improving the collaboration process among design firms, contractors and public administrations. Furthermore, it is possible to consider BIM as an economic driver in a growing market that at a global level is forecast to be worth almost $8 billion by 2020. Notwithstanding, BIM implementation requires major investment in process, technologies, human capital, standards and regulations. The number of investments in the construction sector and especially in the Italian market has dropped significantly in the last year.

Thanks to an improved level of maturity and government policies, demand for BIM requirements in public procurement is accelerating, creating a positive effect. Despite these positive external factors, the market is composed in large part of Small Medium-size Enterprises (SME) that find it difficult sustain levels of investment over time, for a return compatible with their economic plans.

1.1 AECO Market Context

According to the main studies, conducted by research centres, forecasts for the AECO Market foresee a growth of 67% from $ 7.2 trillion to $12 trillion in

2020. After a period dominated by the USA, accounting for 35% of the global construction market in 2001, China overtook the USA in 2011with a market share of 35% [174]. By 2020 new emerging markets such as India, Indonesia, Russia, Vietnam etc., will grow by an estimated 110% equal a $7 trillion, which represents 17.2% of GDP in 2020 [1].

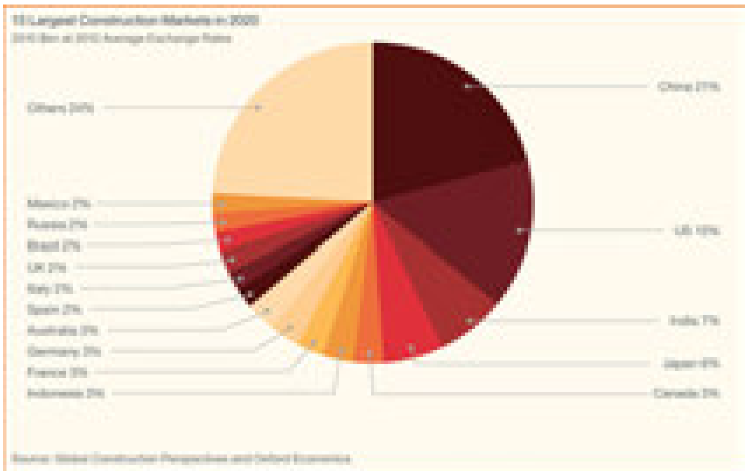
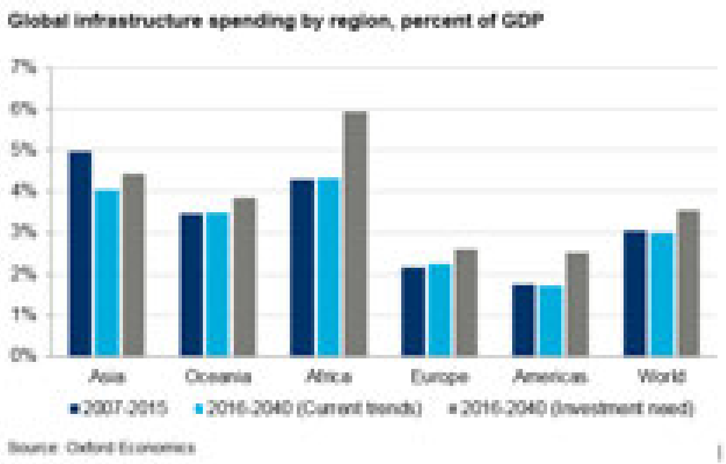


Fig. 1.1 Largest Construction Market in 2020

The infrastructure sector, in particular, plays a key role in stimulating growth in emerging markets, accounting for 128% over the next decade, compared to 18% in developed countries. In this sense, Oxford Economics estimates infrastructure investments from 2016 to 2040 equal to $ 94 trillion [65]. This figure corresponds to a 19% ise on current trends, for an average annual investment of $ 3.7 trillion.

[1] Figure available: https://www.nextbigfuture.com/2011/03/over-next-ten-years-nearly-100-trillion.html (Last view August 2019)



(a) Source: Oxford Economics, day month year

In the future, the market will be dominated by ASIA Figure 1.2a.In fact, forecasts indicate that China alone will account for more than half of Asia's total market and 30% of global expected investment, financing $28 trillion in infrastructure.

In Europe, after the construction market grew by 3.1% in 2018, the CRESME' study forecasts a reduction of 2% in 2019 (Figure 1.3 [1]) a decrease that is set to continue by 1.5% for the period 2020-2021. In this context, infrastructure seems to be the leading sector in the construction market, with an increase in income of 3% for the period 2019-2021.

[1]Figure available at internet resource "BIG PROJECTS ARE DRIVING EUROPE'S CONSTRUCTION INDUSTRY" https://www.webuildvalue.com/en/global-economy-sustainability/big-projects-are-driving-europe-s-construction-industry.html (Last June 2019).

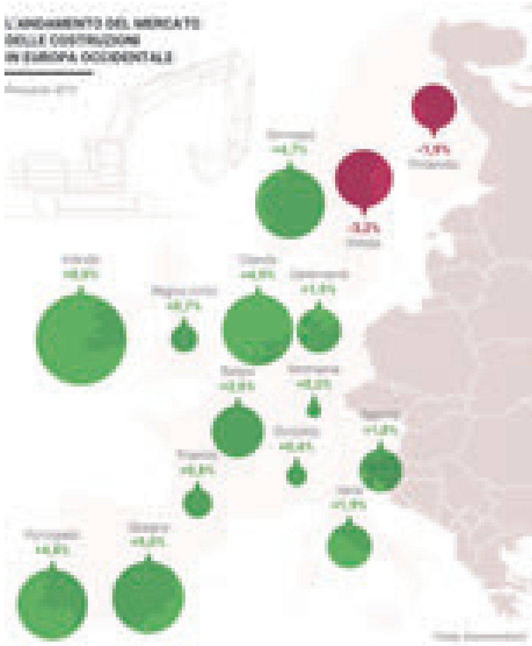


Fig. 1.3 Europe Construction market

Infrastructure market income will increase by 3% per year from 2019 to 2021. This growth will be led by countries like Ireland, the Netherlands, Portugal, Spain and so on, that will reach a figure of 4%. Leading European countries like Germany and France will experience a recession in the infrastructure market, while the United Kingdom and Italy will see moderate growth, probably on average less than 2%.

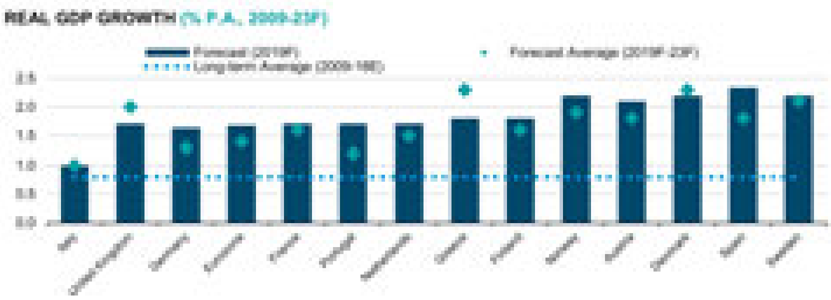


Fig. 1.4 Real GDP Growth

This positive trend derives essentially from initiatives by the European Commission (EC), which in 2011 estimated a range of annual investment requirements of around 150-200 billion euro. For these reasons, in 2013 the EC decided to finance 1 trillion euro for the period up to 2020, in order to tackle the rapid changes taking place on the technological and demographic fronts.

Therefore, the infrastructure market appears to be leading the construction industry, highlighting a strong correlation between infrastructure investment and economic growth. According to literature, infrastructure plays a key role in economic development, producing direct and indirect effects on economic growth. A direct effect, for example, is to lower the cost of input factors in production process, while an indirect effect is to improve the productivity of workers [156]. Moreover, infrastructure investments represent a boost for national economic growth, with positive effects on the productivity of a region, lowering the costs of transportation and leading to economies of scale and better management.

In this context, the Italian market, as reported by the Italian Institute for International Political Studies (ISPI), shows the benefits and positive effects that could be derived by the implementation of TEN-T core network, for instance. The TEN-T project aims to develop a Europe-wide network of transport infrastructure to connect all regions of the EU through the implementation and development of a Europe-wide network of roads, railway lines, inland waterways, maritime shipping routes, ports, airports and railroad terminals. Investment dedicated to the creation of a full TEN-T core network in terms of economic impact could increase EU GDP by 1.6% up until 2030 with respect to the baseline and could generate an additional increase in full-time jobs. [150]

The study has analysed the full TEN-T core network implementation by 2030. In terms of economic impact, EU GDP would increase by 1.6% in 2030 relative to the Baseline and an additional 797,000 full-time equivalent jobs would be generated. GDP growth impact differs substantially between the EU13 (+4.2%) and the EU15 (+1.4%). These large differences between countries are linked to (1) the share of TEN-T investment in the total investments undertaken in a country and (2) country-specific economic structures. The GDP multiplier of TEN-T investments amounts to 3.3%, which indicates that for every euro invested, 3.3 euro of additional GDP are created. In terms of employment, for every billion euro invested in the TEN-T core network between 2017 and 2030, an average of 13,000 additional job-years are generated [148].

The EU's Trans-European Transport Network (TEN-T) policy recognises the importance of a strategic approach for developing a Europe-wide network of transport infrastructure. The TEN-T comprises a dual layer structure in which the comprehensive network ensures connectivity of all regions of the EU, whereas the core network consists of those parts of the network which are of the highest strategic importance for the EU [148]. The TEN-T Regulation 1315/2013/EU defines legally binding targets for its infrastructure aims, with the core network to be implemented by 2030 and the comprehensive network by 2050. The TEN-T Regulation also establishes nine core network corridors (CNC), which represent a further instrument with which to facilitate the coordinated and timely implementation of the core network.

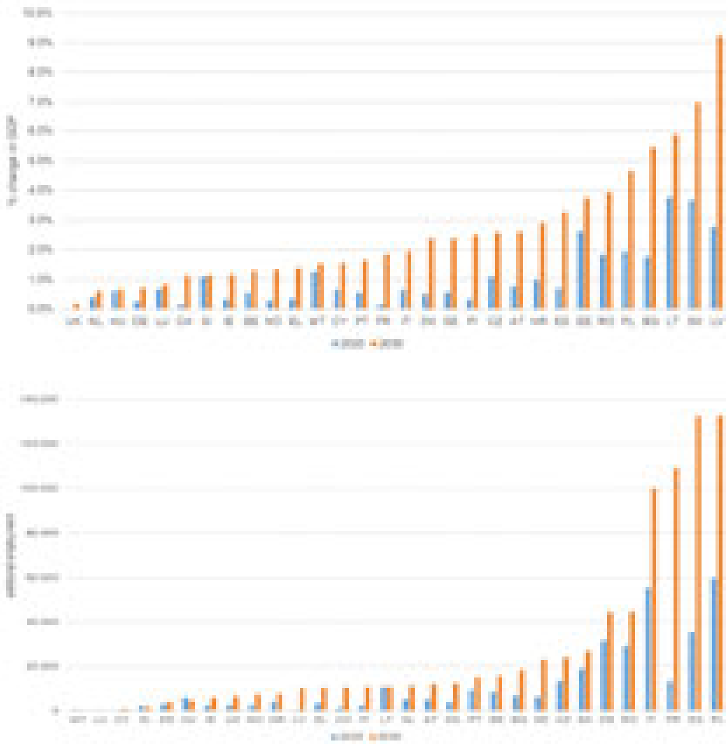


Fig. 1.5 Percentage of GDP change with the realization of TEN-T corridor and additional employment

At Member State level, the impact depends on factors such as: the size of TEN-T investment in relation to a state's GDP or its total investment; the sectoral structure of their economy; specific improvements in transport performance; dependency on trade, and trade structure. The time profile of

TEN-T investments and thus of improvements in travel time differs between countries. As a consequence, the impact on GDP and employment can also vary. Moderate increases in GDP of around 1% in 2030 relative to the Baseline are projected for several EU15 countries, while substantial increases of more than 3% in GDP are shown for many EU13 countries. Countries like Luxembourg, Slovenia, and Hungary reveal positive impacts on GDP that are similar in 2020 and 2030 (Figure1.2a,showing that most of their benefits are from direct effects. Conversely, countries like Bulgaria, Denmark, Sweden, and Latvia have GDP impacts that triple between 2020 and 2030, benefitting from second-round effects. Figure 1.2, showing the impact on employment, indicates that in Italy, France, Spain, and Poland more than 100,000 additional jobs could be created in 2030 relative to the Baseline, mainly because of second-round effects. The relative magnitude of direct or second-round effects depends on (1) the share of imports and exports in the sector benefitting from the investment, (2) the share of domestic input to construction, (3) growth of income and thus consumption, and (4) stimulus of total factor productivity in that country. In particular, the two final effects are mutually reinforcing and can foster medium-term growth dynamics. As a result, demand and productivity effects can significantly exceed direct effects.

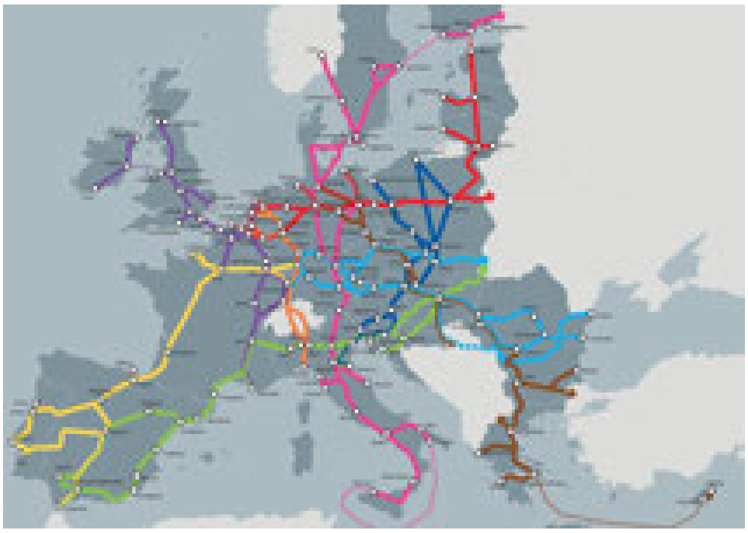


Fig. 1.6 Ten-T Corridor map

The report, provided by the EU commission, has analysed full TEN-T core network implementation by 2030 [148]. In terms of economic impact, GDP would increase by 1.6% in 2030 relative to the Baseline and an additional 797,000 full-time equivalent jobs would be generated. GDP growth impact differs substantially between the EU13 (+4.2%) and the EU15 (+1.4%). These large differences between countries are linked to (1) the share of TEN-T investments in the total investments undertaken in a country and (2) country-specific economic structures. The GDP multiplier of TEN-T investments amounts to 3.3%, which indicates that for every euro invested, 3.3 euro of additional GDP are created. In terms of employment, for every billion euro invested into the TEN-T core network between 2017 and 2030 an average of 13,000 additional job-years are generated.

In an increasingly global context, the AEC sector has to face new challenges. The Infrastructure and Urban (IU) industry is responsible for 30% of global greenhouse gas emissions and is the largest consumer of raw materials. Taking into account these premises, *The word Economic Forum* (WEF),in 2015, identified several initiatives to support the industry's transformation, in order to obtain higher productivity, greater sustainability and enhanced affordability [1]. In particular, the WEF promotes the implementation of new standards based on mega-trends, including impact on jobs, sustainability, technology (Building Information Modelling etc.) highlighting the strategic implications for all stakeholders along the value chain.

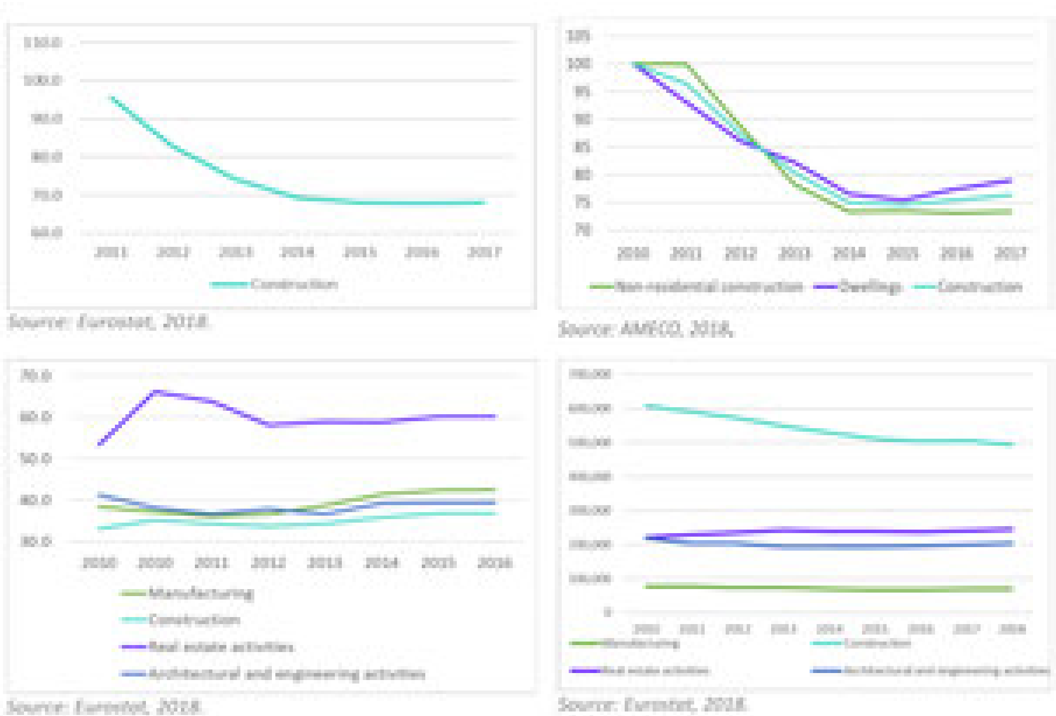
1.1.1 The Italian Market

The Italian infrastructure sector, according to the *World Bank* is at 22 th place in the world and in 12th place in Europe in Europe in terms of network efficiency. This negative performance has a direct effect on economic growth and it is due to several factors, such as fragmentation, lack of digitization and connections, and a drop in investments and employers.

In the period 2010-2017, in the narrow construction sector there was a decrease of about 32%. In the same period, the construction sector recorded a value of 91.8 billion euro, reporting a drop of 15%. This trend was caused by a reduction of 20% in the construction sector, 14% in architectural activities and 13.2% in manufacturing. companies in Italy, totalling 1,017,4131, declined

[1] Data availabel at https://www.weforum.org/projects/future-of-construction

by 9.8% between 2010-2017, contributing to a23% decrease in the number of people in the construction sector. The decline in workforce was led by the decline of the construction (-27.9%) and manufacturing (- 21.3%) sub-sectors, as well as real estate (-12.6%) and engineering/architectural (-11.6%) activities. The productivity of the construction sector has slightly decreased in recent years, falling by 1.2%, influencing the turnover of the construction sector with a 19.3 drop, falling from € 327.6 billion in 2010 to € 261.2 billion in 2016, followed by a slight increase in 2017 to € 264.3 billion [77] [22].



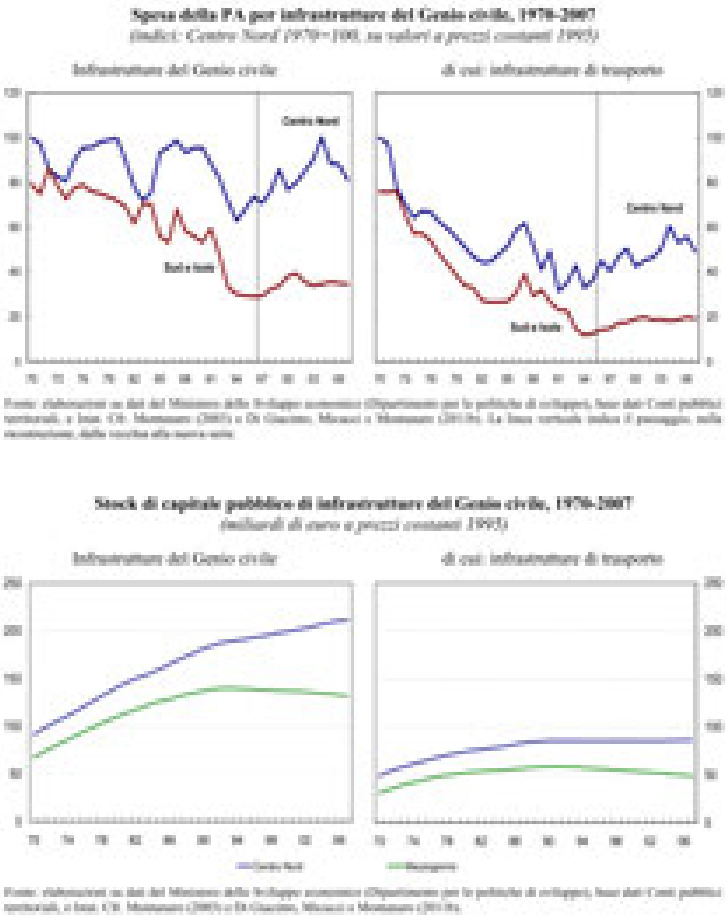
(a) Volume index of production in the construction sector in Italy, 2010-2017

(b) Number of enterprises in the construction sector in Italy over 2010-2017

Fig. 1.7 Italian Trends from 2010 to 2017

The Italian context is also characterized by a historical regional disparity, with several studies and international reports underlining the historical gap between northern and southern regions in terms of capability, efficiency, revenue, etc.. Aggregate investment in Italy from 1996 to 2007 was just under `€140 billion, qual to an annual average of 0.9% of GDP. The GDP ratio by territorial area showed that 1.4% of resources were allocated to southern regions, with

1.0% allocated to the north-east and 0.7% to the centre and north-west. The *per capita* revenues for the infrastructure sector were higher in the North-East, at `€205 per resident, compared to `€ 167 in the South and `€ 148 in Norht-West and Center. Although there has undeniably been investment in the south of Italy, the gap - especially in the period from 1996 to 2007 – has increased.



[22]

(a) PA outlay for infrastrutre in period 1970-2007

(b) Infrastructure public asset stock in period 1970-2007

Fig. 1.9 Italian Trands

Furthermore, with particular reference to the transportation sector, it is noticeable how the gap between North and South increases only by '90. Although PA investments in infrastructure amounted to `€ 119 billion in the period 1996-2007, for an annual average of 0.8% of GDP, the cash flow for these kinds of works were lower in the South than in other areas that continue to grow, thereby accentuating the increase in disparity.

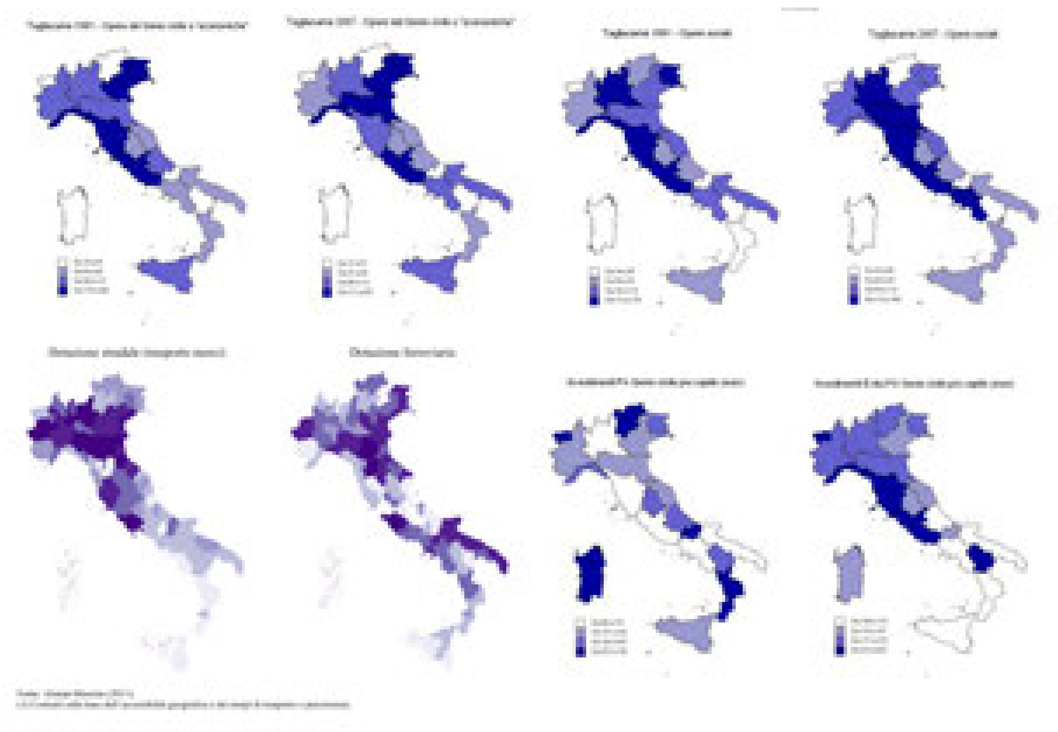


Fig. 1.11 Italian Infrastructural stock

The European Construction Observatory noted that in 2017 the amount of investment in infrastructure in Italy was still low. Despite the introduction of the Programme for Strategic infrastructure 2014-2016 (Programma delle Infrastrutture Strategiche – PIS), with its focus on the integration of Italy's main port, airport and urban hubs with the 4 TEN-T Core Network Corridors throughout the country, and identification of 25 priority projects for a total value of EUR 70.9 billion. The program should have aligned Italian logistical and infrastructure investment priorities with the EU vision [78].Unfortunately, in 2016, a large part of this investment did not produce the expected results, mainly due to the sharp slowdown in the public works sector. There are several reasons for this crisis in public works, one of them without doubt being traceable to the adoption of a new contract code, with analysis of the number of public procurements in the following year reports a net collapse in contracts.

Furthermore, the European Construction Observatory report points to a serious delay regarding the digitalization of the construction sector, resulting in Italy finding itself in 28th place in the EU. In this sense, the EU recognizes BIM as a key factor in improving the innovation of the AECO market, by optimizing the design process to deliver up to 15% less Construction and Demolition Waste (CDW), thanks to detection of design errors and a major collaboration among design teams [79]. Nevertheless, this innovation requires larger investment in technology, organisation processes and training for private and public companies, in order to implement the method.

1.1.2 The BIM into AECO market

Nowadays, BIM is used on a worldwide basis for AECO transformation. A recent study conducted by Deadal Research about the Global BIM market reported that the BIM market is expected to reach almost `$ 8 billion by 2020, , with a compound annual growth rate of 12% between 2015 and 2020 [100]. McGraw Hill reports the use of BIM globally among contractors has reached a value of over 30% [129] [128] [127] [83]. TThe National Building Specification (NBS), in a survey of UK construction market, reported an increase of BIM use from 13% in 2010 to 54% in 2016

The US market estimates a positive growth in the BIM market up to USD 4.9 billion in 2019 and up to USD 8.9 billion by 2024, with an annual growth rate of 12%. Between emerging and fast-growing markets, the APAC zone is expected to lead the construction industry, accounting for a significant number of construction projects carried out worldwide. Other countries ssuch as Japan, South Korea, Australia, and Singapore have introduced mandatory provisions for the adoption of building information modelling, while countries such as China and India intend to adopt building information modelling in coming years[1].

[1] The data are available from the source: https://www.marketsandmarkets.com/Market-Reports/building-information-modeling-market-95037387.html(Last view May 2019)

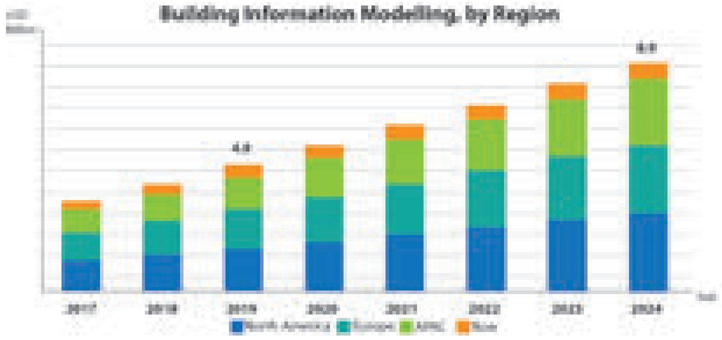
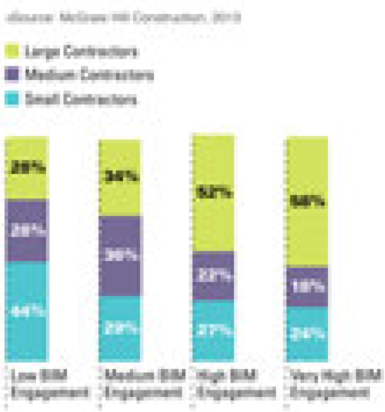


Fig. 1.12 BIM Market Value by area. Source Market and Market

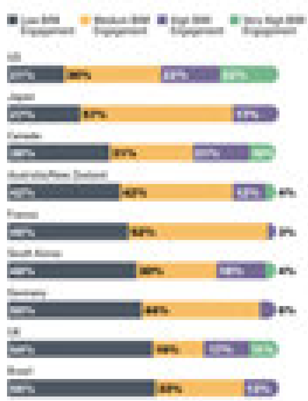
In the EU area, the BIM market was estimated at around € 1.8 billion in 2016, with growth of 13% forecast for 2023, worth around `€ 2.1billion [76]. This growth is the result of a series of factors, such as:

- **Integrated Urban development trends** involving urban renovation projects characterized by high levels of complexity and a wide range of stakeholders.
- **Government policies and initiatives** promoted by Member States for the adoption of BIM in public procurement.

Despite these positive trends, BIM among European industry players remains limited due to a set of factors such as the fragmentation of the supply chain and the lack of demand from owners. Consequently, according to statistics, in the EU area 29% of construction companies use BIM 3D, against 61% of companies that have never used it [70]. This figure is considerably lower when it comes to BIM 4D with only a 6% of companies using it. Fragmentation of the supply chain is the other factor hindering the spread of BIM, being mostly used during the design phase rather than during the operational and maintenance phase [123]. Survey results seem to confirm this situation, where BIM is widely used by architects and general contractors, as evidenced by the UK case study in which 90% of architect design teams used BIM, compared to only 25% of contractors. This means that engineers and trade contractors are still lagging behind in the process of adopting BIM, causing the fragmentation of the supply chain and making it difficult to exchange information for facility management. Similarly, there is often little demand from project owners to proceed more slowly. This is explained by the difficulty they may have in recognising the benefits of BIM, particularly at the construction and facility management stages [76]. According to the European Construction Observatory [76], BIM diffusion is affected by market structure and company size. Large companies have more capability that Small and medium-size enterprises (SME). Particularly in the transport sector, large companies tend to adopt BIM methodology whether they are engineering firms (85% vs. 71% respectively) or contractor firms (81% vs. 54% respectively). This trend can be partly explained when one considers the ability of large firms to have more capacity in terms of human and economic resources, the fact that they normally work on larger and more complex projects, requiring significant amounts of tools and coordination methodology, and finally the fact that large firms work worldwide for leading general contractors where the use of BIM is mandatory [54]. McGraw Hill Construction Research & Analytics [125] [126] [129] [128] [127] found that the diffusion of BIM is mainly confined to large firms and general contractors, supporting the idea that there is a correlation between company size and BIM adoption. Furthermore, the charts shown in Figure 1.14b emphasise two interesting aspects. The first relates to the UK percentage of low engagement users (54%), a figure due to government BIM mandates. The second relates to the percentages in the US, which are very similar, especially between low-level users (21%) and high and very high level users (22%), and the increasing percentage of European countries that are improving BIM adoption.



(a) BIM Engagement according to firm size



(b) Percentage of Contractors by country in Each BIM Engagement Level

Fig. 1.13 BIM Engagement. Source: SmartMark Rerport McGrawHill [128]

Gledson et al. [89], in 2012, conducted a study on 30 large and SME construction contractors to investigate their experiences and perspectives regarding the implementation of BIM processes in their practices. The study reported that 20% of respondents stated that they were unaware of BIM, whereas 6.7% were BIM users, and the remaining respondents stated that they were planning to implement BIM. In terms of the level of maturity and readiness, based on UK Government strategy [42] 36.7% are working at Level 0, 53.33% at Level 1 and only 6.7% at Level 2, representing large firms. The results confirm the difficulty of SMEs in implementing BIM adoption, despite recognizing the benefits thereof and the need to invest in BIM implementation, but there are critical issues relating to clients who are not prepared or willing to pay the extra costs required for BIM activity, or who do not have the competence to manage this type of data. Other critical factors for SMEs were the lack of financial support from the government, and a lack of profit or low revenue against investment in software, hardware and training [21] . In France, for instance, in order to tackle the lack of financial support and to boost BIM implementation, the government has activated BIM initiatives such as KROQI, a collaborative platform designed to help SMEs. The platform provides free BIM mock-ups, access to tools supporting the BIM process, and collaboration. Another initiative, promoted by EduBim, was a knowledge-sharing network offering support with BIM implementation to teachers, trainers and researchers collaborating with the construction and industry sector [76].

1.2 BIM Maturity Level

Preliminary studies conducted up to now highlight how the AECO market is undertaking BIM implementation. Despite the increase in the adoption of BIM, it can still be said that in the EU area there is a lack of homogeneity in terms of provisions and initiatives, due to different levels of maturity. The BIM maturity level was first developed by AIA, in the form of a gradual scale of adoption, considering that it is impossible to pass directly from a traditional CAD-based approach to an Open BIM approach. This process has to be managed step by step, keeping in mind the objectives to be reach, and always taking into account the fact that each implementation step involves costs, time, resources and especially change.

Often it is very common to find the Level of Maturity scale represented like a wedge, divide in 3 o 4 step of implementation. In order to evaluate which level is reached, indicators has been defined. Such indicators like model contents, grade of digitalization of the process, grade of interoperability, grade of collaboration, are useful to evaluate the state of adoption and maturity of the process. These indicators evaluate the process fro the whole project stages and also for the facility management asset.

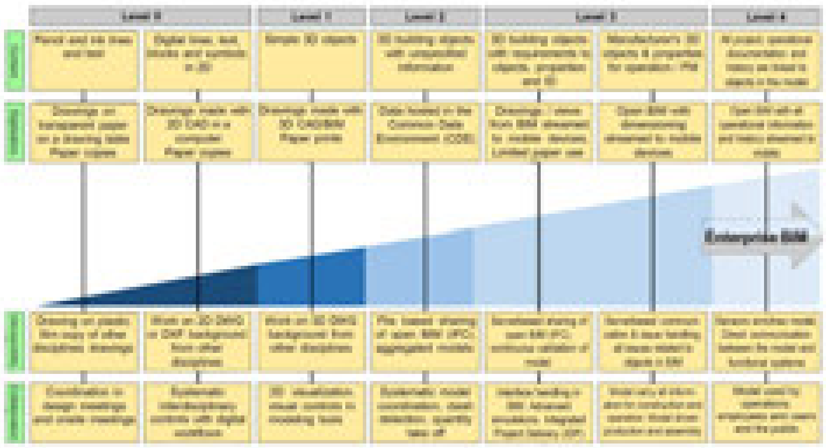


Fig. 1.15 BIM Maturity Level. Soruce: Poljansek et al.[141]

According to several reports and authors the BIM Maturity scale is composed by 4 step [26][56] [1]:

- **Level 0**: Unmanaged computer aided design (CAD) including 2D drawings, and text with paper-based or electronic exchange of information but without common standards and processes. Essentially this is a digital drawing board.
- **Level 1**: Managed CAD in 2D or 3D format using BS1192:2007 with a collaboration tool providing a common data environment, and possibly some standard data structures and formats. Commercial data managed by stand-alone finance and cost management packages with no integration.

[1] On-line resource available at https://www.designingbuildings.co.uk/wiki/BIM_maturity_levels (Last view March 2018)

- **Level 2**: : Managed 3D environment held in separate discipline "BIM(M)" tools with attached data. Commercial data managed by an ERP. Integration on the basis of proprietary interfaces or bespoke middleware could be regarded as "pBIM" (proprietary). This approach may utilize 4D Programme data and 5D cost elements.

- **Level 3**: Fully open process and data integration enabled by IFC / IFD. Managed by a collaborative model server. Can be regarded as iBIM or integrated BIM(M) potentially employing concurrent engineering processes [26].

- **Level 4**: Introducing the concepts of improved social outcomes and well-being.

In order to implement the traditional representation of the BIM maturity level, starting from the wedge concept of BIM Maturity level, the chart shown in Figure 1.16 adds qualitative representations of implementation curves given by interpolation between cost and time. The three curves represent the implementation of Hardware, Software, BIM skills and Training, while the shaded area behind the curves represents the implementation cost. Compared to Figure 1.15 the aim is mainly to represent a specific factor related to the cost, which is not zero at the start of the phase, which is one of the multiple barriers to BIM spread. Furthermore, these costs continue to grow over time, as with the implementation of the system towards Level 3 - meaning full integration of BIM information - the requirements of these factors will increase.

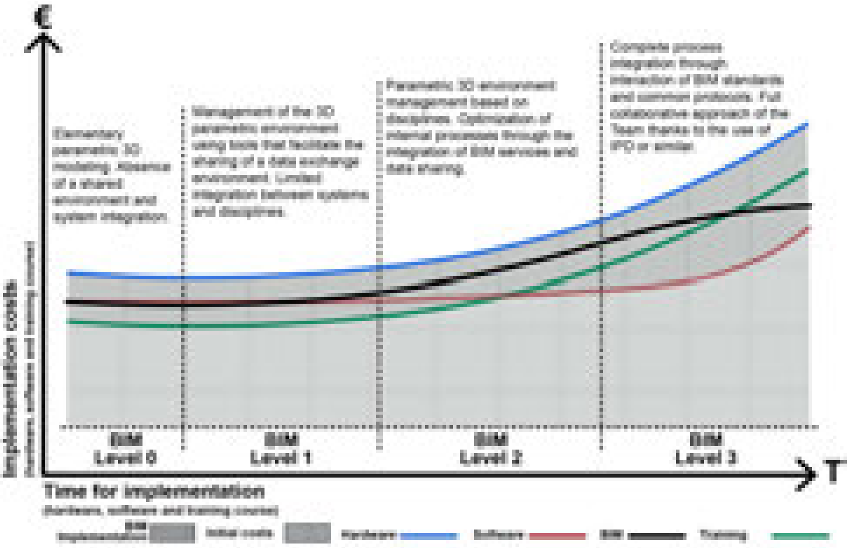


Fig. 1.16 BIM Implemetation

1.2.1 BIM Cost

Several studies have highlighted the benefits due to the implementation of BIM methodology. According to several studies [18] [23] [167] [86] [114] BIM might increase the efficiency of design processes by reducing errors and re-drafting times, increasing project control thanks to clash detection tools, obtaining more precision in the quantity take off phase, reducing the RFI, providing better management during the FM phase, and so on. There are several factors preventing the widespread adoption of BIM and in particular, at the moment, there is the perception of BIM being a cost rather than an investment [152], instead of recognising that the cost of BIM, understood as the acquisition of hardware and software, represents only a small fraction of BIM investment.

"Clients will only pay more for something if they perceive that it has greater value, and the values of BIM models to clients, for now, can be difficult to demonstrate as hypothetical future benefit." (Smith and Tardif, 2009) [155]

The proposed formulae aim to help companies to estimate the financial impact of BIM implementation. Each contribution starts from the identification of BIM outcome, incomes and benefits – in fact, one of the main problems encountered is the fact that some benefits are intangible in nature [121]. To sum up, the elements that compose the key variable of a large part of the equation shown. According to a literature review [137] [121][20] [19] [18] the cost of BIM implementation can be divided as shown in Table 1.1, pinpointing the cost with reference to organizational and human cost. This framework derives from a socio-technical system.

Table 1.1 BIM cost taxonomy. Source: Oesterreich et al. 2018 [137]

	Cost Category
	Indirect cost
Organizational costs	Cost of organizational and busisness process restructuring Cost of change management Cost of productivity loss
Human costs	Cost of management and staff dealing with procurement Cost of management and staff required to start-up activities Cost of administration and operation activities Cost of in-house application development Cost for user training Cost for staff turnover Changes in salaries
	Direct cost
Initial costs	Hardware cost Software cost Cost of software and data modifications Cost of installation and configuration Consulting cost Infrastructure cost
Human costs	Training cost Maintenance cost Support cost Standard development cost Upgrade cost Rental cost Overheads

1.2.2 Global maturity Level

Nowadays, several BIM provisions are investigating, developing or delivering in order to facilitate BIM adoption. Several surveys have been conducted by industry associations and academic institutions, such as the report provided by McGraw Hill [125][126] [129][16]. Among academic research papers, Succar and Kassem provide a study of *"Macro BIM Adoption"*, where they surveyed 21 countries selected on the basis of three criteria: i) countries that have activated at least national and international policies; ii) countries that have authoritative professionals informed about national and international BIM policies; iii) the distribution of countries is irregularly distributed across all continent [109] [160]. The outcomes of this study pointed out several models on the basis of matrix definition that return a ranking on the basis of the model scope. The Macro Maturity model includes eight macro components able to assess the maturity of BIM Adoption. The result of this model, is shown in Figure 1.17,

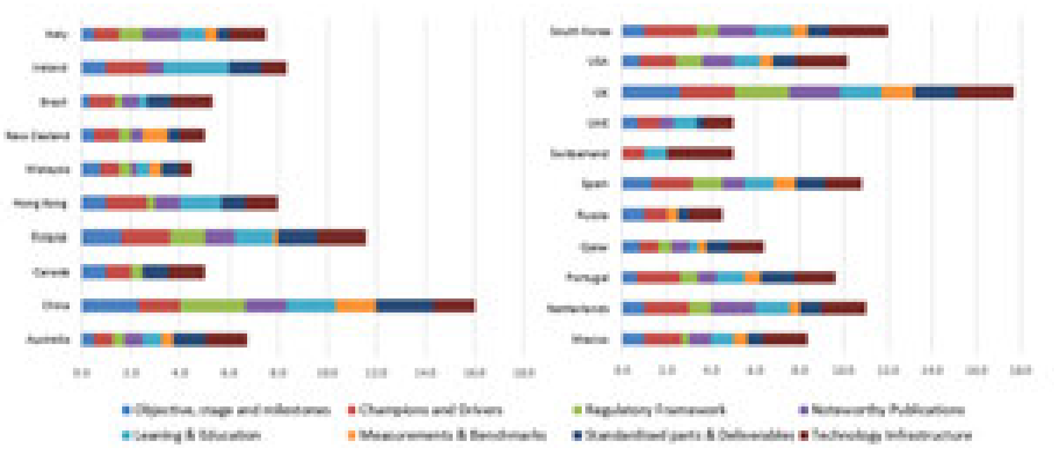


Fig. 1.17 Comparative rating of the macro-maturity components across the 21 countries. Source: Kassem and Succar [109]

The model finds that no country achieves the highest maturity. The UK achieved the best ranking in the largest number of components; Ireland achieved the highest ranking for *Learning & Education*;in technology and Infrastructure the highest score was in South Korea, while *Standardised Part*s and *Deliverable* were highest in China. Italy is near the global average, with a particular mention about *Regulatory Framework*, *Noteworthy Publications* and *Technology*

Infrastructure, while it demonstrated a delay below the average result in *Objectives, Stages & Milestones*, *Standardised Parts & Deliverables* [123] [109].

In conclusion, the study reports an increase of interest in BIM, even though at the moment there is a lack of models and tools to help policy-makers in developing policies, a lack of benchmarks for assessing BIM application policy, and finally a deficiency in terms of guidelines for Macro BIM adoption. In this regard, the EUBIM [75], has proposed a document which should help policy-makers and member states to develop an appropriate set of activities to implement BIM adoption. Notwithstanding, each member state follows different methods, with the Italian case being emblematic, where the introduction of BIM into public works has demonstrated an absence of commissioning between the main stakeholders such as Contract Authorities, firms and contractors. This is despite the fact that ministerial decree 560/2017 mandates the use of BIM for public works and UNI 11337 establishes an essential resource to prepare the Italian system for the transition. Nevertheless, other several aspects remain unsolved such as: i) intellectual property, ii) E-Procurement, iii) legal responsibility of new figures, iv) Collaboration processes and so on.

1.3 BIM spread in relation economic, policy and governance factors

IIn conclusion, after a preliminary and non-exhaustive overview of the AECO market, describing what is in reality a very complex situation, it seems clear that the European construction sector is in a phase of recession. I would like to end this introductory section by formulating a hypothesis that attempts to correlate BIM implementation as the result of different factors such as: i) economic indicators like GFCF, ii) governance factors iii) policy factors. As mentioned above, BIM can be a driver for positive effects, improving the digitalization and standardization of the construction sector, by trying to follow the industrial manufacturing market. According to Fenby-Taylor et al., several factors need to lead the process of BIM implementation, such as: economic, governance and policy factors [82]. A positive economic trend makes it possible to invest in infrastructure development, as a consequence it is easier to promote efficient BIM policy and BIM governance. A high number of governance committees indicates that countries have perceived the importance of the change process, supporting it with appropriate policies through a strong and transparent engagement process with the main stakeholders. Administrations have a responsibility to lead the change, through the creation or empowerment of an organization responsible for implementing BIM [82].

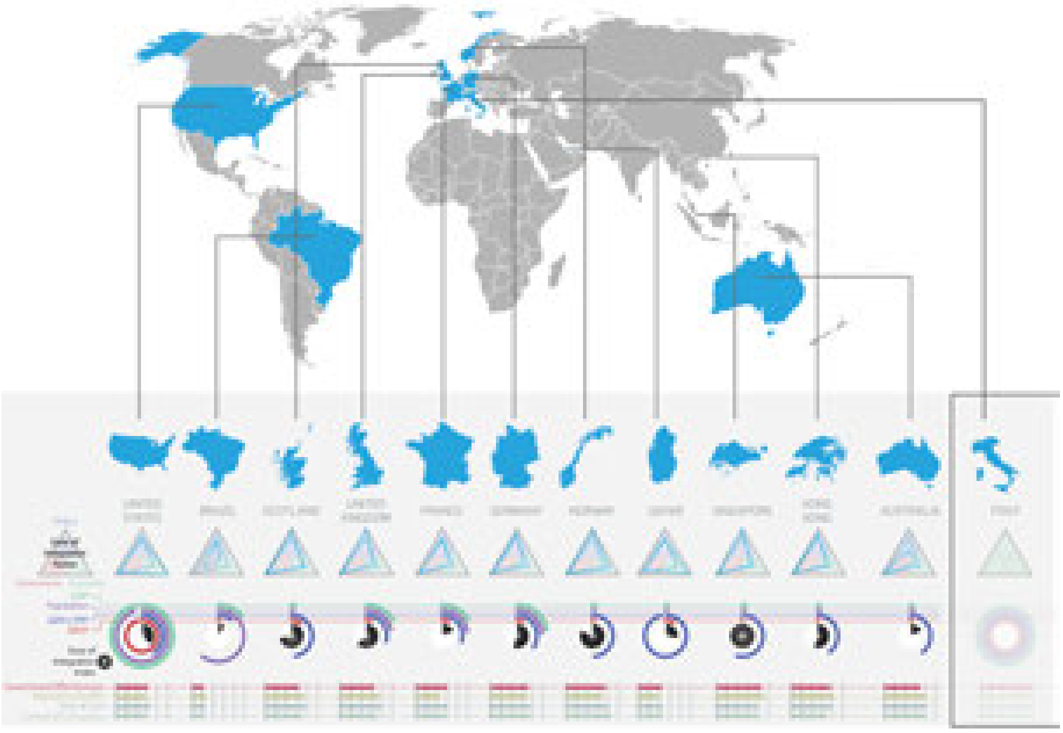


Fig. 1.18 Ease of integration map. Source: Fenby-Taylor et al. [82]

The Map in Figure 1.18, shows an index, known as the Ease of Integration Index (EOI). The EOI index is the score obtained by the pooling economic, policy and governance factors [82]. Results show that Singapore and Norway have a high score thanks to worthwhile investment, demonstrating also outstanding governance and policy [82]. This study is not exhaustive in terms of current BIM adoption worldwide, and since it is a study from 2016 it does not show the EOI index of other countries such as Italy, China, Canada, New Zealand, and so on. Despite this, it is interesting because it expresses BIM implementation level as the result of the integration of several factors. In particular, the relation between economic factors such as the Gross Fixed Capital Formation (GFCF) and BIM implementation. The GFCF is investment, consisting of resident producer acquisition, less disposal, of fixed assets during a given period, plus certain additions to the value of non-produced assets. These acquired assets are intended for use in production processes. GFCF includes the acquisition less disposal of, for example, buildings, structures, machinery and equipment, mineral exploration, computer software, literary or artistic originals and major improvements to land such as the clearance of forests [1].

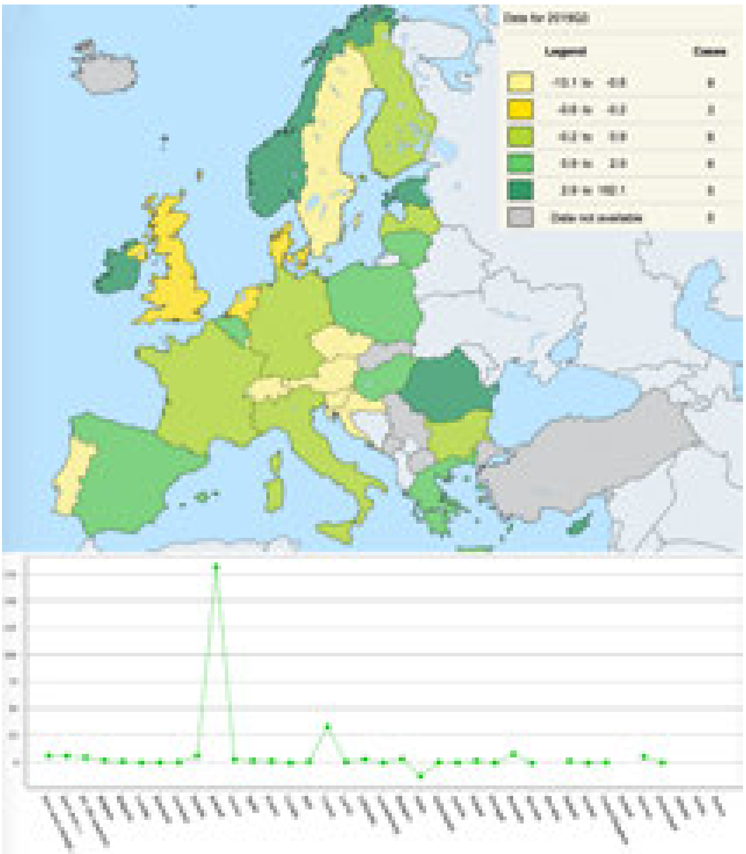


Fig. 1.19 Gross fixed capital formation (GFCF). Source: Eurostat

In conclusion, it is possible to consider the level of BIM implementation as the result of several factors. In particular, a high economic score may indicate a governance that is able to invest in infrastructure development, while a low score indicates lower investment, which may create some resistance, thereby challenging the cost/benefit of investing in BIM.

[1]The source of data provided by Eurostat are available at https://data.europa.eu/euodp/it/data/dataset/OWgAmEa918JlV3dZA51Pkw, (Last view September 2019)

Chapter 2

Theoretical background

This chapter aims to present a theoretical background about BIM, by presenting a collection of initiatives taken from the existing body of knowledge, and highlighting their BIM benefits and cost. Moreover, the chapter will attempt to provide a definition of BIM according to that given by the main authors in literature. Thus, where BIM has been implemented, we shall see how government initiatives are playing an important role in increasing BIM adoption. In particular, the chapter deals with BIM initiatives within European Member States, in order to seek examples that could be useful as guidance for national adoption.

2.1 Why BIM? - The value of BIM in the AEC sector

In the last decade, the process of digitalization has significantly changed the industrial sector, improving productivity, quality and variety. In this context, the AECO sector, even though the use of digital tools continues, remains significantly behind other industry domains. This is due to a lack of integration along the supply chain and the lack of standards for the exchange of information. In fact, most information is still produced in the form of drawings submitted as physical paper or in a digital but limited format [36]. Complex works involve a wide number of stakeholders from different fields of expertise, who have to interact continuously. Currently, this involves the handover of technical drawings in the form of 2D sections, views and detailed drawings. In this case, software used as a drawing board, providing limited information, cannot be use by other applications for further analysis, calculation and simulation. This approach requires data to be re-entered manually, resulting in the need for additional effort with the risk of errors or redundancy, and later requiring a considerable effort from the owner in order to extract the information for facility management [36].

National Institute of Standards and Technology (NIST), in 2004 published a report, *"Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry"* that estimated annual losses in the building industry, due to insufficient interoperability, of up to $15.8 billion [85] by 2002. This is due to the loss of information, as can be seen in Figure 2.1, where at each design stage available data is lost and has to be re-created. Most of costs for this lost data are borne by Owner, and the resulting costs are higher than other life-cycle phases, accounting for approximately $10.6 billion, or about two-thirds of the total estimated costs in 2002. Architects and Engineering firms lost about $1.2 billion, while contractors, manufacturers and suppliers bore costs of $1.8 billion and $2.2 billion, respectively [85].

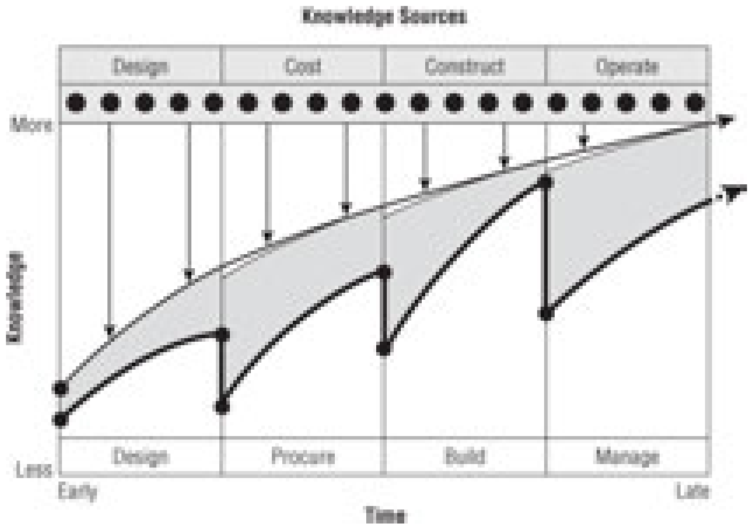


Fig. 2.1 The BIM curve shows lost of data without interoperability at project stages. Source: E. Krygiel , Mastering Autodesk Revit Architecture [113]

BIM may store, maintain and exchange information using comprehensive digital representations: Building Information Models. This approach dramatically improves the coordination of design activities, integration of simulations, setup and control of construction process, as well as handover of building information to the owners. By reducing manual re-entering of data to a minimum and enabling consequent re-use of digital information, laborious and error-prone work is avoided, which in turn results in an increase in productivity and quality in construction projects.

BIM is current expression of construction industry innovation, a set of technologies, processes and policies, affecting the industry's deliverables, relationships and roles. BIM concepts and tools encourage concurrent revolutionary and evolutionary changes across organizational scales from individuals and groups, through organizations and project teams, to industries and whole markets [160]. For these reasons, many authors in literature consider this transition from Computer Aided Design (CAD) to BIM to be a genuine paradigm shift. The introduction of object oriented parametrics establishes a real revolution in the semantic meanings of architectural and construction elements, with respect to traditional symbolism. In fact, for instance the representation of a wall is given by four lines and four vertices, but it is the mind of the viewer that connects those symbols with the idea of a wall, but it is not possible to obtain any other information, beyond the thickness. Instead, thanks to introduction of BIM object parametrics, it is possible to know other information about that wall, such as the material, costs involved, phase of construction and a lot of other information, which is collected in a database [138].

Information is the real strength of this methodology. Thanks to BIM methodology, it should be possible to generate and maintain project information for the entire lifecycle, providing communication (sharing data); collaboration (acting on shared data); simulation (using for prediction); and optimization (using feedback to improve design, data documentation and delivery).[98]

The NIBS introducing BIM: *"...Imagine for a moment all of the individual actors in all of the phases of a facility's lifecycle. Imagine that all of the actors, working in familiar ways within their own specialty areas, are able to gather information, explore options, assemble, test, and perfect the elements of their* *work within a computer-based model before committing their work to be shared with or passed on to others, to be built, or to be operated...* [NIM].

The point is to improve collaboration among stakeholders, by sharing a common goal, i.e. process efficiency. In this way, it should be possible to overcome the historical gap affecting the AECO sector, due to the limitations of technical drawing, by limiting the manual re-entering of information, and using that information directly in applications for analysis, calculation and simulation. In the same way, for the owner it is also an advantage during FM operations, facilitating the extraction and updating of technical documentation [36].

2.1.1 BIM Benefits

The value of BIM, as mention before, is related to a several benefits that this methodology is able to introduce into process at different levels. About BIM benefits, international literature has produced a lot of studies discussing the advantages of BIM implementation. As shown, the value of BIM benefits is both tangible and intangible, as they incur both project level and corporate level costs. Notwithstanding, in the analysis of BIM benefits it is essential to underline how dependent it is on stakeholder perspective [107]. Based on the work of Oesterreich et al. [137] and Sanchez et al. [145] as shown in Table 2.1, BIM benefits have been identified and organize according to a utility effect chain [137]. The authors have identified 31 benefits associated with BIM implementation.

Table 2.1 BIM Benefits Taxonomy. Source: Oesterreich et al. 2018 [137]

	Task and division level	**Corporate Level**	**Market Level**
Improved project management	Optimization of construction sequence		
	Better scenario and alternatives analysis		
	Better programming and scheduling		
	Better change management		
	More effective emergency management		
	Better space management		
	Higher process automation	Reduce cost of rework	Competitive advantage gain
Improved communication collaboration	Improved information exchange		
	Improve communications	Reduce overall execution and lead times	
	Improve coordination		
	Better use of supply chain knowledge		
Improved documentation and information management	Improved documentation quality and process	Asset management labour utilisation savings	
	Faster regulation and requirement compliance		
	Improve data and information management		
	Better data and information sharing		
	More accurate quantity take-off		
	Better Cost accounting		
Improved efficiency	Improved learning curve		
	Improved efficiency		
	Improved training and education		
	Improved safety		
	Reduce Risk		

From critical point of view BIM benefits are more difficult to quantify, as shown in Table 2.1 some benefits may be collect according to economic metrics, such as *"cost savings/ avoidance"* and *"overall cost"* for measuring the economic implications of various benefits [137]. Other benefits are related to the improvement at organization level, facilitating communication and efficiency of the processes, reducing the *"overall execution and leas times"*. In order to try to estimate BIM benefit different approaches were proposed by several authors like the utility effect chains. This process is related to a process-oriented view on different corporate levels in order to emphasize the inter-relations as well as their financial impacts. Other approaches are based on the calculation of the Return Of Investment (ROI), in order to try to estimate the net profit derived by a BIM investment scenario.

The models proposed by international literate are many such as the Prioritaring Efter NyytoGrunder (PENG) model,that means "prioritizing based the contribution of benefits" [106] and the Total Economic Impact (TEI) model. CIFE used the TEI model to asses the ROI for the Holder Construction Company, monitoring 10 projects, tracking constriction clashes discovered with the use of Autodesk Naviswork[88]. For each clash discovered were assigned a level of severity, which correspond a cost[152]. As shown in Table 2.2 [18] the BIM

ROI varies from 140%to 39.999% with an average of 1633% for all project and a 634% for projects without planning or value analysis. Probably, The large spread register is due to the variation of BIM Scope; indeed, in some cases BIM savings are deducted by the detection of clash, which correspond an economic value equivalent to an avoidance of cost or delay. In other cases, BIM saving derived from using BIM during the planning or value analysis phase [18] [144].

Table 2.2 Building information modelling Return of Investiment Analisys. Source: Azhar 2011 [18]

Year	Cost	Project	BIM Scope	BIM Cost ($)	Direct BIM saving ($)	Net BIM Saving ($)	BIM ROI (%)
2005	30	Ashley Overlook	P/PC/CD	5,000	(135,000)	(130,000)	2600%
2006	54	Progressive Data Center	F/CD/FM	120,000	(395,000)	(232,000)	140%
2006	47	Raleigh Marriott	P/PC/VA	4,288	(500,000)	(495,712)	11560%
2006	16	GSU Library	P/PC/CD	10,000	(74,120)	(64,120)	640%
2006	88	Mansion on Peachtree	P/CD	1,440	(15,000)	(6,850)	940%
2007	47	Aquarium Hilton	F/D/PC/CD	90,000	(800,000)	(710,000)	780%
2007	58	1515 Wynkoop	P/D/VA	3,800	(200,000)	(196,200)	5160%
2007	82	HP Data Center	F/D/CD	20,000	(67,500)	(47,500)	240%
2007	14	Savannah State	F/D/PC/VA/CD	5,000	(2,000,000)	(1,995,000)	39900%
2007	32	NAU Sciences	P/CD	1,000	(330,000)	(329,000)	32900%
Lab Total all types				260,528	4,516,620	4,256,092	1633%
Totals without planning/VA phase				247,440	1,816,620	1,569,180	634%

(a) Note: BIM Scope definition: CD = construction documentation; D = design; F = feasibility analysis; FM = facilities management; GSU = Georgia State University; NAU = Northern Arizona University; P = planning; PC = preconstruction services; ROI = return on investment; VA = value analysis.

In conclusion, the impact of BIM investment scenario seems to produce positive benefits. Furthermore, as mention before, these parameter change on the basis of the stakeholder perspective. Furthermore, the large part of methods proposed aim to state a snapshot of BIM benefits, depicting a very high ROI, but without taking into account the cost saving by BIM during the whole life cycle. This approach is directed to private sector, but it is not analyzed by Owner's perspective that have to operate for many years.

David Mitchell [1] reports (Riferimento ad un link), collects a case history of public procurement experiences, that highlight BIM benefits, especially in cost reduction terms, as follows:

- The New Prison, Wrexham, North Wales a project of £ 212 million that had a 26% of cost reduction;

[1]Source available: https://buildingsmart.org.au/category/bim-roi/

- Cookham Wood Young Offenders New Build, project evaluate £ 20 million saved 20%;
- Property Services Cluster of Primary Schools 14%;
- Project Horizon is the project for an highway saved cost for 17,5% againt an estimate construction cost of £100 million;
- The UK's Crossrail is one of the most important stakeholder in the transportation sector. It aims to realize the first major infrastructure project (£25 billion) in Europe with an approach fully BIM. The cost saving estimate until now are around 10-15%;
- US General Service Administration's (GSA), after a long time of project pilots, promoted by the National 3D-4D-BIM Program reported a regular saving in the detection of errors and RFI, reducing also the construction times and improving a fast and accurate space measurements;
- The University of Colorado, Health Sciences Center, is a rare case where it was possible compared similar project developed one with traditional project and the other one with BIM implementation. The first was completed on time and within the budge usign a traditionadelivey approach, the second thank to the use ov Virtual Design and Construction (VDC) demonstrated an improvement of productivity, promoted the prefabrication, reduced RFI's and completed with two month ahead of schedule and under budget;
- UNITEC, New Zealand's largest institute of technology, in 2008, promoted a BIM integrated information system fro the FM activities. It reported an approximately ROI of 23% for the facilities management activities.

2.2 What - What does Building Information Modeling mean?

BIM is an acronym for Building Information Modelling. According to Borrman et al. it is a **digital representation** of a built environment characterized by a great depth of **information** [36]. Eastman et al. define BIM as an update model able to generate and manage 3D representations of physical and functional facilities during the **entire life cyle**, associated with a set of **procedures** and **standards** to produce, communicate and analyse building models [66]. The The National Building Information Modeling Standard-United States (NBIMS-US) [136] defines it as follows:

"Building Information Modeling is a digital representation of physical and functional characteristics of a facility. A BIM is a ***shared knowledge*** *resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition.A basic premise of BIM is* ***collaboration*** *by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder".*

According to Azhar, BIM is an extensive computer-based digital process to develop and generate simulation for planning, design, construction and operation of buildings and structures [19] [20]. The Institution of Civil Engineer (ICE) defines BIM as: *"…. the purposeful management of information through the whole life cycle of an infrastructure asset. Thus, BIM is a managed approach to the collection and exploitation of information across the life cycle of a built environment asset. At its heart are computer-generated models connecting all graphical and tabular information about the design, construction and operation of the asset and associated documents."* [24].

The concept of BIM introduces to the construction sector a semantic approach to information enrichment. This means that BIM objects have a meaning that does not depend only on their geometry, but combines 3D parametric geometry representations with additional information and their relationships with other elements inside the model [36]. For instance, a door will have a geometrical representation and attributed information, but at the same time the creation of a door generates a relationship with the wall and room space in which it will be inserted. Moreover, it creates a direct correlation between quantity take-off, construction planning, structure properties, facility management operations, and so on.

2.3 Where? - International BIM Initiatives

In recent years, a strong trend has emerged among governments around the world to force the construction industry to adopt BIM by policy means. Convinced by the benefits to them as construction clients and to the industry itself in terms of productivity and communication efficiency gains, governments are investing considerable sums in developing not just a BIM vision, but comprehensive requirements and standards to ease delivery. The theory suggests engagement from all levels (bottom-up / top-down); together with a suitable balance of push and pull incentives and common standards, which are essential to support full and comprehensive BIM adoption [43].

Many countries around the world have adopted BIM technology, such as the UK, Norway, Denmark, Sweden, Finland, Netherlands, Australia, Singapore, Hong Kong, South Korea, Canada, US, and so on. They have introduced various forms of government initiatives to promote the adoption of BIM in construction. The Government standpoint is that of the construction client and property owner – a large public sector commissioner with a vast stock of facilities needing to be designed, constructed and maintained over facility life times. The United States is believed to be one of the pioneering countries for BIM adoption. Many public sector bodies at different levels in the United States have established BIM programs, set up BIM goals and implementation roadmaps, and published BIM standards. In 2007, for example, the United States National Institute for Building Sciences (NIBS) published the National Building Information Modelling Standard (NBIMS-USTM). Apart from the United States, many countries in Europe have embarked on significant BIM implementations. The United Kingdom government, for example, mandated that all UK government projects should use BIM by 2016. Although BIM adoption in the public sector came later in Asia, BIM has now developed rapidly in Asian regions. For instance, Singapore and Hong Kong have established their own BIM committees and published several BIM guidelines. The Mainland Chinese government also included BIM-related topics in the 12th National Five Year Plan in 2012.

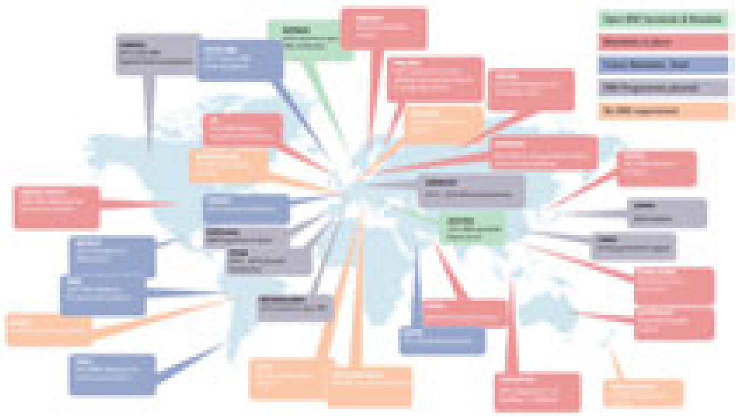


Fig. 2.2 Overwie of Global BIM Adoption. Source McAuley et al. [100]

The public sector plays a vital role in leading the industry towards BIM adoption. In recent years, BIM implementations have continued to increase intensively as more and more government bodies and non-profit organizations from various countries worldwide have implemented BIM in their projects and provided different BIM standards and solutions. Such divergence and coverage highlight the lack of and the necessity for a review of these efforts and the potential roles of the public sector for BIM adoption. However, currently there is no comprehensive study on the efforts and roles of the public sector for BIM adoption.

2.4 How? - National Standards and Initiatives

The introduction of BIM methodology in the construction sector for private firms has become an essential factor for remaining competitive in the market, by trying to introduce innovation and more control into complex works. Nevertheless, it is possible to assume that it is a voluntary decision, involving primarily large companies, rather than SME firms. In this context, the public sector plays a vital role in leading the industry towards BIM adoption [43] [162]. Therefore, in the last decade, thanks to the work of government bodies and non-profit organizations from various countries, BIM implementations have continued to increase intensively in their projects, providing different BIM standards and solutions. A survey led by BuildingSMART has documented 81 *"BIM Guide"* from North America, Europe, Asia and Australasia. Meanwhile, Cheng et al.

listed 123 BIM documents from the same four regions [43]. Later research was focused on European standards and initiatives to provide a theoretical background to different approaches proposed by other Member States.

Fig. 2.3 BIM Guide Line and Mandates distribution

2.4.1 EU

The introduction of BIM into public works, since 2014 thanks to European Directives, has contributed to the spread of BIM to the public sector[1]. Thanks to the efforts of EU BIM - a European panel co-funded by the EU to provide best practice in BIM (building information modelling), incorporating national efforts in a common, aligned European approach to developing a world-class digital construction sector - national public procurers, policy makers and public estate owners are recognising the positive effect of digitalization on both the public works and construction sectors. In fact, in recent years several nations have activated national programmes to encourage the spread of BIM within public works, in order to improve the effectiveness and quality of public estate. In an attempt to cover the digital gap affecting the manufacturing sector in the 1980s and 1990s, and to improve productivity rates and output quality [25]. Nevertheless, as shown below, each member state is approaching BIM implementation in different ways, promoting national standard and initiatives.

[1] European Directives 24/25/26 [80]

2.4.2 United Kindom

In the UK the government introduced a BIM implementation strategy for the construction industry in 2011, with the ambitious target of requiring BIM on all centrally-procured built assets across all government departments by 2016, through a 5-year staged implementation plan. The plan provided budgets and resources to the Construction Industry Council (CIC) to establish the UK BIM Task Group, which defines new ways of working, standards and protocols to help industry in the digital transformation of the sector. The group allowed free access to British Standards (BS) and Publicly Available Specifications (PAS) along with the legal addendum. The next step of the vision provided by the Digital Built Britain is to enable a smart connected high-performing built environment, achieving Level 2 BIM implementation by 2020 and commencing with Level 3 in the same year [93].

2.4.3 Finland

In Finland, the government body Senate Properties, responsible for managing the country's property assets, launched its first BIM pilot projects in 2001. In 2007 they started requiring BIM modelling through an open data exchange format, releasing BIM Guidelines to assist industry transition, updated in 2012 to a National BIM requirement. A strong network of industry parties has been promoted since the start, to develop implementation, management and development of common open standards, processes, methods and tools. At the moment, there is no single body responsible for managing the BIM programme. Some future plans of the Finnish Government include developing more guidelines for stakeholders in BIM-based processes and for simulations and analysis. Other initiatives include tools for BIM model uses and model views for maintenance and operation [133]. The InfraBIM standard Inframodel will be finalised and implemented [123].

2.4.4 Denmark

In 2007, the Danish government, which can also be considered a pioneer in the sector, launched the Digital Construction program, following the results obtained from previous studies since 2001. The aim was to define the requirements of Information and Communication Technologies (ICT) and to promote the use of digital processes, methods and tools among architects, engineers and constructors participating in public tenders. In 2013, the Parliament established a Danish BIM mandate, for all public funded projects worth over 2.7 million euros.

2.4.5 Germany

In December 2015, the Federal Ministry of Transport and Digital Infrastructure (BMVI) launched its strategic BIM Road Map for transport the infrastructure sector in Germany. This internationally aligned plan, a joint project between government and industry, was largely developed by an industry-led initiative – known as "planenbauen 4.0" – in 2014. It was designed to facilitate the target of applying BIM in all new public works projects procured in Germany from the end of 2020. A phased mobilization period prior to 2020 is intended to provide a progressive roadmap for the development of capability and capacity in the market, in particular with three levels of maturity.

2.4.6 France

The Minister of Housing, Equality of Territories and Rurality presented a plan to revive construction. The Plan de Transition Numérique dans le Batiment (PTNB) is one of three action plans initiated to accelerate the deployment of digital tools across the entire building sector. In its roadmap, PTNB identified the use and promotion of standards as a topic of major importance. The PTNB created a French roadmap in 2015 which provides a three-year timeline. This roadmap is structured around three guidelines, related to experimentation, capitalisation and convincing all stakeholders, in an attempt to support the enhancement of professional skills and stimulate the development of tools tailored to small projects. Developing a trusted digital ecosystem through neutral, stable data formats that can be used in the description of the structures of digital models, tailored for software interoperability and for the development of open-source applications.

Chapter 3

Research Methodology

This chapter aims to explain my PhD research activity, defining the main research questions, methodology and context about BIM for infrastructure design, and the main step to be taken to spread BIM methodology into a public contract authority such as ANAS. My research activity was divided into two parts: the first part was dedicated to study of the state of the art in BIM, by collecting a large number of publications in international literature in order to consolidate a solid base of knowledge. The second part of my research activity has been dedicated to practical activities, during a period inside the company, to promote actions and test hypotheses relating to research questions in order to activate the implementation of BIM methodology at company level.

3.1 Research questions

This study begins with an investigation of BIM introduction into infrastructure projects, and of the needs and support systems required to introduce this methodology into a Contracting Authority, like ANAS. This requires management not only of the introduction of new digital tools, but in particular a process of change management involving new standardisation processes, new workflow and skills. Given the complexity of these themes, the research questions focused on BIM introduction, by investigating topics as follows:

- Question 1

Is it possible to adapt BIM methodology to infrastructure projects? What are the main steps to define an effective work-flow of information between different disciplines?

Even though this methodology is more consolidated in the building sector, it is still necessary to test BIM methodology in civil design. The aim is to define a suitable work-flow, dedicated to infrastructure projects able to manage a large amount of information, depending on the correct Level of Development (LOD) and BIM uses. Testing the performance of the main BIM tools for infrastructure projects, given that the current library of parametric objects available for the purpose is still inadequate.

- Question 2

  What are the processes, standards and regulations to be introduced to effectively help the introduction of BIM into contracting authority procedures, with particular reference to Italian public administration?

  Requiring the use of BIM in public works is one of the most important barriers to be overcome for the spread of BIM. Current procurement procedures are based on a series of provisions and regulations that do not consider the use of a BIM model. For these reasons, starting from inter- national and more recently from national standards, this study aims to provide best practices for BIM introduction into the public works procurement process.

- Question 3

  to introduce BIM procurement into public works?

  The introduction of BIM into the construction sector is a change that involves the entire construction sector supply chain (Ministry of Transport, Contracting Authorities, General Contractors, Sub-Contractors and Construction Industries). The objective is to analyse the BIM level of maturity reached in term of standards, model LDO and management of information, thanks to a pilot contract developed by ANAS, and through analysis of other public contracts.

3.2 Research gap and contribution to the research

BIM is a transversal topic that can be described in several ways, not limited to 3D modelling, but involving the whole supply chain. Integration with other systems and the exchange of information plays a key role in the spread of BIM in the AEC sector. BIM implementation requires a change in company processes at organizational level, new skills, new workflows and technologies. Notwithstanding the fact that a great deal of literature has been produced in recent years, some gaps still remain, especially in the application of BIM to civil infrastructure and relating to the BIM implementation in a Contract Authority like ANAS. From the literature review, the topic of implementation BIM at private company level has been studied. However, in terms of Public Administration, despite the presence of a large quantity of guideline standards, that can help to give a direction, there are not many noteworthy contributions.

At workflow level, the use of BIM for civil infrastructure is a new topic, involving the use of tools tailored for Building for another purpose. At the moment there does not exist a suitable workflow for civil infrastructure, given the problems due to the integration of several applications for specific disciplines like Environment, Geology, Hydraulics and so on. In this context, integration between GIS and BIM application plays a key role in developing the spatial analysis typical of civil design. Although GIS-BIM integration is a very common issue, the main examples to be found relate to Smart City, whereas there is a distinct lack of contributions relating to road design.

Interoperability processes play an essential role in supporting workflow. Even the most recent IFC versions, which have now reached version 4.1, still do not map all classes for civil projects. For this reason, it is necessary to define the IFC property Set appropriate for civil works. Notwithstanding, the IFC is not enough to accomplish the interoperability process, and it is necessary to explore the integration with other formats such as LandXML, BCF and so on. In this case the literature review provides several studies relating to semantic implementation of IFC format. Other studies show custom solutions that require IT skills and a great amount of effort on the part of stakeholders.

ANAS, as Contract Authority, aims to contract works and engineering and architecture services and not to execute projects directly. Therefore, it is essential to define the contractual framework in order to obtain an appropriate BIM model. In this sense, BIM procurement has become a new topic in the literature review, with several structures proposed, such as Messner [2] [130] which proposes one of the most famous structures for the pre- and post-contract BIM Execution Plan (BEP). On the other hand, the studies are based on international or American or British regulations, where legal disclaimers are less restrictive.

Research gaps and contributions can be summarised as follows:

- **Research gaps:**
  - – BIM workflow tailored for the integration of BIM inside a Contracting Authority;
  - GIS-BIM integration for civil design;
  - Definition of tailored Interoperability process for civil design;
  - BIM requirements for contract documentation in the Italian context;
- **Research contribution:**
  - Propose strategies for BIM implementation in ANAS;
  - Study of a tailored workflow for InfraBIM;
  - Test of integration BIM-GIS;
  - Benchmark of main BIM tools;
  - Test of main exchange data format and definition of a IFC property set;
  - Definition of BIM requirements according to Italian regulation;

3.2.1 Purpose and objectives

The primary purpose of this work is to contribute to the body of knowledge that may inform the definition of standardisation of production information and administration structure and scope in the construction industry. This may enable greater co-operation and collaboration between industry and project participants, which are currently hindered due to a lack of standardized platforms for digital information sharing and support systems. The work is orientated towards specific needs of the industry to promote collaboration among user-groups and existing BIM-user organizations, seeking to support the sector's needs by testing, evaluating and developing new BIM methodologies that may serve to increase AECO efficiency. In conclusion, research objectives can be summarized as follows:

- Implementation of BIM methodology for infrastructure design;
- Definition of frameworks, strategies, policies and procurement to ensure successful BIM implementation;
- Definition of common methods based on structured data and shared standards in order to facilitate the spread of BIM methodology among owners, stakeholder and the supply chain;
- Definition of a collaborative process based on interoperability and sharing of information, through testing the main exchange of open data format and proprietary format to avoid a lack of information;
- Definition of LODs (as Level of Detail and Development) for different infrastructure work stages (strategy, brief, definition, design, etc...) in order to facilitate the exchange of information between disciplines during project development, avoiding overloading of data model;
- Drafting of the contents of pre-contract Employer's Information Requirements (EIR) and BIM Execution Plan (BEP) for infrastructure;

3.2.2 Focus and delimitation

The research project aims to investigate processes capable of supporting the transition towards digital information management within a specific office of ANAS, in such a way that the exploitation of this transition does not impact on the entire company. Even though as a researcher I am aware that BIM implementation should involve the whole company. This certainly may be considered a limitation, but taking into account the complexity and the large size of ANAS, it is not possible to adopt another approach. For this reason, beginning with international and national initiatives, research activity is focused on testing and validation of BIM modelling strategies and standardization processes, in order to create support mechanisms for the *"Coordinamento e Progettazione"* (CP) office. However, the choice to start from the office that develops the design phase is a point of strength, because the rresearch has the possibility to have an impact on new projects that could start directly with BIM. Nevertheless, the high expectations relating to BIM and its ability to reduce costs and time, has not yet been verified and quantified. Furthermore, at the moment, there are very few examples of BIM application through the entire lifecycle, and as long as the whole supply chain is not involved in the BIM transition, it will be difficult to estimate the real benefits [131]. The focus on the design stage is a strategic choice for several key reasons:

- Design is where the main BIM-authoring activities take place, which in turn have the biggest impact on the quality and downstream usability of the digital asset;
- Architects and Engineers are investing more in BIM, rather than construction firms. They struggle more with the improvement of BIM processes, which heavily affects the construction and operation activities that use their data;
- It is expected that the volume of information created through design development phases will see the most dramatic increase and therefore correct management is essential;
- The greatest impact of BIM on ANAS works starting from 2019, according to DM 560/2017 [132], will be for new projects whose preliminary designs were not activated prior to January 2018.

Nowadays, the market offer for BIM software is very wide and part of this research has focused on testing different applications, because I am certain, and will try to prove later that in this field, that a single tool is not enough to handle all aspects of civil design. Therefore, the interoperability process is even more important and at the same time remains one of the main barriers to the integrity of the associated data; therefore, this study does notattempt to address this particular problem by implementing, for example, a new version of the IFC infrastructure as other eminent authors have done [172] [32] [10] or by introducing new add-ons/add-ins; rather I have attempted to reflect on the difficulty related to the technical implementation of managing different data, which should be exchanged, and how much the cost of information loss costs.

Considering the plurality and great quantity of contents connected to BIM, it is necessary to confine the field of study. First of all, the results of this research project are based on empirical data largely collected by pilot projects, provided by ANAS. Thus, a large part of the study was developed by Italian public administration. Although this might seem to be a weakness, the problems associated with the progression of BIM maturity are international and the emerging conclusions can be considered to have broader international implications. Moreover, the opportunity, to collaborate and exchange views with one of the main representative Contracting Authorities in Italy, has been a real point of strength, enabling me to understand the implications of adopting BIM in a public context. Therefore, in addition to the impact of the research locally, which will be presented later in the thesis, it can also be said that the research has contributed, albeit to a minor extent, to the spread of BIM in ANAS procurement.

3.3 Research Programme

Taking into account the research objectives, a BIM programme has been defined, in order to plan research and company activities. The plan is structured to address the research objectives, and to exploit the findings to provide at company level best practices for BIM management and procurement. Activities have been planned in six stages, as shown in Figure 3.1:

- Kick Off
- Imprinting
- Implementation
- Analysis

- Validation
- Results

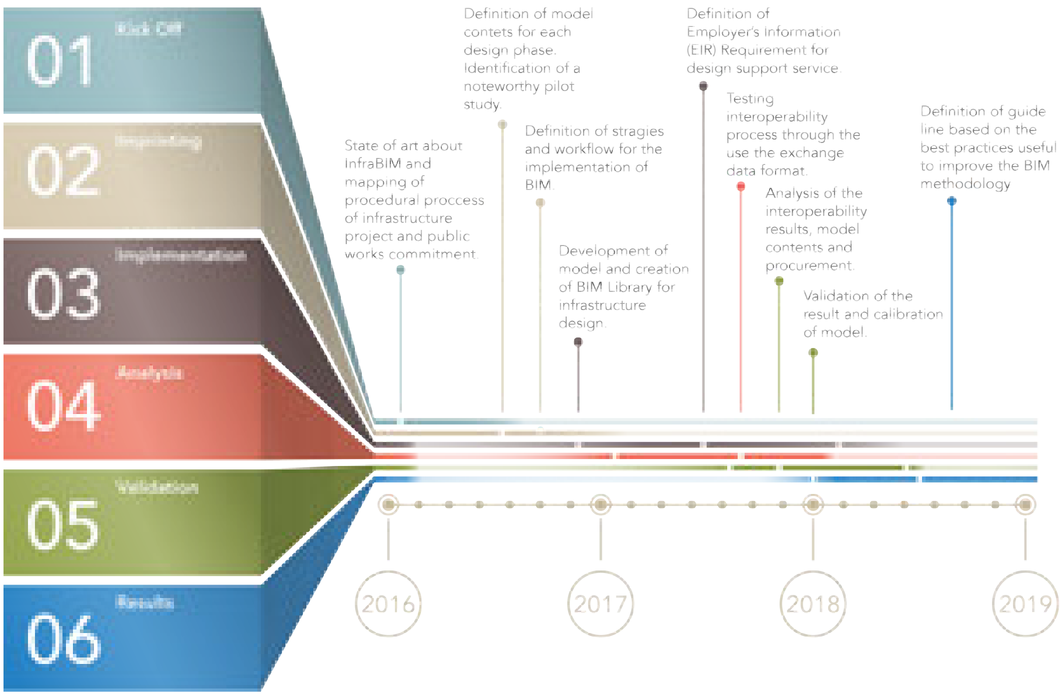


Fig. 3.1 Research Programme

The firs stage - *"Kick Off"* - aims to study the state of the art in terms of BIM for infrastructure projects, identifying best practices, case studies, international standards and guidelines. In this phase, the Contracting Authority's production processes for the project have been mapped, in order to understand what the main differences are between infrastructure and buildings projects, and later how to fit BIM processes into actual practice.

The results of this stage, in the first year, are:

- State of art about BIM .
- Definition of main problems and barriers about BIM adoption and implementation.
- Assessment of production processes.

- Definition of strategies and initiatives to overcome the main barriers

The second stage - *"Imprinting"* - at the end of first and at the beginning of second year of research, focused on the study of different Levels of Development (LOD) for each work stage, definition of BIM library contents, dedicated to infrastructure and testing of interoperability processes through the use of more data format knowledge exchange. At the same time, on the basis of noteworthy publications, different Employer Information Requirements (EIR) have been studied. The results of this stage should contribute:

- Definition of LOD for infrastructure field
- EIR for procurement of works and service modeling
- Creation of BIM Library dedicated to infrastructure
- Procurement procedure for *"Curva Carrai e Acquabona"*

The Third stage - *"Implementation"* - during the second year, was dedicated to development of an InfraBIM model, inside the Contracting Authority, in order to improve work-flows and process standardisation, by creating a system of quality to ensure the correct management of information for each work stage. The expected results are as follows:

- To obtain a BIM model with a LOD equal to definition phase;
- Accomplishment of BIM Libraries;
- Definition of procedure for information management;

The forth stages - *"Analysis"* - will aim to finish with tests on the interoperability process, providing standards and procedures for the data communication relating to different disciplines. In the same period, it will be possible to analyse the results obtained from the procurement process, and it will be necessary to define metrics capable of estimating and evaluating this first experiment.

The expected results will be:

- Analysis of results obtain from the first BIM procurement procedure;

- Enrich of BIM model in accordance to BIM LOD's and BIM Uses;
- Definition of the proper workflow for modelling activities;

The fift stages - *"Validation"* - will focus on Validation of the result and model calibration. Model calibration and loop of operation for testing the bi-directionality of the process and the capability to maintain the information updates while avoiding a lack of data.

The expected results will be:

- State of art about interoperability process;
- Definition interoperability process;
- Definition of appropriate IFC property set;

Finally, the last stages - *"Results"* - at the end of the research, will be dedicated to defining basic guidelines, standards and legal documentation relating to best practices during the research period. Moreover, it will be possible to have a clearer idea about the real barriers hindering the spread of BIM; but it will also be possible to evaluate the real benefits that international literature attributes to BIM methodology.

- State of art about BIM procurement and contractual framework;
- Definition of BIM requirements for Employer Information Requirement (EIR's);
- BIM procurement;

3.4 Research project methodology

The research methodologies proposed are based on exploration of the advancement of BIM adoption, standardisation needs and support systems, with a focus on the design management domain. The research strategy adopted aims a continuous build-up of results and knowledge about BIM standardisation needs and support systems. The methodological framework, shown in Figure 3.2, has been organized under formal steps: plan, do and reflect, as followed:

- Plan
- Execution
- Validation
- Results

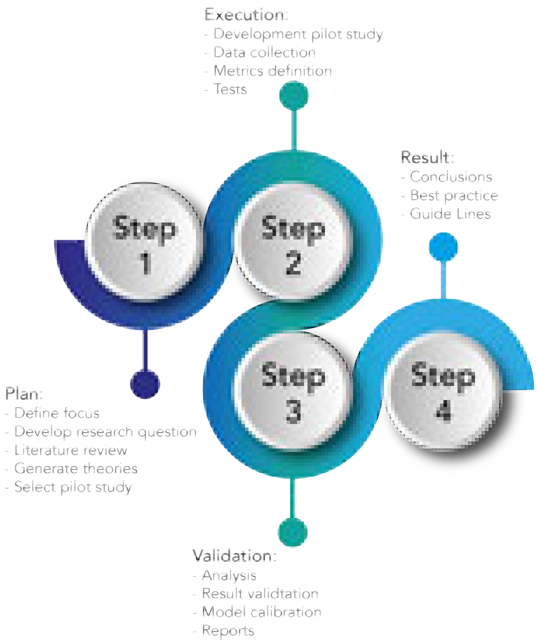


Fig. 3.2 Research Methodology workflow

The first phase - *"Plan"* - developed during the first year of research, was focused on defining objectives, research questions, literature review (international standards, guidelines and initiatives), selection of one or more pilot projects and identification of the main critical issues. The aim of this phase was to analyse the main international experience in terms of guidelines and standards to assist the transition from a CAD to BIM-based approach.

The second phase - *"Execution"* -was dedicated to developing pilot project, standardising information modelling management, according to the several disciplines involved in the different work stages. In this way, it was possible to map information in accordance with LOD and BIM Uses, thereby testing the interoperability process. The aim was to define the right exchange data format, to assure the integrity of information, avoid a lack of data, reduce redundancy and manual re-entering of information.

The third phase - *"Validation"* - was dedicated to report the findings obtained through pilot project were used to implement the existing body of knowledge and to validate the processes and standards, promoting implementation of BIM methodology.

Finally the last stage - *"Result"* - collects the main findings obtained during the research course. These can be used to provide best practice and expertise to continue the process of implementation and to estimate the level of maturity reached.

3.4.1 Literature research strategy

Before launching into the collection of the most relevant literature, it was important to consider and implement a project-specific scientific information management plan. The current body of international BIM literature has become very large with an increase in the number of publications. Many authors offer a different approach to carrying out a review of the literature, but given the variety of topics it is difficult to cover all aspects. Some studies propose different research frameworks. Cheng et al., for instance, authored a study that considers public sector engagement an essential factor to lead transition towards BIM adoption. The study identifies 14 countries/areas and collects data (including BIM programs, BIM pilot projects, BIM standards, annual BIM reports, online training information, etc.) from the official websites of each government body and non-profit organization of countries worldwide [43]. focuses on noteworthy publications such as guidelines, reports and visions related to BIM implementation in many countries such as Australia, Denmark, Finland, Netherlands, Norway, the United States, and a consortium of organisations in Europe. Wong [168] discusses the roles of the public and private sectors as major stakeholders in promoting and providing support for BIM implementation in Singapore, Finland, Norway, and Denmark. Wong et al. [168] conducted a comparative review of BIM initiatives taken in the United States and Hong Kong, including government policy, guidelines, standards, and implementation status. In the first issue of Solibri Magazine 2011, Jauhiainen (2011) presents three public sector BIM adoptions in Statsbygg, Norway, Senate Properties from Finland, and the General Services Administration (GSA) from the United States. Martin (2012) compares national BIM guidelines. Other approaches are based on the study of BIM implementation. For instance, Shou discerns 13 main BIM uses and on the basis of this criteria derives an assessment of the general BIM implementation level in practice at academic and industrial level [154]. Meanwhile, Bottari proposes an approach based on the study of BIM benefits to investigate how to improve BIM performance in Engineering Procurement Construction (EPC) contractors [38].

Fig. 3.3 Literature research

Given the plurality of topics that will be addressed in this research project, the strategy adopted to construct the literature review of this research work begins to define research fields, derived from thesis objectives. As is visible in Figure 3.3, six main research areas have been identified, useful for creating a valid knowledge base for each topic. Once the field of application was defined, initial preliminary research led to the collection of a considerable number of publications, as reported in Table3.1,The database used are *ASCE library,* *Elsevier Science, Taylor and Francis, IEE Explorer, Spriger, Scopus, Google Scholar.*

Table 3.1 Literature survey

Topics	Number
BIM	387
BIM AND Adoption	8
BIM AND InfraBIM	62
BIM AND Contract Management	21
BIM AND Interoperability	14
BIM AND National Standard	46
BIM AND Construction Management	7

Starting from general research carried out on the acronym BIM, the number of search results was very high. Moreover, BIM has multiple connections with a broad range of disciplines in different sectors such as: Architecture, Construction, Civil Engineering, Information and Communications Technology (ITC). For this reason, it was decided to apply a research strategy based on the search topics, later reduced to keywords, shown in Table 3.1.

Chapter 4

Regulation context

This chapter aims to illustrate the context of Italian regulations in order to fix the research perimeter. Since the publication of European Directive (EU Directive 24), BIM may be requested by member states for public works contracts and design contests. The provisions of this directive were adopted by Italian regulations within the new contract code as set out in Legislative Decree no. 50 in 2016. The introduction of BIM into the new contract code by Italian regulations aims to improve the digitization process required by the European Commission. Then, with publication of Ministerial Decree 560 in 2017, the government introduced mandatory use of BIM from 2019, with an expected impact on public procurement. Finally, this chapter aims to present the impact of BIM on ANAS and the initiative expected to address this transition. transition.

4.1 Italian regulation

After the publication in 2014 of EU Directive number 24 [80] up until 2016 the Italian government did not define a program of adoption, leaving the initiative up to individual firms or groups of associations such as OICE (Engineering and Economical Consulting Organizations) or ANCE (National Association of Building Constructors), without any obligation or legal framework regulating BIM services (Figure 4.1). A first step towards BIM integration in the public sector came in 2016, when the Minister of Transportation and Infrastructures

Infrastructure published Legislative Decree no. 50 of 18th April 2016, which states:

"Public contracting authorities may require [...] the use of specific electronic methods and tools, such as building and infrastructure information modelling tools. These tools use interoperable platform through the use of open data format and not proprietary, in ordet to avoid to limit the competition between technology suppliers and the involvement of specific projects among the designers. The use of electronic methods and tools can only be requested by contracting authorities employers with adequately trained ... ".[132]

The decree underlines two main aspects. The first is the use of open data format to share information, while the second is that the use of BIM can be required by public contracting authorities if they have employers who are adequately trained. A short while after publication of Legislative Decree no. 50, the UNI (Italian Standards Institution) published a set of technical national standards and contract protocols, to develop a regulatory framework for BIM implementation by professionals in the construction sector, in order to support the spread of BIM methodology.

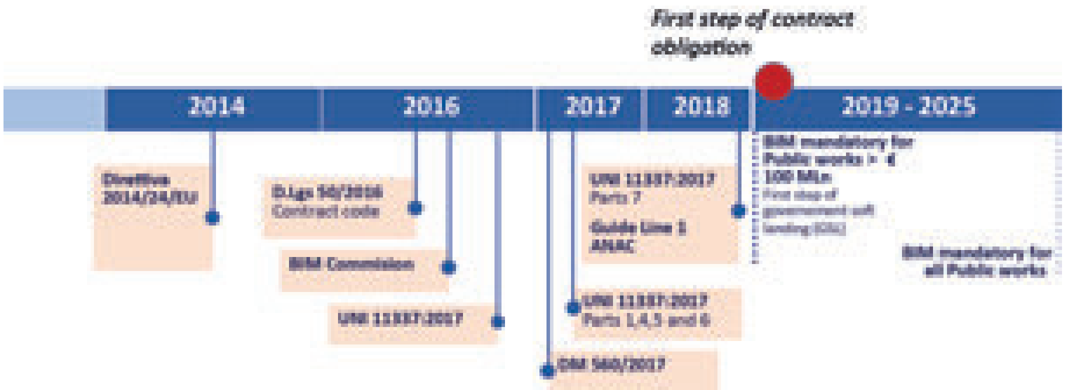


Fig. 4.1 BIM Adoption Road Map

At the end of 2017, in order to give a boost to the ministerial committee's work on spreading BIM adoption in the public sector, Ministerial Decree no. 560 of 1 December 2017 was published. The Decree calls for a plan of mandatory progressive BIM requirement, starting from 2019 for works worth over `€ 100 million, up until 2025 for works under `€ million (Figure 4.2).

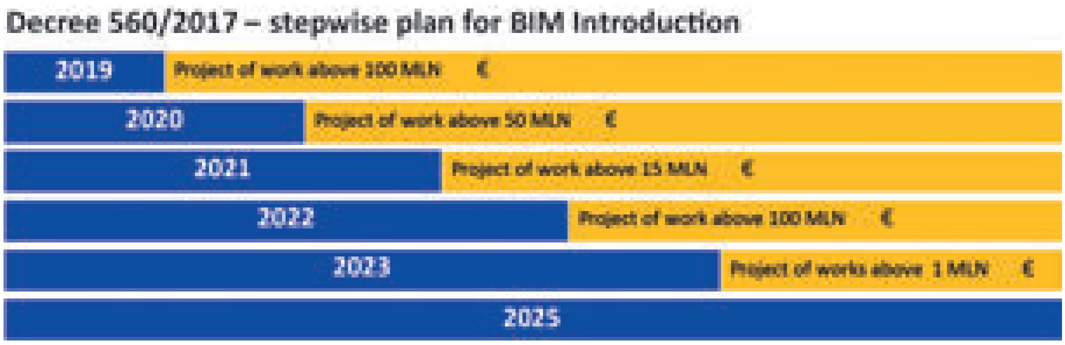


Fig. 4.2 Stepwise plan for BIM introduction

Furthermore, the Decree established other obligations to prepare the contracting authority to manage projects developed using BIM methodology. Articles 2, 3 and 7 of Ministerial Decree 560/2017 state that the use of BIM for public works is subject to the adoption of preliminary actions, as shown below:

- A training plan for employers;
- A plan of acquisition and maintenance of hardware and software;
- An organizational act that clarifies the control and management process, the data and the clash management [1];
- The mandatory use of open exchange data format to communicate and publish the digital project;
- The definition of Contract documents for tender phase, such as the Employers Information Requirements (EIR), to define informative requirements, LODs and all those elements essential to the production, handling and transmission of BIM contents;
- The acquisition of a Common Data Environment (CDE), a digital environment capable of managing and collecting project data, where data sharing is regulated by systems of cyber-security, tracking and versioning of changes;

[1] The organizational act can be transponse by Contracting Auhtorities how the creation of a proprietary BIM Guide. Document aims to explain the process, the workflow of project inside the CDE system, roles and responsibilities.

Finally, Art. 9 of Ministerial Decree 560/2017 states that the decree applies in a compulsory manner to projects whose preliminary design has been activated after the date of entry into force of the decree. Surely, this article will have a dual effect, by avoiding burdening Contracting Authorities with huge efforts in order to transform their structure, while taking into account the Italian scenario, consisting of medium-small Contracting Authorities. On the other hand, the regulator aims to avoid the process of translating traditional projects into BIM projects, by changing contractual agreements, and thereby running the risk of facing legal claims.

4.2 ANAS BIM landing

ANAS, as the most important Contract Authority in Italy, manages around 29,223.270 [Km] of road as shown in Table 4.1. In 2018 ANAS made a net profit of €2.4 million, with revenues of € 2.046 billion, and this year it expects revenues of €1.166 billion. These figures are extremely important and they position ANAS as the main stakeholder in the civil sector. ANAS, as Owner, is responsible for the management and maintenance of a huge amount of assets and for this reason it has a favoured position as a prime mover in the civil sector, having the strength to influence the market, and leading a necessary innovation in the construction sector. Nevertheless, as reported by the European Construction Sector Observatory [77], Italy has historical structural problems in the construction sector, due to late payment by Public Administration (PA). Also in the innovation sector, Italy is classified as a Moderate Innovator. Compared to the EU average, Italy under-performs in venture capital investment, in private co-funding of public RD expenditures, and in License and patent revenues from abroad [77].

Table 4.1 ANAS road assets

ANAS assets	**[Km]**
Motorway directly managed	939,354
Motorway junction	355,101
State roads	22.247,531
Roads in course of classification or declassification (NSA)	777,634
Interchanges and coplanar	4.903,650
Total	29.223,270

The introduction of BIM in public works seems to offer an opportunity to boost the uptake of innovation in the construction sector, by digitizing the process. ANAS, ahead of publication of Ministerial Decree 560/2017, began working on BIM implementation in 2016, when as part of PMO activities, ANAS introduced activity no. 27, called *"Avvio BIM"*. The main objectives of PMO activities was to provide ANAS with a plan of implementation and the structure of contractual documents, employers and tools able to ensure the correct management of projects conducted using BIM methodology. The budget allocated to develop this activity was €400,000.

From 2016, ANAS decided to activate different partnerships with private and academic centres such as the Polytechnics of Turin and Milan, in order to acquire knowledge and support in this complex process of change. The universities provided their knowledge about BIM methodology, processes and standards, while the companies provided support for the introduction of a new methodology within the company and in public tenders.

Fig. 4.3 Anas Polito partnerhip

The results of this partnership are many, as shown in Figure 4.1, starting with the definition of contractual documents like EIR for sub-contract work, engineering and architecture services and support services. These documents are essential to define the requirements to develop BIM projects from a technical point of view and regulate the relationship between supplier and CA. The produced EIRs were published as part of a framework agreement for engineering and architecture services worth a total of `€ 240 million.

Subsequently, in 2017, the first public tender for works was published by ANAS *SS-12 Curva Carrai e Acquabona"*. IIn this case, the contractual prevalence was the traditional project and not the BIM model that was attached to tender documentation. The strategy to use the BIM model as a contract element was adopted to avoid claims, due to the lack of maturity in BIM public procurement in early 2017. After this, the implementation process suffered a slow-down, which finished at the end of 2017, when MIT published Ministerial Decree 560/2017.

According to Ministerial Decree 560/2017, the BIM implementation process was focused on legal requirements, in order to be ready for 1 January 2019, when the use of BIM will be mandatory for public works worth over `€ 100 million. The first step in this direction was to create BIM guidelines tailored to the needs of ANAS. The document explains, at company level, how to manage the project, relations between ANAS and suppliers according to the approved workflow for BIM projects, defining roles and responsibilities towards new figures such as BIM Manager, BIM Coordinator, BIM Specialist and BIM Modeller. Furthermore, the BIM guide provides recommendations regarding the Work Break-down Structure (WBS) and model or sub-model coding. In parallel, ANAS started drafting the Training Plan for employers and the Hardware and software plan, published in mid-2019.

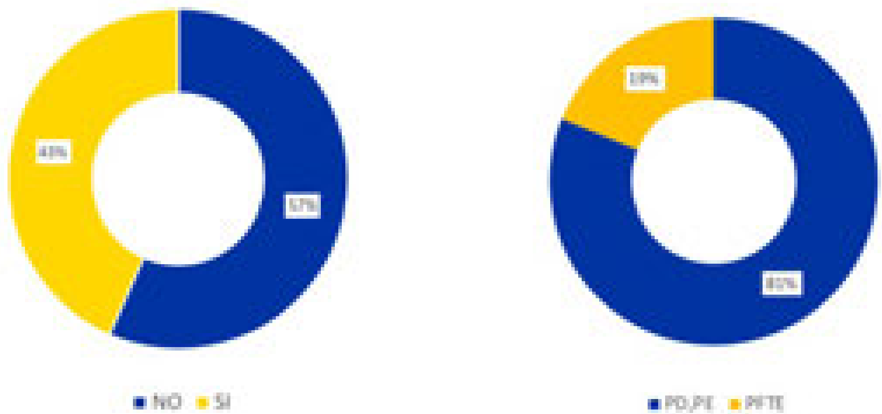
Having satisfied legal requirements and developed a CDE, several projects included in the contract program subject to DM 560/2017 are going to develop as pilot projects to test the strength of BIM Guidance and the EIRs, and they are still under development.

Taking into account the state of the art about exchange data format and regulation, ANAS decided to enter into association with the likes of UNI, IBIMI the Italian chapter of Building Smart as the interested stakeholder for the development of specific parts of Italian regulations, and in order to boost Italian BuildingSmart needs to make up the IFC format gap for the classes relating to civil works (IfcRoads, IfcBridge, etc.).

Fig. 4.4 Anas BIM Approach

4.3 The impact of BIM on ANAS

After the publication of Ministerial Decree (M.D.) 560/2017, it can be said that the time horizon of BIM implementation within ANAS is changing. According to the program contract for the period 2016-2020, mandatory projects will increase year by year, as can be seen in the chart below. From the data derived from the last contracts monitored, the greatest impact on ANAS will be start from 2020, when the mandatory threshold will be reduced for works over € 50 million and so on. Out of a total of 137 contract program projects in the period 2016-2020, almost half require mandatory BIM, as shown in Figure 4.5, Of these projects, around 19% are preliminary designs (PFTE) and 81% are definitive/executive designs. Observing the annual trend reported in Figure 4.6 it is possible to notice an exponential increase in the number of projects from 2019, where mandatory projects are almost zero, and then move from just over `€ 200,000 in 2020 to almost `€ 2.5 million in 2022 [1]. As is visible, it is estimated that the trend in 2022 will see BIM projects exceeded compared to traditional ones.



(a) Project monitoring for BIM mandatory (b) Project level for BIM mandatory

Fig. 4.5 BIM contract program screening

[1]The value are referred to amount of works on the amounts financed by the 2016-2020 program agreement

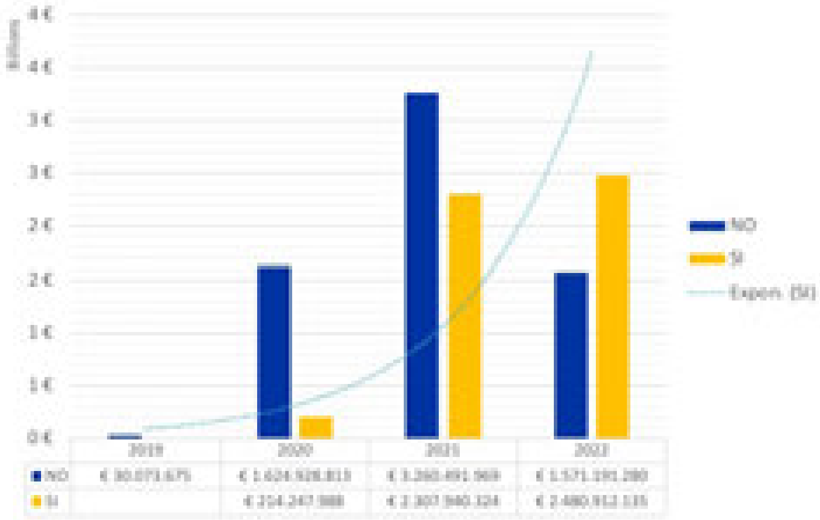


Fig. 4.6 BIM Anas projects manadatory

In the last chart, shown in Figure 4.7, , it can be seen how most of the projects that will necessarily require the use of BIM will be concentrated in central and southern Italy. This is largely due to recent events involving this area and a request to complete and modernize current transport assets, as mentioned in Chapter 1 above.

Fig. 4.7 BIM Mandatory for Area

Chapter 5

BIM Framework Adoption

This chapter aims to describe activities promoted to implement BIM methodology in ANAS. Starting from the analysis of international experiences about BIM Adoption, the aim is to define an appropriate framework to perform the development of BIM projects within a contracting authority, providing a process and identifying a Point of Adoption (PoA) on the basis of the BIM maturity level established. The digital transformation incurred with BIM adoption requires new workflows, new standards, new tools and figures, that have to be inserted within an organizational structure. Therefore, in order to illustrate the research activities carried out to deal with this change management process, this chapter presents the organizational provisions proposed to convert the current process into a BIM-oriented process.

5.1 BIM Adoption

According to the roadmap, during the Kick Off phase, the current "as is" process has been mapped, in order to understand how to manage the progressive introduction of BIM. In this phase, it is essential to define a Technical Adoption Model (TAM) [143] [93] to support the structure in identifying an appropriate PoA to overcome the obstacle of the transition from a pre-BIM to Modelling stage. The PoA is the point at which, after a preparation period,the organization transforms into organizational capability/maturity, successfully adopting object-based modelling tools and workflows [160]. Therefore, can be seen in 5.1, the

PoA has been established at the end of the analytic phase, in order to overcome problems of collaboration design, where the interoperability process is not efficient enough to allow real BIM integration. Despite the immaturity of BIM application, it should be possible to generate a BIM model providing information useful for subsequent work stages.

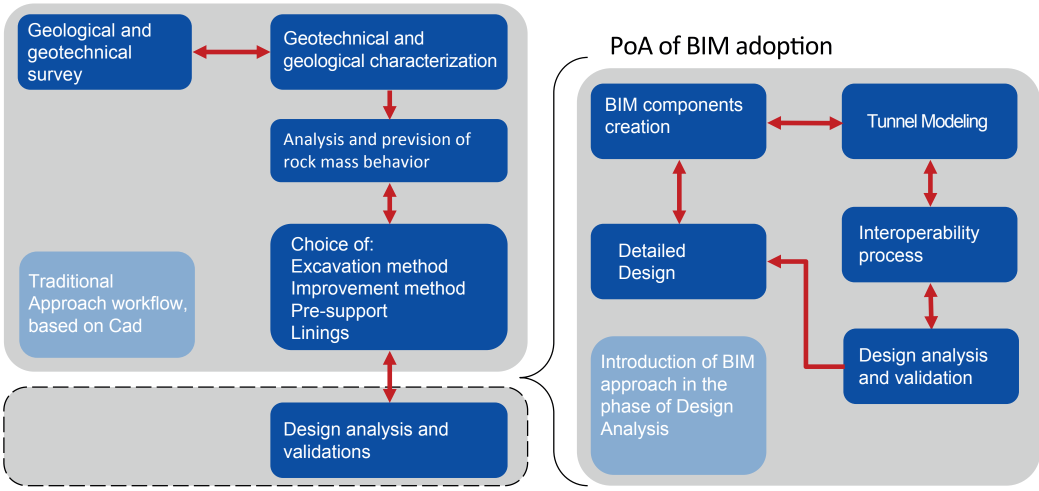


Fig. 5.1 BIM Implementation - Point of Adoption

5.2 As-is Process Mapping

The preliminary phase analyses the internal process based on a traditional approach. The infrastructure project involves several disciplines such as Geology, Environmental, Geotechnical, Hydraulic, Cartography, Cost estimates, Interferences, Roads, MEP systems and so on. The process to design an infrastructure begins with the identification of the project area and the with analysis of best corridor solution, drafting road alignment on cartographic data.

The road corridor is the main item of information because it is an input for other disciplines involved in the process. During the road design process, it is necessary to evaluate information, limitations and restrictions coming from other disciplines such as Geology, Environmental and Hydraulics. In fact, as can be seen in Figure 5.2 these disciplines provide information about boundary conditions, and project restraints, that are essential for development of the corridor project. Once the road corridor is finished, details are exchanged with other disciplines. Starting from the road corridor each disciplines integrates the project with their specific output production. In this phase it is possible to observe how the work is divided among the different offices and each discipline works separately until the delivery.

TA lack of collaboration and checking analysis often produces errors due to the delay or lack of information exchange, consequently requiring re-design of the project. Thus, each discipline returns their output to the Roads discipline, which has the task of unifying all the project data in a single file and improving alignment with the other work. At the same time these outputs are exchanged with the Estate and Interference disciplines, in order to obtain the cost estimation and interference control with service networks such as gas, oil, water, electric and so on.

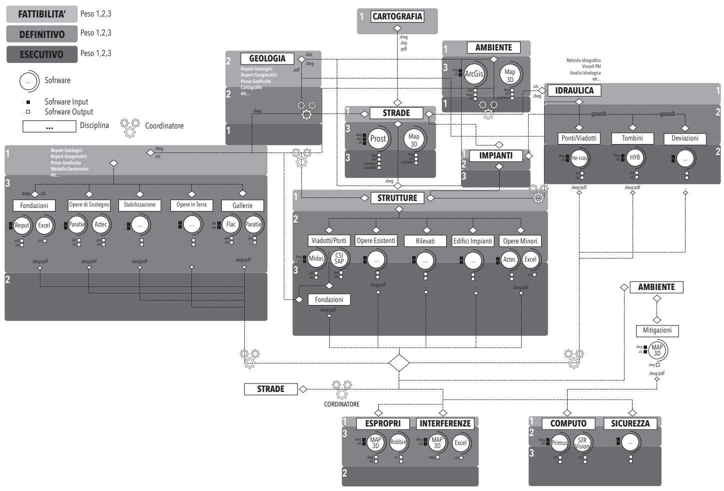


Fig. 5.2 As-is Process mapping

The current workflow shown in figure 5.3,reflects the organizational structure of the management department. In fact, Workflow mapping is related to the areas, known as *Coordinamento Nuove Opere (CP)* behind the management department *Direzione Progettazione e Realizzazione Lavori (DPRL*. The *As-is* organization structure is structured into a business functional unit model. This structure is typical of wider organization, where each unit is responsible for different aspects of projects. The advantages of this structure are the maximization of technical know-how, the fact that employers may work on different projects simultaneously, and finally the fact that budget responsibilities are clearly partitioned within each division. Points of weakness are the lack of cross functional horizontal coordination and integration among the different disciplines, resulting in hierarchical communication and fragmentation of responsibilities across the area [58].

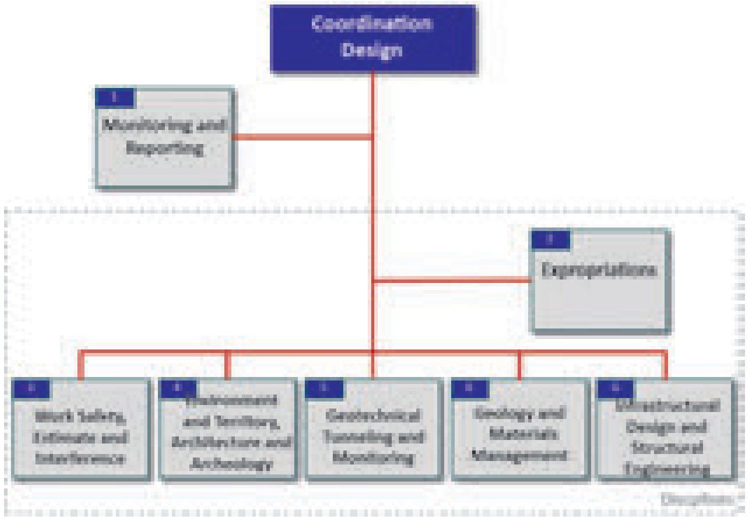


Fig. 5.3 Coordination and Design office structure

The next phase - the as-is mapping process - was described in order to point out project development according to the design stage. As the Contracting Authority, ANAS follows two main project development methodologies: i) Design in outsourcing ii) Internal Desing with external support. These two methodology depicted in Figure 5.4 and Figure 5.5 (Appendix A.1, A.2) were mapped to re-construct project realization, including those offices involved in the authorisation process. Nevertheless, it is important to emphasise that those maps were related to CP areas and they did not include the communication phase with other ANAS management or ministerial offices. This is due to the aim to simplify the map, in order to re-design these process in a BIM-oriented manner.

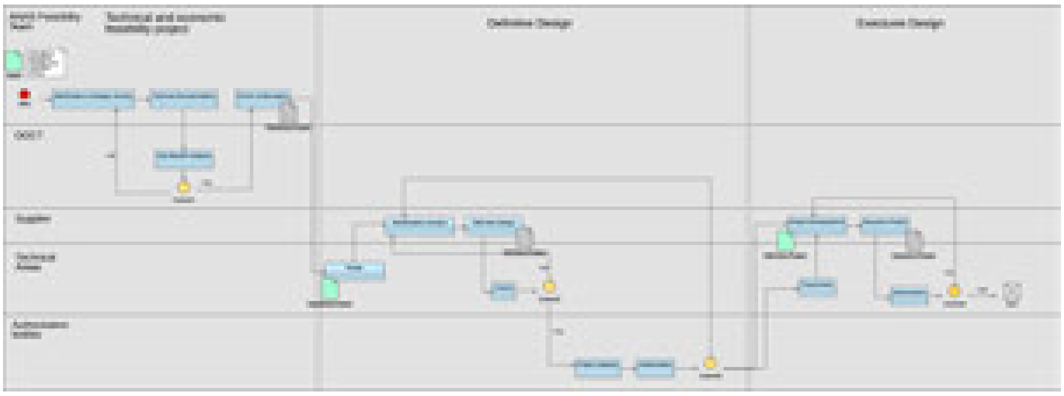


Fig. 5.4 As-is process with Design in outsourcing

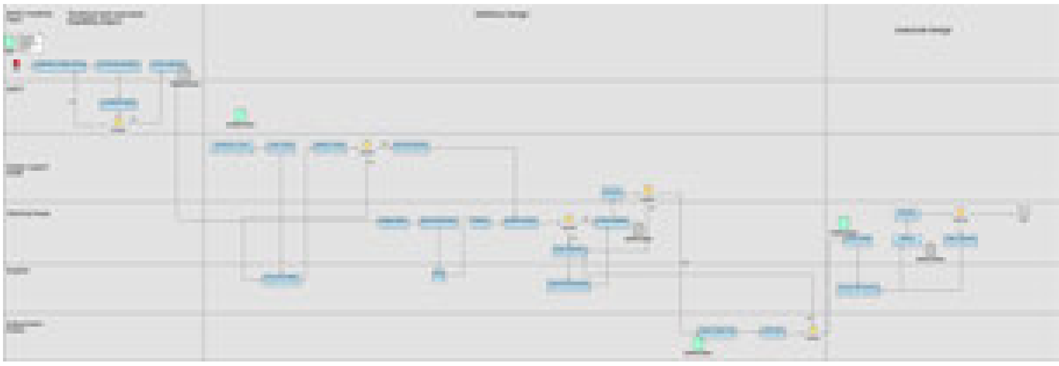


Fig. 5.5 As-is process with internal design and support srvices

Finally, the last step in this section was to conduct a survey of software currently used in the CP, in order to understand the type of software architectures used and whether or not they are compliant with the BIM environment and with the IFC format. This was essential in order to prepare the Plan of Hardware and Software acquisition required by M.D. 560/2017. The software survey, shown in Table 5.1, indicates that most software currently in use is not BIM-compliant, with a wide range of basic CAD applications and little use of GIS software. Furthermore, few applications were IFC-compliant and therefore it is possible to notice the lack of a CDE. This survey gives an overview of IT status, providing information useful for estimating the substantial investments that will have been committed by ANAS.

Table 5.1 Software identification

Discipline	Software	Data Input	Exchange Format	Data Output	BIM Complaint	IFC compliant
Cartography	Map3D	.dwg, .shp, .tif, etc.	.dwg	.dwg, .pdf, shp, etc.	no	no
	Word	.doc	.doc, .pdf	.doc, .pdf	no	no
Geology	Map3D	.dwg, .shp, .tif, etc.	.dwg	.dwg, .pdf, shp, etc.	no	no
	Word	.doc	.doc, .pdf	.doc, .pdf	no	no
Environment	Map3D	.dwg, .shp, .tif, etc.	.dwg	.dwg, .pdf, shp, etc.	no	no
	Excel	.xls	.xls, .pdf	.doc, .pdf	no	no
	Arcgis	.shp, .dwg	.txt, .dwg, etc	.shp, .dwg, .pdf	si	no
Hydraulic	Hec-Ras	.shp, .sdf, .txt., xml	.xml, .txt	.shp, xml, .xls	si	no
	HY8	.xls, .dwg	.txt, .xls	.dwg, .pdf	no	no
	Map3D	.dwg, .shp, .tif, etc.	.dwg	.dwg, .pdf, shp, etc.	no	no
Road	Map3D	.dwg, .shp, .tif, etc.	.dwg	.dwg, .pdf, shp, etc.	no	no
	Word	.doc	.doc, .pdf	.doc, .pdf	no	no
Geotecnique	Hec-Ras	.shp, .sdf, .txt., xml	.xml, .txt	.shp, xml, .xls	si	no
	HY8	.xls, .dwg	.txt, .xls	.dwg, .pdf	no	no
	Map3D	.dwg, .shp, .tif, etc.	.dwg	.dwg, .pdf, shp, etc.	no	no
Structure	Hec-Ras	.shp, .sdf, .txt., xml	.xml, .txt	.shp, xml, .xls	si	no
	HY8	.xls, .dwg	.txt, .xls	.dwg, .pdf	no	no
	Map3D	.dwg, .shp, .tif, etc.	.dwg	.dwg, .pdf, shp, etc.	no	no
System						
Valuation	Map3D	.dwg, .shp, .tif, etc.	.dwg	.dwg, .pdf, shp, etc.	no	no
	Word	.doc	.doc, .pdf	.doc, .pdf	no	no
Expropriation	Map3D	.dwg, .shp, .tif, etc.	.dwg	.dwg, .pdf, shp, etc.	no	no
	Word	.doc	.doc, .pdf	.doc, .pdf	no	no
Interference	Map3D	.dwg, .shp, .tif, etc.	.dwg	.dwg, .pdf, shp, etc.	no	no
	Word	.doc	.doc, .pdf	.doc, .pdf	no	no

5.3 To be Process Definition

After mapping the *"As-is process"*,it was necessary to re-design the process according to BIM methodology, in order to facilitate collaboration and sharing of information among the different disciplines. As mentioned before in this dissertation, the adoption of BIM in a public company like ANAS, does not involve only the field of technology or IT, although these components could represent the main aspects requiring attention. However, according to Succar [159] successful BIM implementation depends on conducting the necessary organizational changes [120], improving work practices and the skill of project participants [84], drafting policy deliverables and indicating the main rules guiding decision-making. Policy deliverables have a direct impact on the delivery process of models, drawings and documents and also on the definition of roles and responsibilities of the main actors involved. Thus "...such roles, evolving from new business models, carry specific responsibilities that never existed before BIM and are closely tied to project and design management domains.

Their remit often includes policing new requirements to ensure information and process standards are applied in project team participants' work..." [98].

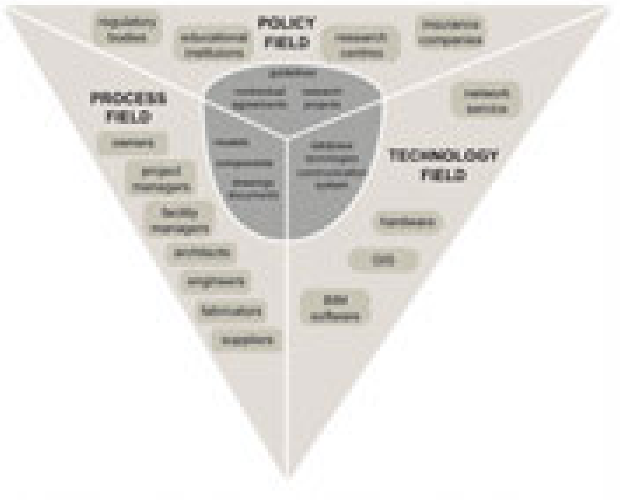


Fig. 5.6 BIM implementation domains

BIM innovation, like other types of IT innovation, should be able to create economic value, in terms of efficiency, reduction of costs and greater market competitiveness, under certain conditions, relating to the creation of new forms of organizational capital and re-shaping of their business processes [40].

The *"To-be"* workflow, shown in Figure 5.7 compared to the *As-is* workflow, considers the project as a data set of information, relating to development the whole project. All disciplines involved have the duty to improve asset knowledge, merging all information into a unique model; it is thus more advisable to introduce the concept of *Project Information Modelling*, (PIM).

In the PIM structure shown in Figure 5.8 (Appendix A.3) all disciplines involved in the project share information, collecting data into a database. Then, thanks to the Interoperability process, which will be described in section 6.5,it will be possible to exchange an appropriate set of data for each discipline on the basis of BIM use, defined by the project objectives. In this way, it should be possible to preserve all information, ensuring reliability, efficiency, feasibility and easier, up-to-date management, while at the same time reducing the probability of errors due to a lack and/or an excess of data and/or the manual re-entering of data.

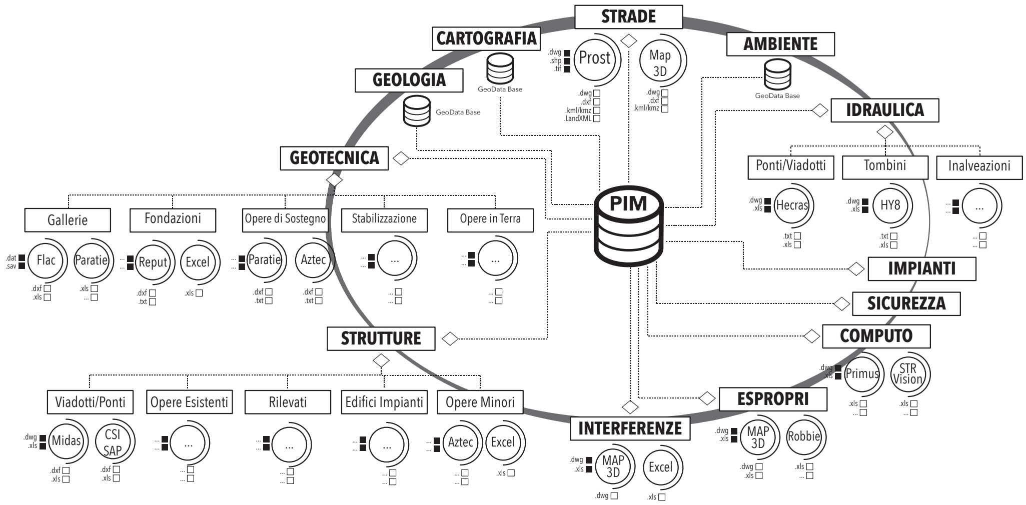


Fig. 5.7 To be process definition

On the basis of workflow diagram, the organization process has been redesigned in a BIM-compliant manner, taking into account the organizational steps that have to be followed by a project developed using BIM methodology. In the diagram shown in Figure 5.8, rather than the as-is process, for the outsourcing project that uses support services, new roles have been introduced in the process. Beyond tradition technical areas, an ANAS BIM manager has been inserted to validate the BIM model, achieved by means of information accuracy, interacting with the BIM coordinator and BIM specialist, and at the end changing the status from L0 to C0. The project may be published only after the double check approved by the BIM Manager and Project Manager that validate the project from an engineering point of view. The presence of the BIM Manager and Project Manager may be considered an additional step that might cause delays. Nevertheless, in this preliminary phase ANAS decided to maintain both roles for a period of adaptation to the new workflow and taking into account the time required for training.

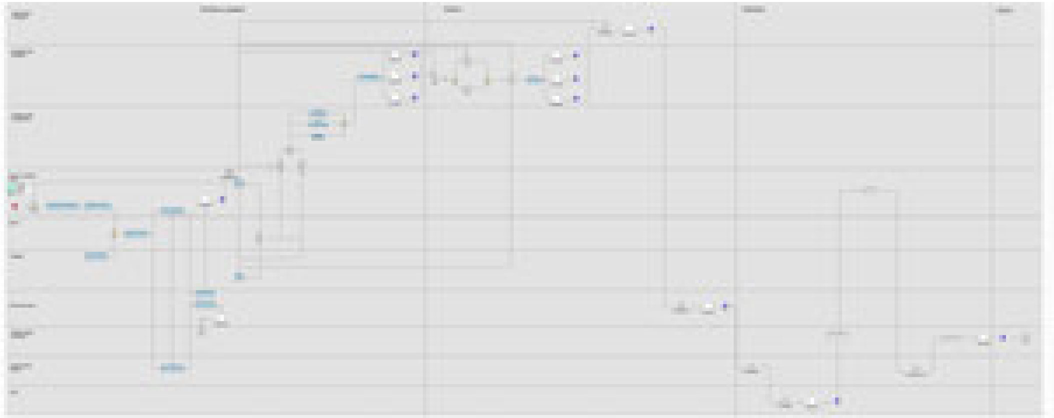


Fig. 5.8 To be process for outsorsicing

The new process requires new roles and knowledge, according to UNI 11337 part 6 [49] and BS PAS1192. Each of these new figures has roles and responsibilities defined within the ANAS Guidelines. In addition to the figure proposed by UNI 11337 part 6, two new figure have been inserted in the organization - *BIM Strategy Manager* and *BIM IT Architect* . The former has a horizontal role in the process and does not deal directly with project development, but is involved in the monitoring of BIM projects, in order to evaluate workflow, standards, knowledge, and process points of weakness. He has an overview and has to provide future steps for innovation, by promoting activities, policies and standards at company level. The latter operates always at company level and not on individual contracts, his tasks are related to management and organisation of the CDE area on the basis of contracts and to maintain hardware and software procurement. Furthermore, he has the task of proposing custom solutions such as API to improve software integration with other Public administration applications.

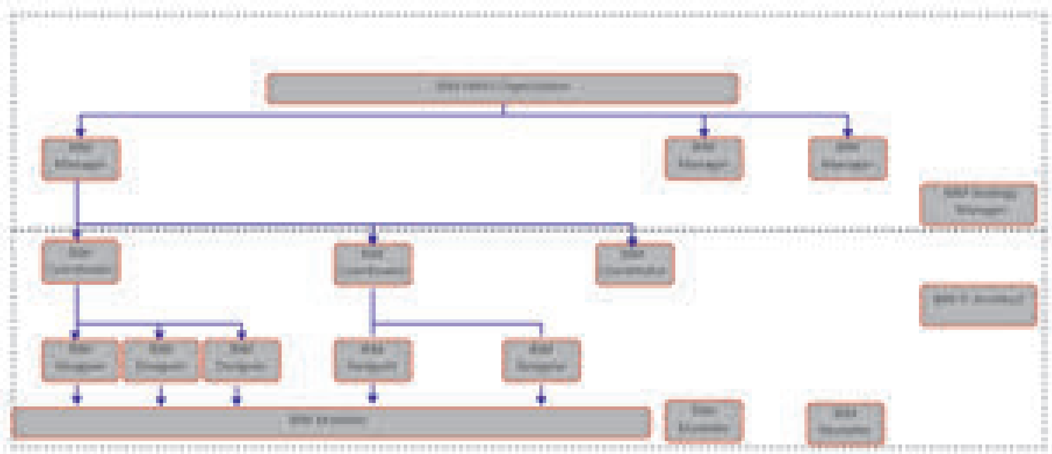


Fig. 5.9 BIM role

IIn conclusion, according to M.D. 560, article 3, requiring Contracting Authorities to perform an organizational act where control and management processes, data owners and clash management are explicitly defined. In a sense, this specific article of the M.D. may be read as the definition of a Guideline tailored to ANAS. The process of change management has to overcome many obstacles, deriving from a resistance to change.

Chapter 6

InfraBIM

This chapter aims to illustrate InfraBIM workflow, identifying the main aspects that differ in BIM applications for civil and building design, by examining the literature related to the main topics, such as: BIM uses, parametric libraries, LOD and information exchange. Moreover, the chapter aims to provide a workflow to organize information between the disciplines involved through the definition of appropriate BIM uses, lod and information exchange.

6.1 From Building Information Modeling (BIM) to InfraBIM

Infrastructure projects involve considerable interaction between geospatial contexts and physical elements according to standards and constraints. The application of BIM in this sector aims to create value in designing transport infrastructure, management and control of the entire project, and increases profits and optimal results, as mentioned in 2.1. Furthermore, in the early stages, GIS environment plays a key role in site analysis and in the evaluation of the environmental context. Thus, both GIS and BIM solutions support infrastructure projects on various scales and at all stages, including planning, building, management and maintenance [72]. However, exploitation from building to infrastructure applications, also ddepends on the adaptability of processes and software tools. Compared to building projects, the application of BIM in infrastructure projects includes management of complex facilities composed of several parts such as roads, tunnels, channels, networks, buildings, earthworks and so on, involving multiple actors such as: design offices, manufacturers, builders, public administration [166]. In addition, the convergence of several scales of representation from territory to building scale make information flow difficult not only between disciplinary areas but especially from one representation scale to another. Furthermore, the wide extension of a linear infrastructure leads to additional critical issues such as the digital dimension of files and the proper management of geographic data [117] [92].

Linear infrastructure projects involve several disciplines and a large amount of heterogeneous data. Thus, an infrastructure BIM dataset may be composed of different models, each coordinated and contributing to enrichment of project knowledge [81]. As can be seen in Figure 6.1 the InfraBIM dataset may include several models such as:

- Survey model
- Ground surface model
- Utilities model
- Geological surface models
- Network and route models (traffic or water modelling)
- Environmental model
- Land-ownership model
- Alignment model
- Continuous linear entities model
- Linear component model
- Utility and drainage network model
- Structural models – bridges, tunnels and retaining walls
- Building models – structural, architectural, M&E

TThis list is not exhaustive, but it is useful to point out the complexity of BIM application in Civil projects. It follows that at the moment there are no applications present on the market that are capable of managing all the disciplines required to address the world of infrastructure [81]. According to Guo [91], iit is necessary to introduce an integrated management approach to assist transportation agencies in improving the management and maintenance of their assets. In this context, the Federal Highway Administration, American Road & Transportation Builders Association, American Association of State Highway and Transportation Officials, and the Associated General Contractors of America (FHWA, AASHTO, ARTBA, & AGC) [91] coined the *"Civil Integrated Management"* (CIM) [146] [91] [171] a term relating to the collection, organization, managed accessibility, and use of data and information throughout the entire lifecycle of a transportation asset [91]. Other studies defined BIM for civil works as *"Horizontal BIM"*,*"Heavy BIM"* [126] or *"I-BIM"* [Dell'Acqua]. Later in this dissertation, BIM for civil design has been named *"InfraBIM"*, as the system to manage geometrical data, properties and information integrating BIM and GIS platforms to perform design efficiency as proposed by Cho et al., exploiting BIM possibilities for tunnel design starting from the definition of a standard BIM library[45].

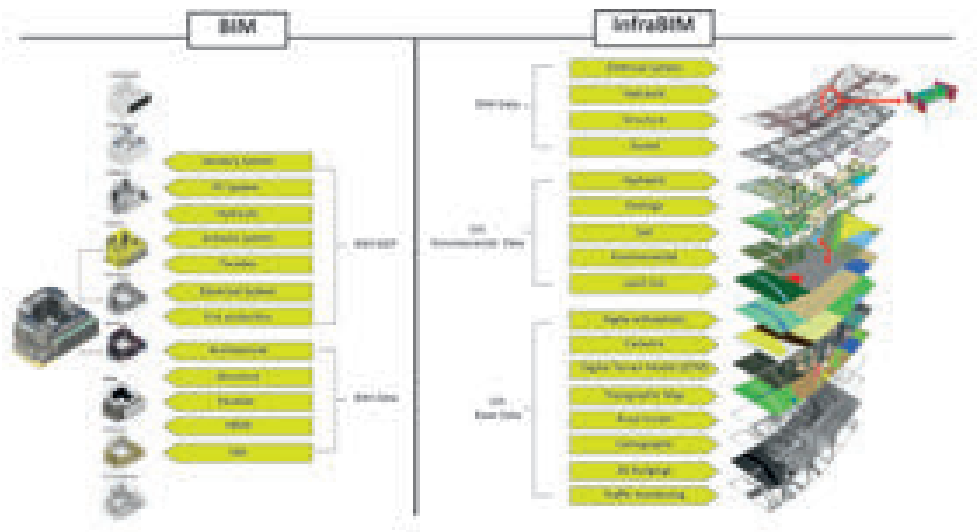


Fig. 6.1 Comparizon between BIM for Building and BIM for Infrastructure

6.1.1 InfraBIM Workflow

The conceptual workflow proposed, as shown in Figure 6.2 is based on several service providers, contain information related to GIS, BIM, Sensor Information Modelling (SIM) and Facility Management (FM) domains. These domains are essentially relational databases, that share information among the different disciplines and then through an appropriate exchange data format, adding to a central database that collect all this information, named Project Information Modelling (PIM). The PIM is stored on a CDE platform, containing the entire digital project, not only the information model but also the technical drawings, cost reports, analysis reports and so on. Although BIM in the civil field has to manage information at different and more extended scales. In fact, infrastructural projects involve a wide area, requiring an approach composed of multi-scale models. They are characterised by a top-down approach in which, starting from a linear representation of the path, a continuous improvement of information and scale is achieved [32].

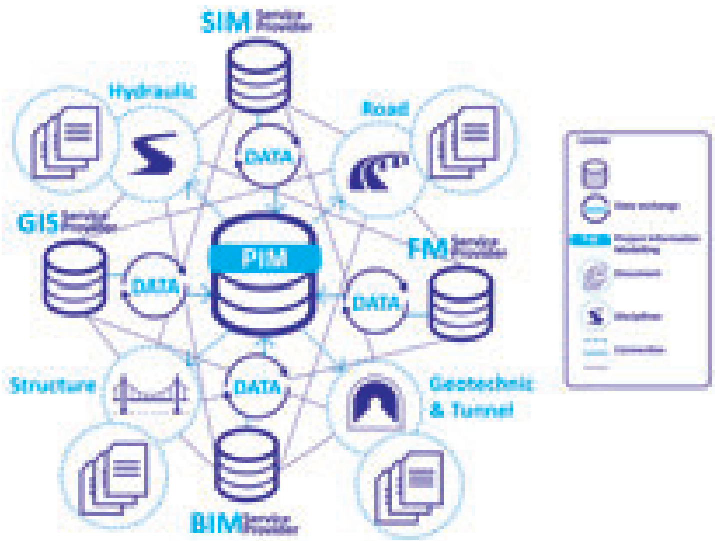


Fig. 6.2 InfraBIM Workflow

The implementation of BIM in the field of infrastructure, is one of the fundamental and most innovative aspects especially for the AECO sector, for the management of data from territorial scale to construction scale. At the moment, especially in various project proposals, design phases are evaluated according to different criteria, such as: environmental impact, environmental constraints, hydro-geological aspects, etc.. Even if the main parameter in the selection is ultimately the income statement, which overwhelmingly determines the choice of the best route to use. Usually, analysis data collected from surveys and other documentation are given in different types of scales and formats, often originating from inter-dependent sources [149].In order to improve information aggregation, Borrmann et al. proposed a multi-scale model approach, to organize model definition and representation scale. This is particularly important at the planning phase, where the study area is very wide. Nevertheless, currently, representation and data exchange in support of multi-scale modelling is very limited [35]. Mekawy proposes a bi-directional approach through mapping between IFC and CityGML, in order to create an integrated urban model, defined "unified building model" (UBM), capable of gathering information both on the urban scale and on the building scale [69].]. In Hijazi, we try to integrate the urban model with the data relating to the building utilities [97]. Meanwhile, Tolmer et al. introduced the Conceptual Data Model (CDM), an approach to integrate information for infrastructure design, based on an object-oriented model such as Unified Modelling Language (UML) [165]. Nevertheless, one of the main problems is to adapt a part of the applications, created for vertical to horizontal modelling. Another aspect concerns the geometrical dimension which, as far as the building is concerned, is substantially enclosed in the building's imprint on the ground. Meanwhile, InfraBIM has to manage projects that can be many kilometres in length, and consequently, the horizontal dimension becomes prevalent and this involves management of the facility on the territory. The interaction between facilities and environmental context takes on a central role in the development of the project. It involves analysis at different scales, promoting the integration of GIS, and BIM data for effective asset design. For this reason, interoperability process plays a key role in InfraBIM workflow. The exchange process is even more complex given the heterogeneity of data passing from a territorial and constructive scale. Therefore, the use of multiple exchange data formats is necessary, as described in more detail in this Chapter at Section 6.5.

The aim of the Entity Relationship Model, shown in Figure 6.3, is to map the relations that are created among disciplines, defining which elements are contained, shared and enriched during facility development. In this case, the Road discipline collects information in order to define the corridor, and then produces alignments, cross sections, profiles and so on. Corridor information is shared with other disciplines for designing bridges, tunnels, and geotechincal parts. These contains elements for defining geometrical shapes and attributes according to BIM-based objects. This preliminary standard is not exhaustive in representing the complexity of interactions within infrastructure projects. Rather, it represents the starting point for definition of a Multi-scale model

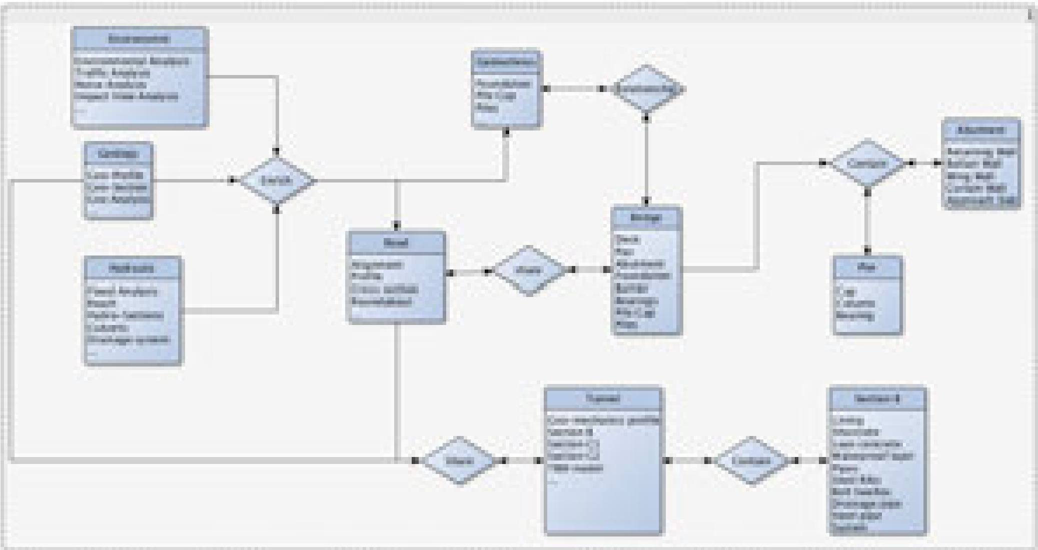


Fig. 6.3 Entity Relationship Model

The multi-scale model, shown in Figure 6.4 (Appendix B.1), describes the relationship between elements, domains and LODs. It is the evolution of the Entity Relationship Model presented previously. Starting from the study conducted by Borrmann et al. [35], the aim was to investigate project evolution, according to LOD scale and reference domains, in order to map the information flow at different stages and scales. The complexity of infrastructure projects is very high, involving a large amount of information, requiring an appropriate representation scale and interaction between several environments. For this reason, on the right side of the diagram one can see the geometrical representation according to project evolution. In this way, it should be possible to provide a clear idea of the information workflow, mapping the correct domain to a query, based on the information that needs to be collected or shared between the different disciplines. In addition, for this standard it hasbeen useful to define some BIM requirements, such as: PIM model structure, LOD information, model outputs and so on.

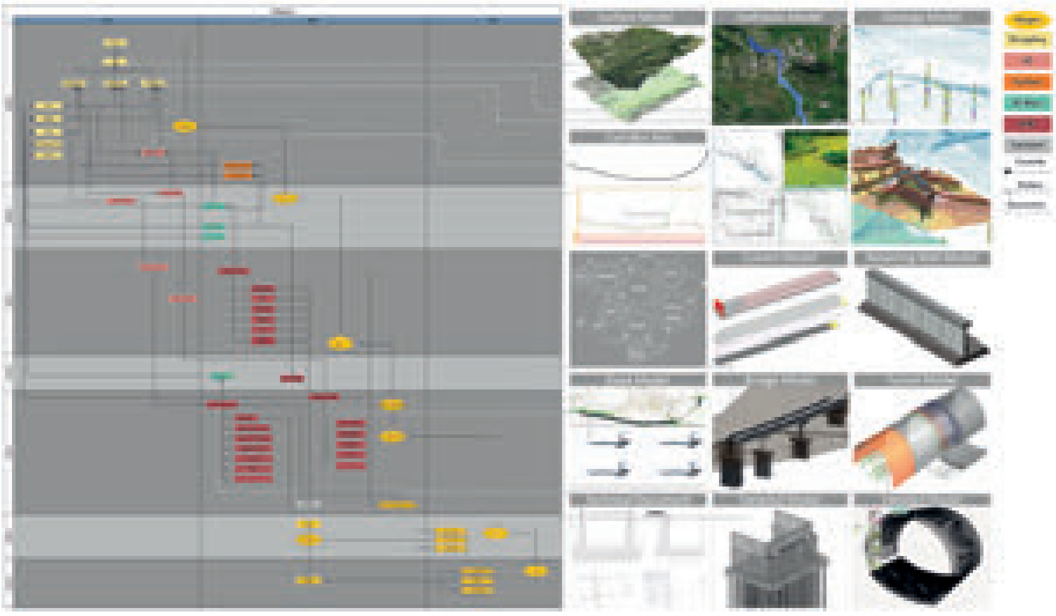


Fig. 6.4 InfraBIM Multi-scale model

FFinally, having addressed the definition of multi-scale modelling for project development, it is necessary to correlate these standards with a model that contains the application software to use for the modelling phase. Thus, as can be seen in Figure 6.5 a software standard has been provided to respond to project needs. The diagram is divided in two parts, the upper part collecting application workflow data for modelling and collaboration, while the lower section is dedicated to coordination activities. In this part the federated model has been created to coordinate each BIM model, to exploit verification and validation activities (for instance clash detection and code checking) and then to execute 4D (Time) and 5D (Cost) simulation. Obviously, this diagram is only one of the many examples that can be used, and is not exhaustive, nor is it suitable for all civil projects. Nevertheless, it is useful for displaying the plurality of applications necessary and also highlights where data flow is mono- or bi-directional and which exchange data format is used.

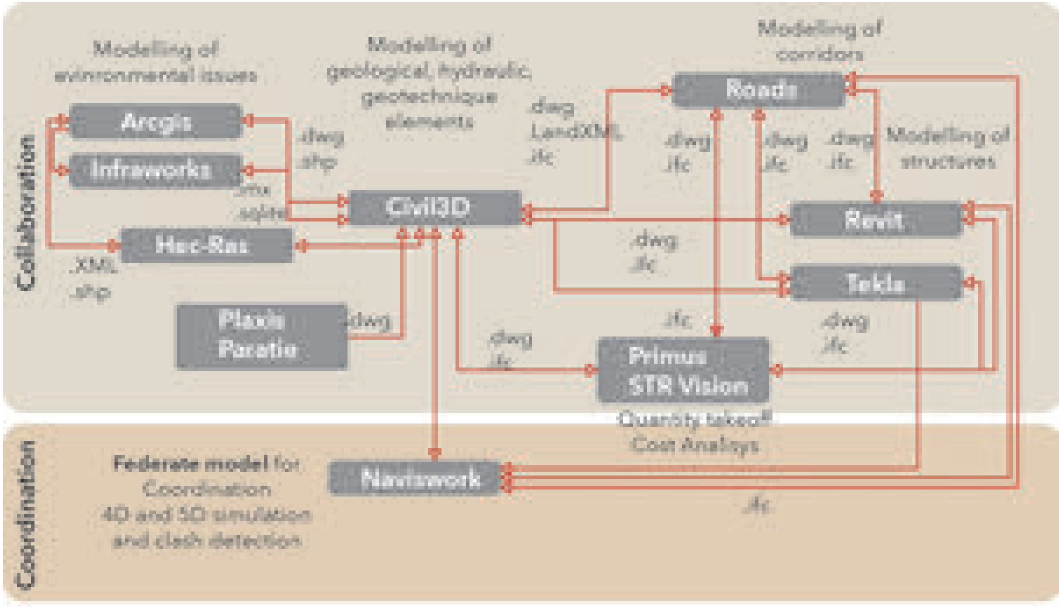


Fig. 6.5 Workflow schema with software indication

6.2 BIM Uses

The idea of a single information model, a "SMART" container of all the information relating to work from the early stages to building and operation, and ending with demolition, is an ambitious and at the moment a very complex goal to reach. The current complexity of the world of AECO and its fragmentation involves considerable waste of effort in the management and organization of the process. For this reason, it is necessary to make a clear definition not only of roles, responsibilities and information levels, but also of the model objectives, which must be clarified as follow:

- The identification of the project requirements and the projects, defined by the Employer's Information Requirement (EIR), BIM Execution Plan (BEP) pre-contract and BEP post-contract;
- Certification of individual roles and competences and organizational skills, for the creation of a company qualification system;
- The definition of usable results from which to derive best practices, for the improvement of use and control of the information model;

- Interoperability and collaboration of information models, defining data exchange requirements;

The objectives of the model, or "BIM uses", can be defined as the specific field of application of the information model during the different phases of the life cycle of the work, capable of achieving one or multiple objectives [112]. From the literature review, it is possible to identify different BIM Uses:

- **PENN State BIM Project Execution Planning Guide (2010)**: identified 25 BIM Uses;
- **VA BIM Guide (2010)** : identified 19 BIM Uses;
- **PD ISO/TS 12911-2012 (2012)** : identified a generic list;
- **New York City BIM Guide (2012**) : identified 15 BIM Uses;
- **Finland COBIM Standards (2012)** : identified 12 BIM Uses;
- **BIM Essential Guide Singapore (2013)** : identified 24 BIM Uses;
- **Massport Authority BIM Guide (2014)** : identified 51 BIM Uses;
- **BIM Essential Guide (2014)** : identified 28 BIM Uses;
- **The Port Authority of NY & NJ (2015)** : identified 38 BIM Uses;
- **Australian National BIM Guidelines and Case Studies for Infrastructure (2017)**: identified 40 BIM Uses;
- **BIMe Initiative (2017)**: realized a framework composed by three main categories (General Model Uses, Domain Model Uses e Custom Model Uses) [159];
- **UNI 11337-4 (2017)** : as is visible in Figure 6.6 the UNI did not provide a list of BIM Uses, but it proposed a conceptual un framework where the BIM Use were defined starting from identification of design state, phases and objectives [47];

Matrix definition of BIM objective and Uses

	Phases	Phase objective	Model	Model Objectives	Model Uses
Strategic planning	Necessity	Identification of needs, definition of works or part works, environment analysis, internal planning according to commitment needs	Historical		
			Territorial		
			Urban		
			Others...		
	Feasibility	Requirements definition, identification of works typology, analysis of the existing situations, definition of internal and external constrains, general planning process.	Historical		
			Territorial		
			Urban		
			Zoning		
			Site		
			Others...		

To be continued...

Fig. 6.6 BIM uses matrix, extracted by the UNI 11337 part 4

The main problems that emerge from the study of proposed BIM Uses consists in the lack of correlation between Objectives, Phases, LOD and Project Outputs and in the underlying ambiguity arising from having a separate information model for each BIM Use. Moreover, in agreement with Succar, it is possible to highlight further criticalities such as; i) the small number of identified BIM Uses, the ambiguity of some names, the strict association of some BIM Uses to certain phases and facilities; ii) the lack of correlation between BIM Uses and Project Outputs; iii) conceptual ambiguity and isolation, which does not allow for the generation of relationships between BIM Uses and other concepts such as skills [161].

The importance of correctly defining BIM uses is fundamental for several aspects related to the usability, control, management and coordination of the process, but at the same time represents a contractual obligation as expressed within the EIR (*Capitolato Informativo*). For these reasons, starting from the noteworthy publication examined, and in particular following the approaches of UNI 11337-4 and the PENN Stata BEP guide, it has proposed a system of sub-classes defining a total of 22 BIM uses. The general classes define the purpose for which the BIM model will be used and how the information will be used and managed.

The class system is composed of six main classes as reported in Figure 6.7. For each main use, some sub-classes have been described, for a total of 22 Bim

Uses. They should be used to develop an appropriate BIM model, overcoming limitations to include all information in a single model.

BIM USES			Description
1 Collect		Collect and organize information regarding the state of the context and related works	
	1.1	Survey	survey of the assets, environmental, geological surveys, etc.
	1.2	Monitoring	monitoring of the asset, traffic flows, etc.
	1.3	Identification	identification of the work and of the main project evidences
	1.4	Quantification	estimate of costs for the assessment of technical and economic feasibility
	1.5	Provisions	determination of requirements and design constraints
2 Generate		Model Generation	
	2.1	Location	facility geo-location
	2.2	Modelling	information modeling of project elements
	2.3	Sharing	sharing of the design elements between the disciplines
3 Analyze		Analysis of the design elements	
	3.1	Coordination	coordinamento di tutti gli elementi progettuali per le verifiche di interferenze
	3.2	Simulation	analysis using mathematical models to verify the sizing of the facility
	3.3	Validation	validation according to the rule from the engineering point of view
4 Communicate		Representation and communication of the elements that can be exchanged and shared	
	4.1	Visualization	asset visualization (VR, AR, Photoinsert)
	4.2	Update	collection of progress authorization status and updating of information models following design changes or following the implementation of the provisions
	4.3	Graphic representation	production of design documents extrapolated from the information model
	4.4	Documentation	generation of documentation extrapolated from the model or related to it
5 Realize		Control of the work execution	
	5.1	Fabrication	information on the construction facilities and provisional works
	5.2	Assembly	information on the production of prefabricated parts, assembly and any provisional works
	5.3	Field control	management of timing and costs implementation (4D and 5D)
	5.4	Verification	informativa di raccolta e analisi delle verifiche di congruità normativa effettuate durante la realizzazione
6 Operate		Asset management and maintenance	
	6.1	As is	survey
	6.2	Monitoring	monitoring of the asset during the operation phase
	6.3	Update	update of the information model, following maintenance interventions on the asset

Fig. 6.7 BIM Uses classes and subclasses

Compared to the classes proposed by Messner and Kreider, the maintenance class has been added, for the future management of assets over time, through the information deriving from the information model and the updating of this tool during maintenance cycles. In this way, users will have a knowledge of the maintenance history of the work, so as to facilitate future interventions.

On the basis of the classes identified, we have tried to define a framework in which the characteristics and outputs can be discerned from the determination of the objectives, in this way the determination of the LOD of the objects derives from the expected functionality of the information model, as suggested by the UNI 11337-4, and moreover with respect to the traditional approach, the outputs will be defined that will then be fundamental for the verification and investigation phases, but also for the sharing of models between disciplines and subsequent processing phases.

Often, the phase and the target are clearly identified, but the output is not explained, generating an intrinsic criticality of mapping which information is generated by each model. especially in the context of Italian legislation, in which

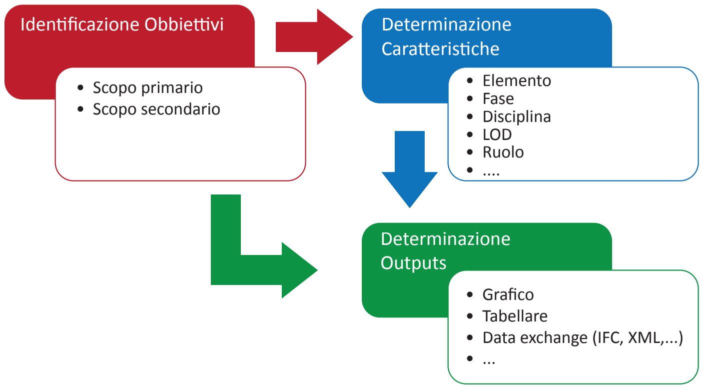


Fig. 6.8 BIM Uses framework

certain outputs correspond to other outputs, as established by Presidential Decree 210, of 2006. Moreover, in object modelling, defining the phase and the objective should be sufficient to determine the LOD, but none of the cases mentioned above shows a practical example.

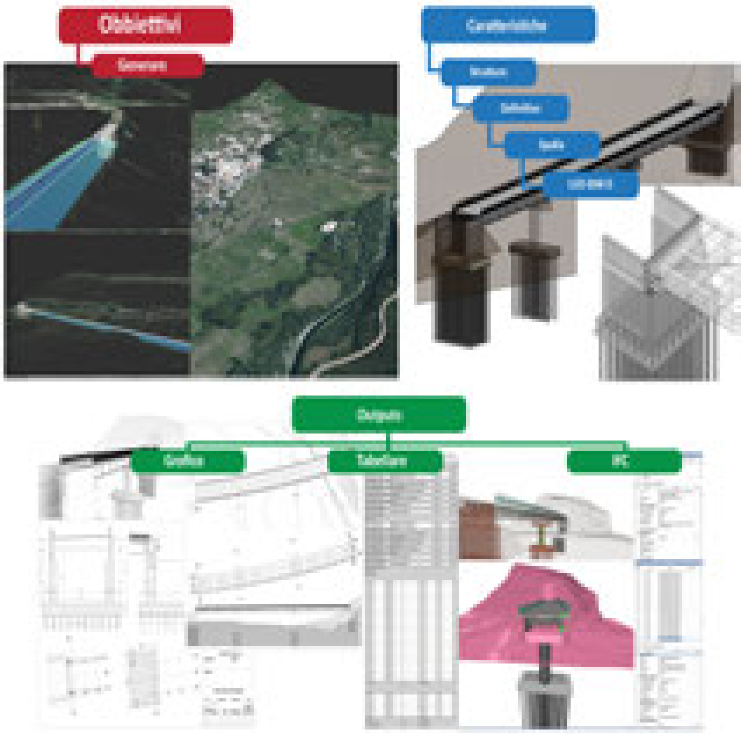


Fig. 6.9 BIM Use framework application

Starting from the definition of such BIM Uses - in this case "Generate" was the main aim - it is possible to derive the main characteristics of use, such as: Discipline, Design Stage, BIM components, LODs. Then, based on the correlation between objectives and characteristics, it is possible to define the output, which can be graphical, or a data sheet or an output in open data format.

6.3 Standard Parametric Libraries

According to Hooper, BIM needs standardization [99]] and a part of this process passes through the quality of parametric objects used in the design phase. The quantity and quality of information of a BIM model is a direct link to the capacity of parametric elements used to enrich the database of information. Otherwise, there may be errors of quantity or due to large amounts of useless information [111]. Nevertheless, despite the insufficient maturity of BIM methodology and tools in infrastructure projects, one of the main obstacles observed is the lack of BIM objects suitable for InfraBIM, useful and usable not only for the geometrical representations but especially for managing the large amounts of information involved. In this sense, ANAS, starting from a classification of common elements, representing the majority of its civil works, is going to provide the first free BIM library, available for BIM applications and for service providers and contractors. This strategy presents multiple objectives from different points of view. Primarily, it should promote diffusion of BIM, overcoming the lack of suitable objects in the authoring software. Secondary, it aims to contribute to the creation of an ANAS Standard for the development and management of information derived from the model. Each BIM object is characterized by geometrical and alphanumerical information, additionally there are several parameters created according to ANAS encoding, to facilitate verification, validation and maintenance operations. This set of parameters should be able to create a reliable structure of data and standards both for the supplier and the contract Authority, thereby avoiding the risk of redundancy and incongruity of data. Otherwise, it should be impossible to obtain appropriate parametric models capable of providing information for each work stage and especially during the maintenance phase. At the moment, the first objects were created for Revit Autodesk, in order to facilitate the estimation of quantity for each part. In fact, as shown in Figure 6.11 complex elements such as abutments, for instance, are composed of several nested components such as a ballast wall, retaining wall, winning wall and pedestals. Although this approach could require enormous effort in the development of parametric objects, it should also facilitate the connection between models and price lists. In this way, it should be possible to easily associate work price with the model and also link different kinds of information for each phase.

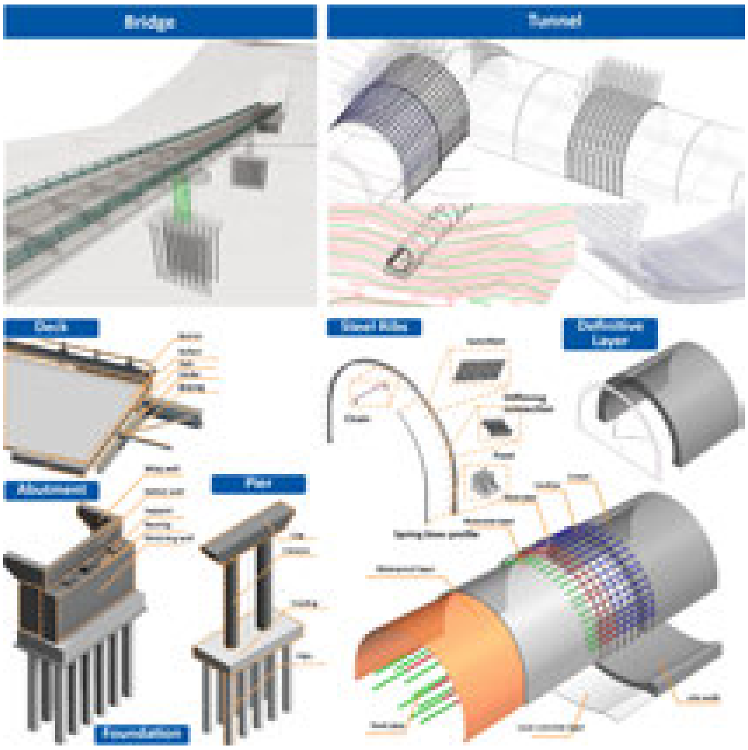


Fig. 6.10 BIM paramentric objects for bridge and tunnel

A parametric element is characterized by graphical and non-graphical information, as shown in Figure6.11. Geometrical parameters determine the geometry and thereby the quantity of concrete, steel, number of piles required, which change with the geometry. For each component three levels of detail are defined (Low, Medium and High), as shown in Figure6.12 and also the part that makes up single object, because with respect to building elements each part has a different computation. Non-graphical information (Figure 6.13) have a code form *"A_Parameter"* to improve data standardization and to obtain organized and usable information.

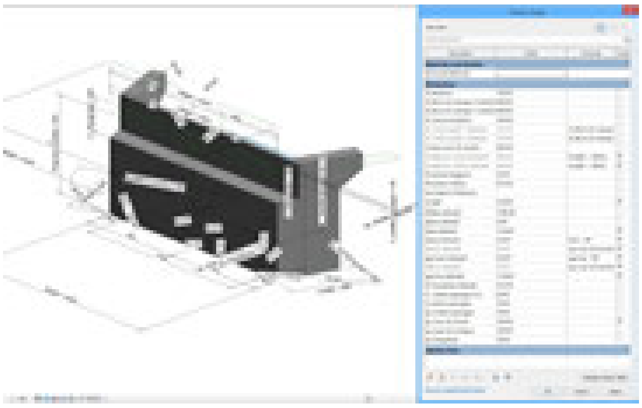


Fig. 6.11 BIM parametric object - Bridge Shoulder

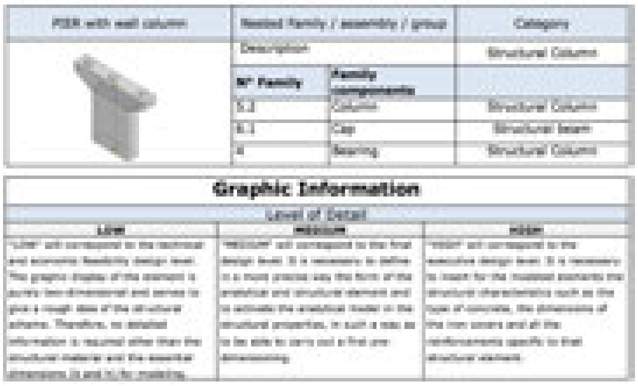


Fig. 6.12 BIM parametric object - graphical information

Informazioni NON grafiche						
	Parametro	Descrizione parametro	Tipo di parametro	Disciplina	Tipo di dati del parametro	Raggruppamento parametro
Codifica	A_Progressiva	Codice progressiva	Condiviso / Istanza	Comune	Testo	Dati
	A_Elemento Strutturale	Contrassegno di posizione	Condiviso / Istanza	Comune	Testo	Dati
	A_Codice Paraghiaia	Codice ID dell'oggetto	Condiviso / Istanza	Comune	Testo	Dati
Computo	A_Codice Tariffa	Il codice da elenco prezzi ANAS	Condiviso / Tipo	Comune	Testo	Altro
Generale	...	...	...	...	...	...
Proprietà calcestruzzo	...	...	...	...	...	...
Proprietà acciaio	...	...	...	...	...	...
Sicurezza	...	...	...	...	...	...
Aspetto	...	...	...	...	...	...

Fig. 6.13 BIM parametric object - not-graphical information

6.4 LOD for Infrastructure

6.4.1 State of art LODs

The Product Information Model (PIM), i.e. the digital representation of the facility, is not only a faithful copy of the work in all its geometric details, but it is also the instrument used for coordination, collection and sharing of information (geometric, analytical) and documents, for the entire life cycle of the facility. Assuming that the information model is the result of an iterative process of continuous geometric and informative enrichment. Models and objects will have a certain geometric detail and number of attributes. Therefore, the definition of information contents for each phase should be extremely precise. Therefore, in practice each design stage is regulated by a regulation, which identifies the design contents. For this reason, in my opinion it is correct to ask some questions:

- Is it possible assume assumed that a model at LOD E / LOD 4 / LOD 350 / LOD3 (depending on whether it is UNI11337-4, BS PAS 1191-2, AIA, OGC), is corresponding to the level of executive design according to the regulation?
- Do Project LODs define the level of all object or should they be considered as the average of LOD of each object?
- Do LODs project depend on use cases and objectives based on the design stages?

These questions are essential in order to try to standardise information modelling management, and require an appropriate level of information. Otherwise, the risk could be an excess of modelling, especially from a geometrical point of view, requiring excessive effort from suppliers and contractors. Let us take the example of modelling of reinforcing bars, which at an executive level is a required piece of information. Must they be modelled for the entire structure or it is sufficient to model only a certain type, with a detailed study of particular elements, while for the other elements it is enough to insert an attribute relating to the reinforcing bars?

EIR’s should be the tools used to try to solve these problems, providing direction for information modelling management. Nevertheless, it is difficult to provide a single LOD definition, and at this stage for suppliers and general contractors the potential risk could be ever-changing demands from Contracting Authorities. In fact, at the moment several LOD concepts exist, such as:

- Level of Detail (LOD)
- Level of Development (LODt)
- Level of Information (LOi)
- Level of Accuracy (LOa)
- Level of Definition (LOd)

The lack of a unique, shared definition of information levels is a critical issue not only at the regulatory level but above all in contracts for the definition of EIR’s and in the pre-contract BEP. In the first case, both public and private clients are forced to specify the desired level of development, drawing up the information sheets for all the elements of the project. This approach requires a lot of effort and a knowledge of the project that in the feasibility phase is not easy to achieve. Meanwhile, proposing an overall LOD for each state of in-depth design implies a lack of homogeneity of the elements of the model.

In literature, the topic of LOD has been widely investigated and included in many of the regulations and guidelines to facilitate its implementation as a national standard. In 2006, Denmark published the "3D Working Method" which defines six levels of information, which describe the increase in detail corresponding to the level of in-depth design [27][30]. The level of information refers to both the geometrical and the alphanumeric information related to the model and its elements.

Later, in 2008, the American Institute of Architects (AIA), released E202 ™-2008. Building Information Modeling Protocol Exhibit [5]. The big difference compared to its predecessors lies in the introduction of the concept of *"Level of Development"*, understood as *"...the level of completeness to which a Model Element is developed..."* [5]; in fact, within the document produced by the AIA there is no reference to the "Level of Detail". The scale proposed by AIA consists of 5 levels (100,200, 300, 350, 400), although there is also a level 500, which represents a verification level for form, position and orientation, with which non-graphic information can be associated. This level does not define a further progression of the model from the point of view of information contents, since level 400 is considered sufficient for construction and manufacturing.

In the AIA system, the LODs aim to guarantee the reliability of the elements of the model, going to define the contents *"...minimal size, spatial, quantitative, qualitative and other data included by the model element to support the uses authorized with this LOD..."* (E203 ™ -2013);); in fact, for each level a Model Content Requirement is defined, referring to the Model Element Table (MET), which also specifies the responsibility of each author of the elements constituting the model, through the Model Element Author (MEA). Finally, in 2011, the BIMForum based on the LOD defined by the AIA, developed the LOD Specification (BIMForum, 2013), introducing the LOD 350 level and going on to specify the non-graphical attributes related to the geometric elements [29].

At beginning, with AIA E202-2008, the concept of LOD was introduced into several guidelines, in which further concepts such as the definitions of *"Model Granularity"* and *"Grade Definition"* were also introduced. In July 2012, the New York City Department of Design + Construction introduced the concept of *"Model Granularity"* rrelated to the geometric representation necessary to achieve specific "*BIM uses*" [28]. Linking the LOD to a specific BIM use represents a distinctive element, which denotes the search for a balance between the geometric detail and the information content suitable for a specific purpose. Notwithstanding the guideline provided by the NYC DDC, there is a lack of clarity on the level of development of the model and its constituent elements.

In the United Kingdom (UK), the AEC (UK) Initiative released the BIM Protocol in 2009, followed by an update in 2012, introducing the concept of Model Development Methodology related to the degree of definition. In 2013, PAS 1192-2 introduced the concept of *"Level of Definition"*, which includes both *"level of model detail"* (LOD) and *"level of information detail"* (LOI). TThe level of detail of the model (LOD) represents the graphical description of the contents of the model in each stage, while the level of detail of the information

(LOI) is related to the non-graphic information of the models at each stage. The PAS 1192-2: 2013 [3] identifies seven levels inter-connected to the phase of in-depth design, such as:

- Brief
- Concept
- Definition
- Design
- Build and commission
- Handover and closeout
- Operation

In 2015, the National Building Standard (NBS) released the "BIM Toolkit" with the aim of promoting better integration between the classification system and the "Digital Plan of Work". In this way it is possible to trace the level of detail, roles, responsibilities and deliverables for each design phase [30]. This tool is one of the first examples of the application of a "BIM oriented"digital platform, capable of managing assets during the entire life cycle. Recently, in 2015, AEC (UK) released the "BIM Technology Protocol", which introduces the concept of "Grade" in which graphic content and information content are completely detached. Therefore, it will be possible to have an element that graphically is a symbolic representation "Grade LOD1 (Symbolic)", but which still contains all data relating to the construction, including costs and specifications (AEC (UK), 2015).

In Italy, in 2017, the UNI 11337: 2017 [47] standard was issued, in which the concept of LOD was described as the level of development of the object, which consists of a level of geometric development of objects (LOG) and a level of information development of objects (LOI).

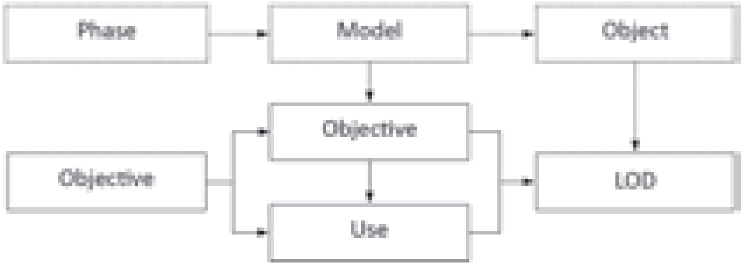


Fig. 6.14 Framework to define model and phases uses and objectives. Source: UNI 11334 part 4 [47]

UNI 11337-4 points out a further two main aspects. The first relates to methods for generating the LOD of each object that is not defined, regardless of the design phase, such as occurs in the PAS 1192-3, but is a process of deductive definition starting from the use of the model. For example, if we think of a BIM model for Facility Management (FM), the main objective is the management of assets, equipment, spaces, etc.. Consequently, it will be necessary to have spatially correct objects, but with a wealth of very high non-graphic information such as the maintenance card, the commercial product sheet, the assembly diagram etc. In this sense, the UNI is very close to the concept of Grade expressed by AEC (UK). The second aspect concerns the contractual aspects in which *"...the level of development of the objects is requested by the client in the informational specifications or agreed between the client and the assignee through the information management plan (PGI) of the work (or the complex of works) in the compliance with the information management offer (oGI) and the information documents (CI)...* "[47].

The UNI identifies a scale of levels, in which each sub-following level, as previously described by AIA (AIA, 2008) [5],considers data and consolidating information from the previous level, and each level cannot fully meet the requirements of the next level [47]. The UNI level scale identifies the different levels of digital development of objects using an alphabetic scale:

- **LOD A** - symbolic object
- **LOD B** - generic object
- **LOD C** - defined object
- **LOD D** - detailed object

- **LOD E** - specific object
- **LOD F** - object executed
- **LOD G** - updated object

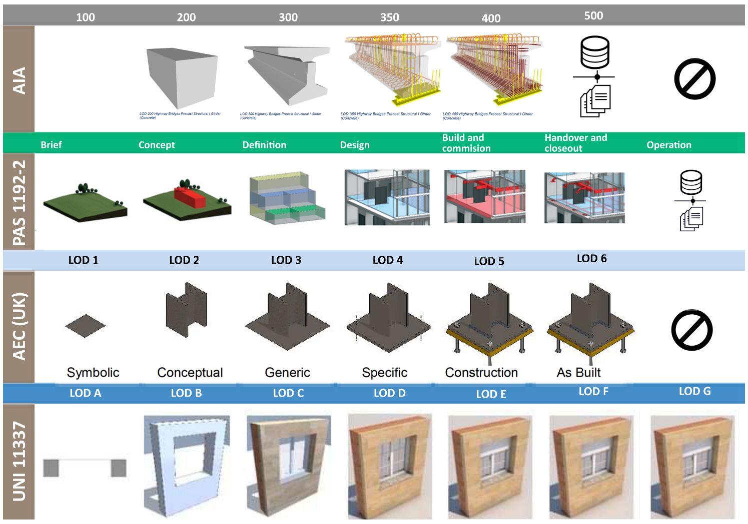


Fig. 6.15 BIM LODs comparison

6.4.2 InfraBIM LODs

Despite the fact that the concept of LOD, as mentioned above, is described in a different way depending on whether it is meant as Detail, Development, Granularity or Information, there is no doubt that they have been conceived for buildings. The LOD for infrastructures cannot follow the same references, because the information to be managed is almost totally different [Dell'Acqua]. Within infrastructures, defining LODs as the level of object development, for some areas, is not possible, for example the river branch of a watercourse, the geological evolution of the subsoil, the same road body being defined by entities, such as profile and level, that cannot be called BIM objects.

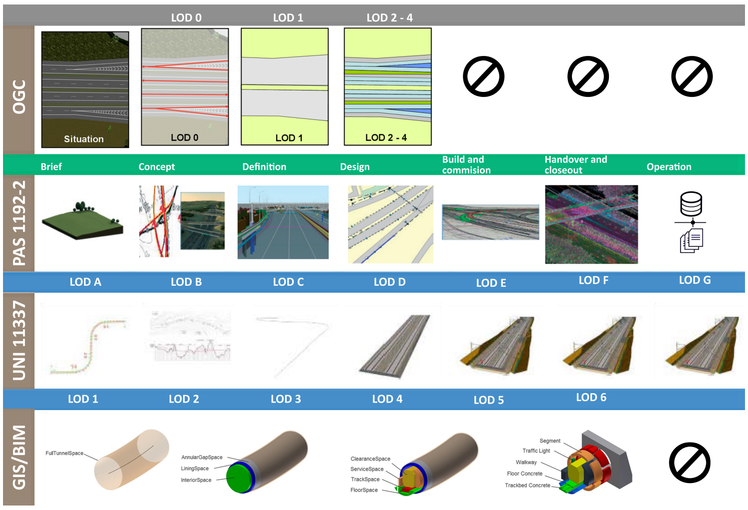


Fig. 6.16 LOD for infrastrutture

The PAS 1192-2 and the UNI 11337-4, apply the same concepts of LOD used for buildings also to infrastructural planning (roads, railways, tunnels, etc.). There should be a limit, because such information, relating to those disciplines involved especially in preliminary design and context analysis, are based on the handling of geo-spatial data. These models contain largely environmental information, which are often generated by means of a simple representation such as cartography, geo-section, hydraulic profiling and so on. The risk is to have over-modelling of a great deal of data, taking account only of physical objects. Meanwhile, infrastructural planning is based on the close interaction between the environmental, hydro-geological and geo-morphological context and the physical objects that make up the infrastructure [74]. Thus, civil design and geo-spatial models need an interoperable approach to be able to integrate heterogeneous data.

Given the growing need to create 3D virtual cities, the he Open Geospatial Consortium (OGC) has introduced the CityGML, an informative semantic model for the representation of urban objects, which allows interoperability between different applications [90]. The CityGML format is structured according to classes and relationships, representing the majority of topographic objects characteristic of urban and territorial models, while maintaining geometric, topological, semantic and appearance properties [90]. The LOD scale, proposed by the OGC, for representation of the motorway platform consists of four levels of information. In LoD0, objects are modelled using linear entities that define a network, LoD1, through a geometric surface that reflects its actual shape; from LoD2 to LoD4 the model contains "*TrafficAreas*", destined for the transit of vehicles or pedestrians, and the "*AuxiliaryTrafficAreas*", i.e. horizontal signs, flower beds or road margins, etc. [147]. Although the class and entity structure used by the CityGML allows the coding of some objects, they are not sufficient to describe all the spatial entities characteristic of the infrastructures, especially when the level of in-depth design increases. It therefore becomes necessary to introduce the concept of a Multi-scale Model [33][95] in which the semantic correlation between the model and LOD objects is explained in such a way as to maintain the hierarchy between the different LODs. Moreover, the use of objects referring to spaces (indicating uses), and physical objects (indicating the construction parts), allows complete "*compliance*" with the IFC standard.

Esfahani et. al. proposes an approach in which the concept of LOD becomes a type of filter for information deriving from different domains (GIS, BIM, SIM etc.), starting with a catalog that describes the level of detail for each object and spatial entity. The problem with this approach is the idea of continuously increasing the information level of the objects starting from the information of the previous LOD. For example, the definition of the profile and the cross-sections is defined starting from LOD3, where it is possible to start sketching the earth movements and the design definition of the main works. LoD4 defines the design aspects such as those related to flooring or the drainage system. The components of the road axis are exactly defined at LoD5, such as shoulders, ditches, barriers, etc. [74].

In conclusion, based on international literature, the concept of LOD is one of the most widely discussed subjects but at the same time remains a point of weakness, given the difficulty of defining a unique definition. A possible solution, as shown in Figure 6.17, while waiting development of a better way to interrogate information models, is to clearly define the aims and purposes for which the information models are to be used. Later, having clearly defined the "BIM Uses" it will be possible to determine the minimum contents for the different LODs, mapping outputs in order to know from which domain it should be possible to obtain information. For this reason, the study provides an interpolation between LOD and Uses highlighting GIS and BIM domains. The early stage will have a greater contribution by GIS domain, tailored for the study of the facility from an environmental point of view. Conversely, as projects progress, the quantity of information from the GIS domain will decrease, while that provided by the BIM environment will increase.

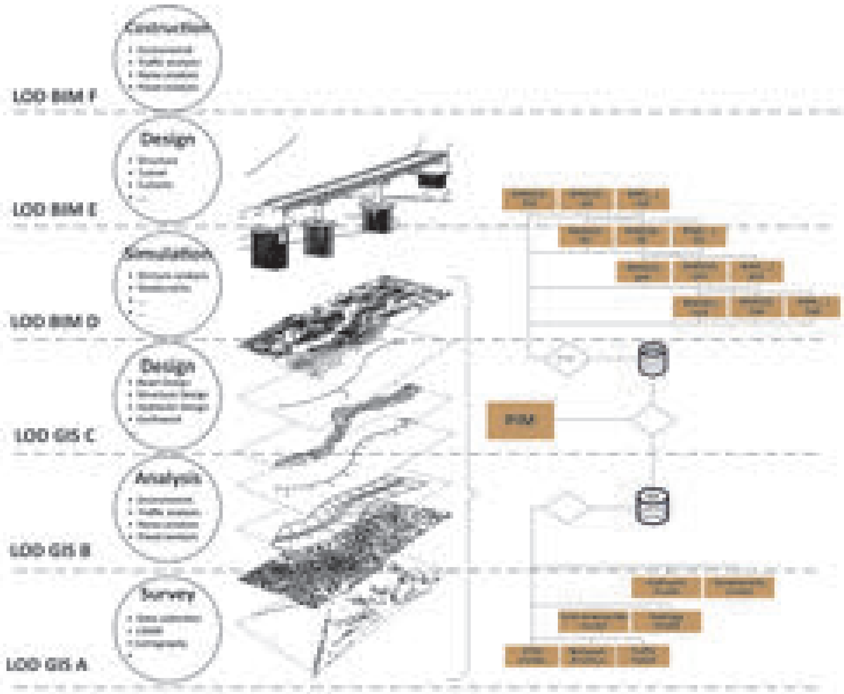


Fig. 6.17 LOD taxonomy

6.5 Interoperability

The idea of BIM cannot afford to disregard the concept of *interopearbilty*, which may be defined as the ability of various organizations or individuals to operate together to achieve a common goal [101].

The ability of systems, units, or forces to provide services to and accept services from other systems, units, or forces, and to use the services so exchanged to enable them to operate effectively together

IInteroperability aims to promote standardization, integration, cooperation, and even synergy. Interoperability specifics, however, which are often situation-dependent, come in various forms and degrees, and can occur at various strategic, operational, and tactical as well as technological levels [101]. From the perspective of construction, interoperability is the ability of a system to share information derived from different disciplines, minimising both the potential absence of data and over-production of information [101].

IInteroperability has a cost, which may be difficult to define and estimate. The important thing is to understand what sorts of interoperability are worth what sorts of costs. In the construction sector, given the highly fragmented nature of the supply chain, a lack of standardization, and inconsistent technology adoption among stakeholders, the cost according to the NIST report in the U.S in 2002, stood at $ 15.8 billion [85]. Most of the estimated costs mainly affected the owners of facilities during the operation and maintenance phases, where it is essential have available all necessary information for asset management. The hurdles to accessibility caused by insufficient interoperability, cost owners and operators approximately $10.6 billion or about two-thirds of total estimated costs in 2002. Architects and engineers had the lowest interoperability costs at $1.2 billion. General contractors and specialist manufacturers and suppliers bore the balance of costs at $1.8 billion and $2.2 billion, respectively [85].

Fig. 6.18 Application and Interoperability world

Currently, the software market offers several applications capable of developing all the characteristic aspects for each stages of building and civil projects. As shown in Figure 6.18 [1] for each project stage there are appropriate applications. The lines between the different stages indicate the need to communicate data. The aims of this communication process is to avoid a lack of data and to guarantee the data reliability. For this reasons the interoperability process plays a key role in the efficient implementation of the BIM workflow.

[1] Available at https://parametricmonkey.com/2016/06/20/bim-ecosystem/

6.6 Exchange data format

As mentioned many times in this dissertation, BIM is a methodology, one that includes the use of several building models, on the basis of data exchange operations. This should help to avoid the manual re-entering of data and information, thereby reducing the accompanying risk of errors. The software market provides a wide range of tools capable of operating in several fields such as: structural design, heating requirements, costing, facility management, and so on. Nevertheless, these tools still have limited support for data exchange, with the consequent manual re-entering of data and information. The solution could be an exchange data format capable of translating building components in a uniform and unequivocal manner, following the example of other sectors such as the automobile and aircraft manufacturing sectors, where manufacturers have established within their supply chain which format to use. On the other hand, software manufacturers solved the classification of many parts by providing their own exchange data format. This is more straightforward in the manufacturing field, because they have full control of production and of the supply chain, without having to pass through lengthy and complex standardisation procedures [36].

The Building sector, on the other hand, has different industry boundary conditions that it make more difficult to achieve complete data exchange. This is due to supply chain fragmentation, and the large number of different and independent participants [140] [115]. This means that the most of the tools used lack a uniform standard to exchange. At the same time, public administrations are required to use open data formats, in order to avoid having to put the work out to tender [29].

Currently, there is no single application which can cover all the requirements of the AEC/FM industry [15] There is therefore a need to identify the right data format for editing and converting building data during the whole process, where a large quantity of information is created [67]. There is currently a large number of exchange data formats, as shown in Figure 6.19 [1]

[1] Figure 6.19 available at http://www.harpaceas.it/sito/simple.nsf/PagOK/Pilloledi-BIM (last visit 3 June 2016). In Italian.

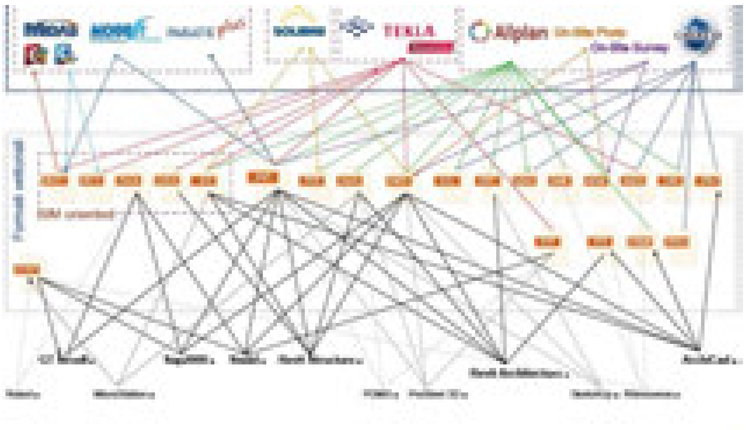


Fig. 6.19 Interoperability between different platforms

Initially, exchange formats such as DXF (Drawing eXchange Format) or IGES (Initial Graphic Exchange Specification) focused on geometrical information [15][66]. TThen, from the 1980s, the necessity to export information among different industries led information exchange technology to an international standard (ISO-STEP) [29]. AAmong the various definitions of data exchange within applications, it is important to underline two different levels. The first is related to the meaning of the data exchanged, as defined in the program. For instance, programs such as: IGES, IFC, CIMsteel Integration Standard version 2 (CIS/2), Standard for the Exchange of Product Model Data (STEP), Building Automation and Control networks (BACnet), Automating Equipment Information Exchange (AEX), AECXML and City Geography Markup Language (cityGML). The second aspect is related to how the program formats the information such as: SQL (Structured Query Language), EXPRESS and XML (eXtensible Markup Language) [29].

6.6.1 IFC

The international organisation buildingSMART aims to promote development of an international standard exchange data format to support the wide use of BIM. It has dedicated several years to developing a vendor-neutral open data format, the Industry Foundation Classes (IFC). This is a complex data model which can represent both the geometry and the semantic structure of the BIM model, using an object-oriented approach [36].

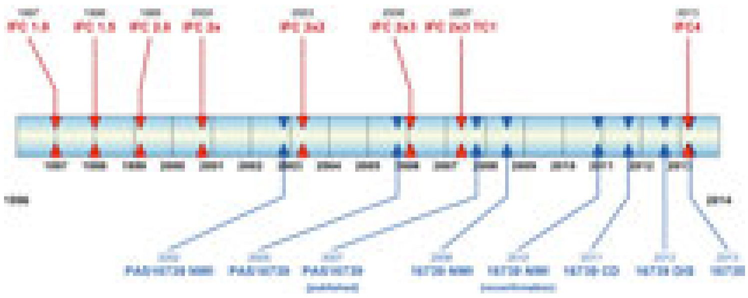


Fig. 6.20 IFC version history Source: buildingSMART International [118]

The basic idea of IFC is derived from ISO STEP ideology of having a common universal resource able to cover the diverse range of industries, improving the concept Building Construction Core Model (BCCM). The BCCM aimed to aggregate most of the main aspects of the data model and universal concepts across the major AEC/FM disciplines [115]. Since its first release, IFC 1.0 in 1997 [115] other releases have followed, as shown in Figure 6.20, up to the last version IFC4, in 2014. During this implementation period, there was a continuing process of improvement aimed at increasingly incorporating the building model, in order to map the infrastructure model together with architectural and engineering processes. Currently the most widely used IFC version is 2x3, although this is gradually being replaced by IFC 4 (as of late 2017) [36].

The IFC structure data model is divided into four main layers: Domain, interoperability, core, and resource layers. These layers have a top-down hierarchical structure. This means that data in the resource layer are independent of the upper classes. The resource layer contains the resource standard that describes the object basic definition contained in the layers above. The core layers contain kernel and extension modules. The Kernel provides objects model structure, relations, attributes, roles and descriptions. Core extension, on the other hand, defines the specialisation classes stated in the Kernel area. The interoperability layer aims to provide the exchange mechanism to enable interoperability across domains. The domain layer contains domain models for processes in specific AEC domains or types of applications, such as architecture, structural engineering, and HVAC, among others [115].

Fig. 6.21 IFC schema. Source Borrmann et .al [36]

The IFC diagram was developed to map AEC/FM objects and processes, even though the first application related to buildings. Nowadays, given the urgent demand of international infrastructure stakeholders to extend IFC to the infrastructure sector, many studies were conducted. The first examples designed to extend use to the infrastructure sector, were developed in the academic field. Yabuki et al., for instance, proposed an IFC implementation for the bridge product model, starting from the basic diagram of IFC2x3. They introduced new classes and property sets for geometrical representation and attributes [172]. Following on from this work, Borremann et al. provided an extended diagram for bridges [37], for the infrastructure room of Building SMART. for the infrastructure room of Building SMART. For tunnelling, several implementations provide implementing IFC diagrams introducing classes for the implementation of tunnel product data model [170] [9] [33].

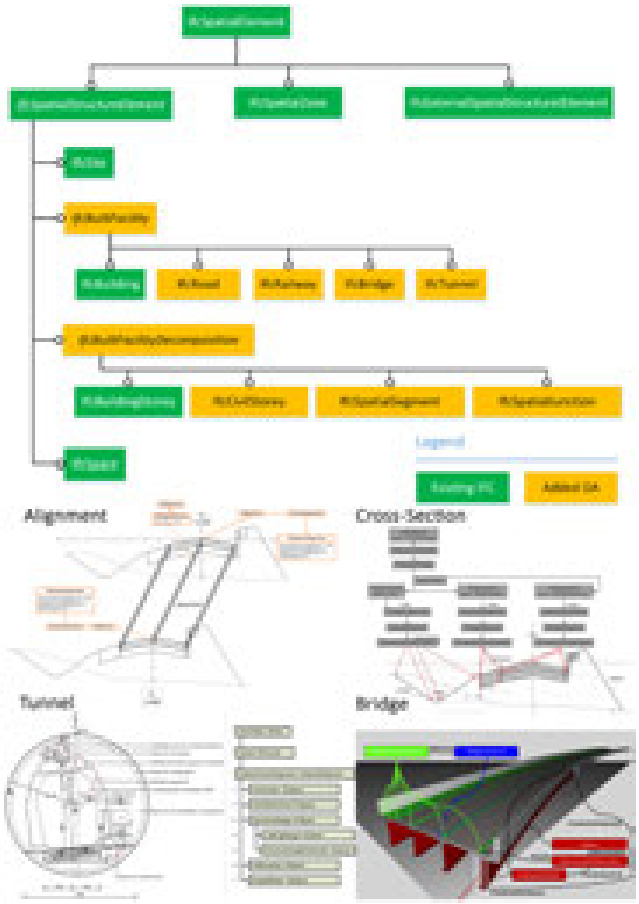


Fig. 6.22 IFC Infrastructure architecture

After the preliminary experience, thanks to the work carried out by the infrastructure room, buildingSMART provided initiatives to develop IFC infrastructure standards. The initiatives originated from the OpenINFRA initiative, which adopts LandXML and uses it to extend the IFC with IFC Alignment [8] as a basis for further development for roads and bridges (IFC-Road, IFCBridge). Currently an IFC extension regarding tunnels (IFC-Tunnel) is under development but, in order for it to become a standard for tunnel design, additional progress is needed [119] [33]. The current state of the art about IFC-Infra is reported in the standard shown in Figure 6.21. It aims to extend the IFC standard for infrastructure domain adding IFC-Road, IFC-Rail and IFC-Bridge. This implementation was carried out in parallel with the IFC-Alignment 1.1 project and in strict collaboration with the OGC in order to implement a conceptual model useful for both IFC-Infra and InfraGML [31].

The diagram shows the spatial hierarchy for spatial positioning of physical entities within an infrastructure project. It follows the same principle of previous IFC releases, introducing a new abstract as *ifcBuiltFacility* and *ifcBuiltFacilityDecomposition* FacilityDecomposition but maintaining, at the same time, the four levels of decomposition. In this way the hierarchic structure remains intact, having at the top level an *ifcProject* consisting of an *ifcSite* and an *ifcBuilding*. Added to this are the spatial elements that have to be located, and are contained in two entities *ifcBuiltFacility* and *ifcBuiltFacilityDecomposition*. This is due to the great complexity and wide scale of infrastructure projects, that generally consist of more than on category. For example, a road project will consist of a road line as well as bridges, tunnel, geotechnical features, and hydraulic works that are described by *ifcBuilding* entities, while bridges or tunnels can be split into other elements contained into ifcCivilStoreys, each carrying one or more road (ifcSpatialSegments) [31].

As contracting Authority, ANAS has to maintain a neutral attitude towards the specific use of BIM software, and needs to avoiding requiring proprietary exchange data format, typical of software authoring, because it could create a disturbance in the bidding phase, which could exclude certain participants. For this reason, the use of the IFC format is essential to guarantee appropriate PIM communication. However, the IFC standard for infrastructure design is not yet complete and exhaustive enough to represent all classes and attributes. In order to solve this problem, where possible, a set of new parameters and property sets has been created.

The *IfcPropertySet* is defined as: all dynamically extensible properties. It is a container class that holds properties within a property tree. These properties are interpreted according to their name attribute. Property sets, defining a particular type of object, can be assigned an object type (*IfcTypeObject*). Property sets are assigned to objects (*IfcObject*) through an objectified relationship (*IfcRelDefinedByProperties*). IIf the same set of properties applies to more than one object, it should be assigned by a single instance of *IfcRelDefinedByProperties* to a set of related objects. Those property sets are referred to as shared property sets [41]. The *IfcPropertySet* iis useful to add properties and attributes to a model, overcoming the limitations of some software programs when it comes to storing certain attributes.

Each BIM authoring application follows a specific rule to implement the property set. The precondition is that the attribute exists in the list of *IfcPropertySet* within the IFC layout. Therefore, in order to create these parameters, they have to be created using the exact name, the correct type (text/number/yes/no, visible in the buildingSMART documentation) [17].

Pset_Concrete Element General

[illegible]	[illegible]	[illegible]	
ConstructionMethod	P_SINGLEVALUE / IfcLabel	Construction Method	[illegible]
StructuralClass	P_SINGLEVALUE / IfcLabel	Structural Class	[illegible]
StrengthClass	P_SINGLEVALUE / IfcLabel	Strength Class	[illegible]
ExposureClass	P_SINGLEVALUE / IfcLabel	Exposure Class	[illegible]
ReinforcementVolumeRatio	P_SINGLEVALUE / IfcMassDensityMeasure	Reinforcement Volume Ratio	[illegible]
ReinforcementAreaRatio	P_SINGLEVALUE / IfcAreaDensityMeasure	Reinforcement Area Ratio	[illegible]
DimensionalAccuracyClass	P_SINGLEVALUE / IfcLabel	Dimensional Accuracy Class	[illegible]
ConstructionToleranceClass	P_SINGLEVALUE / IfcLabel	Construction Tolerance Class	[illegible]
ConcreteCover	P_SINGLEVALUE / IfcPositiveLengthMeasure	Concrete Cover	[illegible]
ConcreteCoverAtMainBars	P_SINGLEVALUE / IfcPositiveLengthMeasure	Concrete Cover At Main Bars	[illegible]
ConcreteCoverAtLinks	P_SINGLEVALUE / IfcPositiveLengthMeasure	Concrete Cover At Links	[illegible]
ReinforcementStrengthClass	P_SINGLEVALUE / IfcLabel	Reinforcement Strength Class	[illegible]

Fig. 6.23 IfcPropertySet for Concrete element general. Source: *buildingSMART international* [41]

From technical documentation provided by buildingSMART, it is possible to identify, for each class of elements, the *IfcPropertySet* able to implement standard export of BIM applications. For instance, the property set Concrete Element General, shown in Figure 6.23 provided several attribute such as: *StrengthClass*, *ExposureClass*, *ReinforcementVolumeRatio*, *ConcreteCover*, *ReinforcementStrengthClass* and so on. These parameters have been introduced within a BIM model, to enrich data information. The test was conducted using Autodesk Revit as the BIM authoring application. The first stage was to create a set of *share parameters*, in Revit environment, through the use a simple text file. It is then possible to assign those parameters to BIM objects by category. Once assigned, the parameters created are collected behind the I*FC Parameters* and they are visible in the object property panel and it is possible to fill out these fields.

The exportation process has been carried out tested different approach and IFC versions. The best result, visible in the Figure 6.24, has been obtained through the export with release IFC 4x1, that allow a full exportation of *IfcPropertySet* attributes.

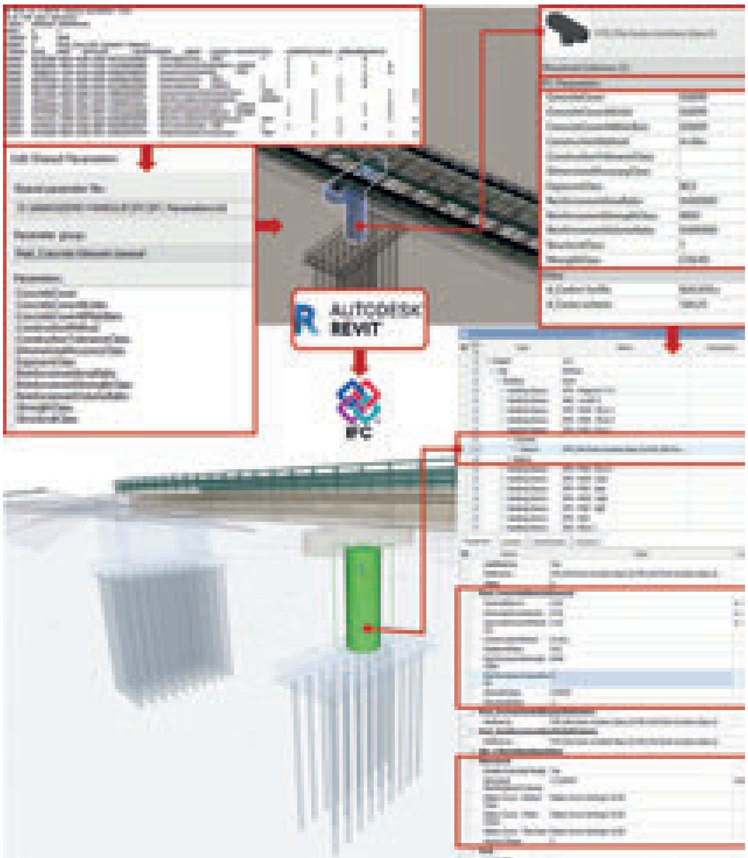


Fig. 6.24 Bridge Model IFC exchange

The attributes are collected below the *Pset* label, providing essential information that without this approach would otherwise not have been stored. In fact, by adding the same shared parameter, without the use of *IfcPropertySet* not all types of exportation or tools guarantee storage of this information.

IIn conclusion, IFC export makes it possible to communicate most information in the AEC sector, thanks to the implementation of *IfcPropertySet* enabling further information to be shares, and ensuring the reliability of data. Nevertheless, the lack of classes and appropriate attributes for steel elements, geology, hydraulic, and environmental data represent a weakness. For this reason, several examples provide and promote the integration between different export programs such as LandXML, Okstra, CityGML and so on.

6.6.2 CityGML

Given the growing need to represent the urban context in 3D, the Open Geospatial Consortium (OGC) has introduced the CityGML format. An informative semantic model for the representation of urban objects, which allows interoperability between different applications [90]. The CityGML format is structured according to classes and relationships, describing most of the topographic objects characteristic of urban and territorial models, while maintaining the geometric, topological, semantic and appearance properties [90]. In regard to road model objects, there is a special class called *"TransportationComplex"*, which is composed of two other parts - *"TrafficArea"* and *"AuxiliaryTrafficArea"*. The class *"TransportationComplex"* can be thematically differentiated in the sub- classes, road, rail and square. Each *"TransportationComplex"* is characterized by the "function" and "usage" attributes. The "function" attribute describes the purpose of the object, such as a national road, highway, provincial road, or airport, while the "usage" attribute represents the way in which the object is currently used with respect to the function. In addition, every *"TrafficArea"* can also have different attributes: i) function; ii) usage; iii) surface Material. The function and use attributes describe the object (for example lane, pavement, bike path, etc.) and the methods of use (for example pedestrian, car, tram, etc.). On the other hand, the *"surfaceMaterial"* attribute specifies the type of flooring. Even the OGC has gone on to define its own LOD scale that is representative of the informative contents on an urban / territorial scale that consists of four information levels. In LoD0 the objects are modelled by linear entities that define a network, LoD1 through a geometric surface that reflects its actual shape; from LoD2 to LoD4 the model contains the *"TrafficAreas"*, intended for the transit of vehicles or pedestrians, and the *"AuxiliaryTrafficAreas"*, i.e. road markings, flower beds or road edges, etc. [147]

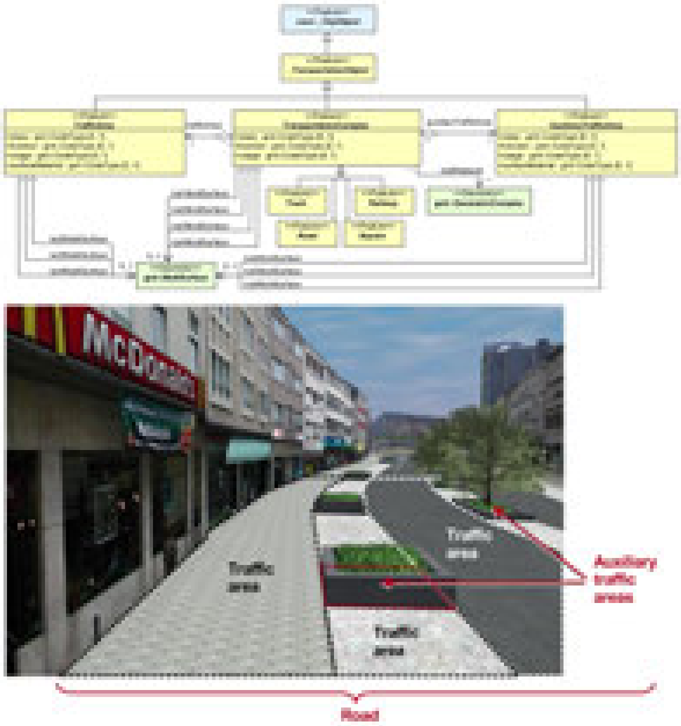


Fig. 6.25 CityGML trasportation objects

CityGML is an open data model and XML-based format for the storage and exchange of virtual 3D city models. It is an application for the Geography Markup Language (GML), the extendible international standard for spatial data exchange issued by the Open Geospatial Consortium (OGC). Its models are composed both of a geometric part and a thematic part. In the second release (CityGML 2.0) two new thematic modules for the explicit representation of bridges and tunnels are introduced. Bridges and tunnels can be represented with different levels of detail (LOD) and the underlying data models have a coherent structure with the building model. For example, bridges and tunnels can be broken down into parts, thematic boundary surfaces with openings are available to semantically classify parts of the shell, and installations as well as interior built structures can be represented [90]. This coherent model structure facilitates the similar understanding of semantic entities and helps to reduce software implementation efforts but unfortunately it is not possible to model the ground with its properties. For this purpose, Tegtmeier et al. [164] have proposed and extension - called GeoSciML - specific data model and encoding for the storage and exchange of geoscience information. Notwithstanding, it is possible assume, that the use of CityGML is not supported by the amount of authoring software, requiring complex post-processing. Moreover, it doesn't allow to store all information of an infrastructure project such as steel details, reinforcements, alignments and so on.

6.6.3 LandXML

The development of data programs capable of converting alignment models started in the 1960s [10]. Since then, before the introduction of IFC, the most widely used format for data exchange for civil engineering and measurements was the LandXML. LandXML is a data format based on eXtensible Markup Language (XML) developed in the U.S. in January 2000 [110]. According to Esfahani et al. the creation of one comprehensive data format like IFC, capable of interoperating with any kind of data is not the right approach [73]. The proper solution should be a system ontology based on allowing communication and data exchange among application models [72] [74]. Several studies propose an approach designed to integrate several items of information provides by different formats, such as the Open Infra Platform (OIP), proposed by Amann et al., that allows views of alignment and digital elevation model data. Moreover, it supports several other exchange data formats such as: IFC Alignment, FC 2x3, IFC 4, IFC Bridge, LandXML, OKSTRA, LAS 1.1/1.2 and so on [8]. This is due to the fact that none of the existing standards are able to translate all the information typical of Civil Engineering. For instance, when it comes to alignment, there are no standards that can support all types of transition curves: LandXML does not have Clothid curve type, OKSTRA does not have a sinusoid curve type, and the IfcAlignment does not support a Bloss transition curve type [11].

The LandXML is not a proprietary data format that supports land-development elements information, allowing an exchange of data with different applications. It is well suited for representing and exchanging surface, alignment and profile data, providing a limit manipulation of geometric/ parametric road and railway design, as shown in Figure 6.26. Nevertheless, this program has some criticalities related to syntax errors, weak point typing, name options, clothid curves and so on [10]. Furthermore, after a period of implementation, it seems that development of this program has slowed down, in the absence of a standard organization that guarantees its longevity [10].

In this context of information exchange, the object is to facilitate the communication of data among applications, through open data format. Even though the program does not allow a complete export of the facility, it provides suitable possibilities to share infrastructure information. For instance, as shown in Figure 6.27, some different roads solution have been imported into a BIM application, for the concept design. The various alignments created in a dedicated application have been exported, through LandXML format. In this way, it is possible to produce a correct corridor alignment, verified from a normative point of view, to proceed to concept design development. One of the weaknesses of this process, is the lack of a bi-directional process and also the problem of conducting regulatory verification on the open data program.

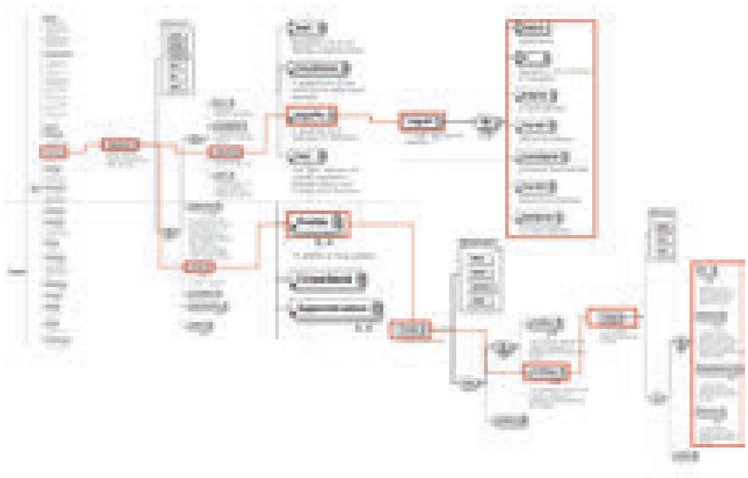


Fig. 6.26 LandXML schema

IIn conclusion, the use of the LandXML program provided an appropriate support to communicate specific types of data, and it is one of the most common formats used by many import and export applications. Nevertheless, as mentioned above, it is not the right solution for sharing all the data that makes up the specifications of a civil project. The most interesting approach should be to implement an ontology based platform able to read information provided through different data formats, as proposed by El-Diraby et al.. This study introduced the Infrastructure Product Ontology (IPD-Onto), a system based on five domains (Project, Process, Actor,Resource and Product) of utility infrastructure. The ontology process starts with the assumption that a project is composed of a set of processes, that it involves a set of Actors to control/use resources in order to produce Products. Products are the central core of ontology concept, divided into four distinct groups [68]. Although it seems the open data format development follows a different direction, improving the IFC layout with tailored classes for infrastructure design. This choice probably will require a lot of time and effort to reach full exportation of a meta-model able not only to communicate geometrical and attribute information, but also to include information related to project, processes, actors and resources.

Fig. 6.27 LandXML data exchange

6.7 Conclusion

In conclusion, after this preliminary and non-exhaustive overview of interoperability formats, it is possible to assume that at the moment there is not a unique exchange data format able to collect, translate and share information in the civil engineer field. The IFC data is model is surely one of the most mature and internationally standardized data model. Permitting an high level of integration between various software vendors and supports a diverse range of application scenarios. Landxml, as shown, is able to overpass some limitation of IFC standard, but at the same way, it doesn't assure a contininuty of update and it doesn't contain features and classes able to map construction element or data relative to cost and time. Then, the CityGML doesn't support by the large part of BIM authoring software, requiring complex work of re-processing with the danger of running into data loss. For these reason it is necessary to use different standards data model, exploiting the potentiality of each standards. The IFC has the advantages to model buildings digitally in great detail including the comprehensive semantic description of a building, the modeling of all building elements and spaces as well as the reciprocal relationships between them. The LandXML is very powerful to share topography and road information. Then, the CityGML is very useful to provide information at district and city level.

The next steps will dedicated in the field of extending geometric representations, such as point clouds, model servers and using Semantic Web Technologies. To improve model consistency, it would be desirable in the long term to parametrize objects to remedy the currently lacking connection between an attribute and its geometric representation for infrastructure objects such as bridges and tunnels or streets and railway tracks are currently being actively developed.

Chapter 7

Integration BIM requirements

This chapter aims to investigate the procurement contract approaches provided by international literature and to illustrate the ANAS approach to BIM procurement. Then from the analysis of such national experiences, the evaluation of BIM requirements has been carried out defining different metrics to compare those examples. Finally, the chapter tried to relate the contractual approach provided with other framework agreement, based on collaboration and to show the exploitation of this type of contract in the national context.

7.1 BIM procurement overview

In spite of increasing demand for adoption of BIM throughout the AEC industry and the desire from clients and society for teams to upskill and deliver, there are still significant difficulties in realizing the higher potential of BIM's utility. Knowledge about how to better align information management process and expectations on information deliveries through the design, construct and operate phases of construction projects is a central concern for the industry and its clients; yet, standards and support systems are lacking.

According to Ciribini et al. *"...Nowadays, there is not an Italian governmental strategy to guide the growing implementation of information-based technologies. Thus, several Italian public calls for tender have required the use of BIM 'tools' without a proper change in the working process...* [46]. M.D. 560/2017 aims to promote BIM methodology diffusion starting from contractingauthorities, in order to create a boost effect, and to facilitate the spread of BIM within public works, according to the European Directive. Therefore, Italian regulations are carefully dealing with this topic to avoid using BIM simply as a technological change, but rather as BIM-based methodology [46].

Considering the difficulties involved in managing BIM procurement using traditional methods, full potential cannot be reached. Traditional procurement, such as Design-Bid-Build [29], can be a real impediment to a proper BIM implementation [52]. Currently, the maximization of value and the minimization of waste is difficult when the contractual structure inhibits coordination, stifles collaboration and innovation, but incentivises individual goals at the expense of others [46]. In fact, with the emergence of claims due to the gap between design and construction, the creation of a new contract approach has been necessary [7]. Nowadays, several new partnering approaches have been introduced to support principles required for Lean/BIM implementation including collaboration and integration[52], approaches such as AIA E202 and AIA E203, JTC, the CodensudDOC301, the NEC3 and so on [29]. These contracts mainly have the same characteristics, which can be summarized as follows: i) multi-party, ii) Early Involvement of key participants, iii) team goal validation, iv) shared risks and rewarding, v) collaborative decision making [7].

In this context, it is possible to identify two main approaches. The first one consists in the American approach named Integrated Project Delivery (IPD), where all different participants are grouped into a single contract for all project stages. The second one is typically used in a European context and is based on the union of several contracts, previously awarded via an alliance framework [7]. In the first group, there are contracts such as the ConsensusDOCS 301 [87] for example, which proposed the introduction of BIM in contract agreements as addendum to contractual documentation, maintaining traditional projects as an object of the contract. In 2013, the New Engineering Contract (NEC) institutes provided the guide *"How to use BIM with NEC3 Contracts"*,it is a compendium that integrates the CIC protocol with added clauses to improve some aspects. The guide proposes an appropriate introduction of BIM in contracts, such as works information, the scope of any information, tables referring for instance to the timing of Model Productions and software used to produce models. Moreover, the guide suggests including some additional compensation for parties that are unable to generate data using BIM parametric modelling or for whom it is out of their control, or the introduction of clauses that allow the owner to revoke any license or contractual obligations in the event of failure to achieve contractual obligations [71]. The Journal Contract Tribunal (JCT) in 2011, published the *Public Sector Supplement*, which includes amendments for the adoption of BIM in public sector projects. The JTC's amendments propose that any agreed BIM protocols, such as the CIC Protocol, are included in the contract documentation, encouraging collaborative working with forms of contract, namely JCT Constructing Excellence [135]. Conversely, the PPC2000 does not make reference to the CIC BIM protocol, rather it offers a multi-party contract integrating all consultant appointments with the main contractor appointment and a corresponding sub-contract [135]. Furthermore, it supports *"trust, fairness and mutual cooperation"* at the clause 1.3, and "...Partnering Timetable and Project Timetable which under the two stage, multi-party structure relate firstly to the pre-construction phase and then the construction phase, creating mutual commitments to agreed deadlines by the client, main contractor, all consultants and selected key sub-contractors" [135]. In 2013, CPC2013 provided an agreement suitable for international building and construction projects, addressing complex works, to support BIM protocols. It states that the model is to be used only for the design stage and copyright and ownership rights remains the property of the creator with particular reference to the contractor [87]. It encourages collaboration, requires the creation of federated models and the use of a CDE for full information exchange through the chosen format. Moreover, for each project team it defines the role and responsibility matrix dealing with responsibility for creating, analysing and updating specific project information at different stages of the project [87]. Compared to CIC BIM Protocol [51],it identifies six design stages and LoD references for the design elements, which have to be classified using theUniclass standard. Finally, contractual prevalence is established in the information relating to federated models and in the information derived from it over the use of technical drawings. Moreover, if there is a contractual clash between contract and protocol, the contract will prevail. These documents may include summaries such as: i) aggregation of teams, ii) entrusting the project, iii) construction and maintenance phase [7].

IIn the second group, on the other hand, the most important example is the FAC-1, which is structured according to a multi-part, or rather a poly-part configuration, adding to a contract core all the participants involved in the process. Fac-1 is a Framework Alliance Contract, developed by Prof. D. Mosey of King's College London Centre of Construction Law. It aims to improve and support contract collaboration to save significant costs and to create an increase in value [134]. Given its nature, this type of contract seems to be in synergy with BIM philosophy. It is structured as a Common Law Contract, to provide a standard form designed to help plan and integrate a large number of two-party contracts and/or related projects for works and/or services and/or supplies [134]. IIn fact, one of the main features of this contract is the possibility of adapting it to the requirements of collaborating members, by selecting the clauses that they wish to apply [62]. The FAC-1 is composed of several modules suitable for general goals called Objectives, which will be address specific Objectives measured through Key Performance Indicators (KPI) [62]. Furthermore, the contract performs both the aims of a Project or a Program. The collaboration is set among the Client, the Alliance Manager and the Collaboration Members who sign the FAC-1 [62]

According to Mosey et al. BIM *"...is a way of working that facilitates early contractor involvement, underpinned by the digital technologies which unlock more efficient methods of designing, creating and maintaining our assets"* [135]. So, the choice of procurement model is essential to support the supply chain in a more integrated manner, in order to obtain sufficiently early BIM model contribution from designers, contractors and sub-contractors, thereby avoiding the risk of delay or fragmentation of data. Moreover, incorrect advice regarding procurement models might give rise to significant disputes [135]. For this reason, the provisions of FAC-1 support the BIM approach by underpinning design, supply chain engagement, costing, Risk Management and programming [134]. In relation to obtaining an increase in value through BIM the contract provisions relate to [1]:

- Data transparency and team integration
- Agreed software
- Integration of documents enabling and supporting BIM
- Agreed BIM deadlines, gateways and interfaces

[1]These provisions are reported by Mosey in FAC-1 Briefing Paper [134]

- Flexibility to agree any combination of BIM contributions
- Flexibility to bring in BIM contributions from specialist sub-contractors and manufacturers
- Direct mutual licences of Intellectual Property Rights
- Integration of BIM management with governance and clash resolution
- Flexibility to obtain BIM contributions from additional Alliance Members involved in the occupation, operation, repair, alteration and demolition of a completed Project
- Potential for the BIM team to learn and improve from Project to Project

The collaborative approach seems to underpin the introduction of BIM in procurement, promoting collaboration of the entire supply chain. As reported in this paragraph the are several framework agreements suited to support BIM procurement. A common point to these provisions is the idea of *"good faith"*, *"mutual trust and co-operation"* and *"fairness"* [135]. Nevertheless, this type of contract is still not used more in the Italian context; particularly, it is difficult to promote this idea of mutual trust between clients and other parties due to a historical context of disputes that lead to particular stress in terms of public procurement.

7.1.1 BIM Requirements

In the Italian context, Anafyo reports [13] that in 2015 a business value of BIM amounted to €1 billion among private and public sector works, and this figure was estimated to grow to a value of `€ 2.6 billion in 2016 [14] [151]. The number of public tenders where BIM is required is increasing. In order to evaluate how different Public Administrations are approaching the introduction of BIM in public tenders, several cases studies have been analysed (as shown in Table

Table 7.1 Italina BIM procurement examples

	Navetta	**San Donnino**	**Demanio**	**Cortina 2021**	**Sacrario Militare**
Year	2017	2018	2018	2019	2019
Dimension	70 [m]	181,10 [m]	-	-	-
Works amount	€ 1.340.000	€ 3.359.889	-	€ 40.000.000	€ 753.000
Type	Infrastructure	Infrastructure	Building	Infrastructure	Building

IIn public procurement one of the main aspects requiring investigation, as a researcher, relates to the definition of BIM requirements. The Italian office for standardisation – UNI - with the publication of UNI 11337-5, in 2017 provided a standard form for EIR documentation. The aim is to define roles, requirements and the necessary workflow for the production, maintenance and transmission of information and its connection and interaction in digital processes [48] [49] [50]. UNI introduced levels of coordination and verification to solve data error and to manage clash resolution. The levels of coordination are: i) LC1 model to same model authoring; ii) LC2 between model with other models authoring iii) LC3 between information extrapolated from the model with other documentation. The EIR defined by the general contractor is attached to contractual agreements, and is mandatory under M.D. 506/2017 [132].

The metric used for this study derived from previous examples of contract and from the literature review about legal BIM, and from the noteworthy publications relating to CIC Protocol. The EIR plays a key role in contract support in the definition of technical BIM requirements, becoming part of the contract documentation with the BEP produced by the contractor, during the tender phase. The parameter to evaluate the EIR is as follow:

- BIM Uses
- Hardware and software specification;
- Level of detail/accuracy of the model (LOD, LOI);
- Coordinate system and units

- Exchange data format (only IFC or also native file format);
- Model structure;
- WBS of model structure;
- File naming;
- Definition of Information Project Delivery Plan (IPDP);
- Clash detection Matrix;
- Role and responsibility;

Table 7.2 italina examples of BIM procurement

	Navetta 2017	**San Donnino** 2018	**Demanio** 2018	**Cortina 2021** 2018	**Sacrario Militare** 2018
BIM Uses	yes	yes	yes	yes	yes
Hardware and software specification	yes	yes	yes	yes	yes
CDE	required to contractor	required to contractor	By Contract Authority	By Contract Authority	required to contractor
Level of detail/accuracy of the model (LOD, LOI)	UNI LoD	UNI LoD	UNI LoD	UNI LoD	AIA LoD
Coordinate system and units	yes	yes	yes	yes	yes
Exchange data format (only IFC or also native file format)	yes	yes	yes	yes	yes
Model structure	yes	yes	yes	yes	yes
WBS of model structure	yes	no	yes	yes	no
File naming	yes	no	yes	yes	yes
Definition of Information Project Delivery Plan (IPDP)	no	no	no	yes	no
Coordination and verification process	yes	yes	no	no	yes
Clash detection Matrix	yes	no	no	no	no
Role and responsibility	yes	no	yes	yes	yes
Contractual condition	2D document	not defined	paper documentation	BIM model	paper documentation

7.2 ANAS BIM procurement

The first BIM public tender realized by ANAS was in 2017, for the development of works relating to the project known as *Lavori di sistemazione della curva "Carrai" e della curva "Acqubona"*, in Figure 7.1. IIt was the first test conducted by ANAS to apply BIM methodology to a public tender, before publication of the standards UNI 11337 and the M.D. 560/2017. In the absence of these important references, the strategy adopted followed that proposed by ConsensusDOCS 301 to add the BIM model to contractual documentation as additional information, while the contract object remained the traditional project. In this way, it has been possible to maintain the traditional project as the contract object, thereby avoiding risks due to the lack of regulations and interoperability of BIM models. Furthermore, the contractor is constrained to use the model for the construction phase and update it at each milestone. Unlike for other requirements, such as LOD references, model review and so on, the EIR refers to BS PAS 1192 and AIA requirements [3].

The EIR defines the contract obligations for BIM services in terms of time, commitments and sanctions; but specifically, it defines how to manage the model, the information required, data exchange format, the number of models for each discipline, and so on.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IL DIRETTORE APPALTI E ACQUISTI
Adriana Palmigiano

Fig. 7.1 BIM Procurement - *Lavori di sistemazione della curva "Carrai" e della curva "Acqubona"*

For this first pilot project, two EIR were created, the first for engineering and architecture services to transform a traditional project into a BIM project, and the second for works. The design services EIR defines how to develop the model, the LOD scale to be reached, the exchange data format required, model, sub-model and element coding according to the WBS project. The model structure required is shown in Figure 7.2 and Figure 7.3, in parts of disciplinary models according to WBS such as roads, retaining walls, tunnels, MEP systems and so on. Furthermore, they do not exceed 150 MB in size. The disciplinary models have been aggregated in a unique *"Aggregated Model"*, in order to obtain schedules and technical drawings. The coordination model is obtained through a *"Federate Model"* to attach time and cost (4D and 5D).

Fig. 7.2 Model structure schema

The EIR defined the coordinates according to Gauss-Boaga system projection. The LOD scale used was that indicated by UNI 11337 part 4 [47] as reported in Chapter 7. The LOD scale required is LOD E, which should correspond to executive designs according to DPR 207/2010. In this case, given the nature of the service and tender - being a direct procedure worth more than `€ 40.000 - it was also possible to indicate how to develop the project with specific software chosen by the Contracting Authority. The contract was obliged to deliver the project in native format and in the form of IFC release 2x3. In Art.2.11, ANAS defined that the Intellectual property of the model and the libraries *"...will remain the full and absolute property of ANAS; which will therefore be the exclusive owner of any and all rights to use, exploit and destroy the material..."*. In this first procurement, some important indications were excluded, such as the CDE, the roles and responsibilities matrix, the definition of level of coordination and verification, the clash matrix, BIM uses and so on. This is due to the nature of the service and a sort of inexperience and a lack of example to follow to conduct this kind of service. Notwithstanding, the model obtained and experience gained during this brief procurement was essential for the definition of EIRs for subsequent works.

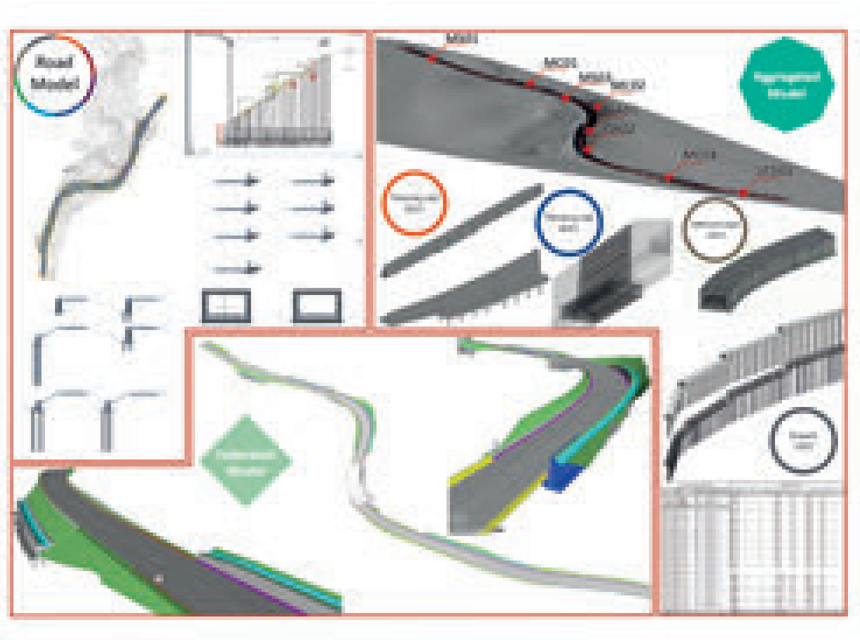


Fig. 7.3 *"Curva Carrai e Acquabona"* model structure

The second generation of EIR's provided by ANAS (Figure7.4) integrated the proposals suggested by UNI 11337 part five and six [48] [49]. It is a technical part of more a complex contract agreement. It standardises the activities of contractor and the mode of communication and verification with the Contract Authority. Furthermore, it defines the timing and mode of payment for the activities carried out. The EIRs produced are for *Contract works* and for *Engineering and architecture services*. The bidder has to draft an BEP in answer to ANAS 's EIR that becomes a contractual obligation during the activities development.

Fig. 7.4 ANAS EIR's

The EIR's proposed establish the requirements to develop BIM activities :

- the LOD of model to reach;
- The Coding of model, sub-model and elements, according to a WBS structure;
- The minimum of information required that model have to mandatory;
- The exchange data format (native and open) admissible;
- The modality of verification executed by ANAS;
- The intellectual property;

The requirements required to the contractor are:

- Hardware and software;
- Matrix Roles and Responsibilities;
- A definition of Information Delivery Plan(IPD);

TThe result of this work was publication of EIRs for the engineering and architecture services inserted into the Framework Agreement, contracted for `€ 240 million. It takes the structure developed in the contract works adds the ANAS Protocol, named *"Linea Guida BIM preliminare"*, published by ANAS in 2018. This is useful for addressing BIM processes, explaining in greater detail the workflow between ANAS and contractors, and development of the process within the CDE provided by ANAS. The CDE workflow is described in the ANAS Guidelines, identifying three main workflows: i) *in-house design*; ii) *external design*; iii) i*n-house desgin with external support.* For each workflow, the Guideline explains the verification, validation, archiving and authorization process, and also identifying the roles and responsibilities related to carrying out the project during different state changes. In addition to EIRs for contract work, it introduces important innovations, introducing (A) a table where the contractor has to define the BIM Objectives and relative BIM Uses, and at clause 11.2 indications as to how to derive the various outputs (i.e. Model, CAD, reports and so on). Moreover, at clause 21 it defines standards for clash detection, which can be; i) Hard if there is a physical interference, solvable through a change of position of the elements involved; ii) Soft/Clearance clash if the proximity of elements is higher and falls within the limit of acceptable tolerance; iii) Workflow clash if the interference is between timing or work phases. For each interference a value will be assigned, shown in a Clash matrix where the contractor highlights the type of clash, its value and how he intends to solve it.

As reported in Table 7.3 the EIRs define which exchange data formats are permitted in native or open formats for BIM models, Technical drawings, schedules and other documents. In this regard, it is important to underline that ANAS as a Contracting Authority and Public administration cannot require the use of specific software to develop its project. This would cause a failure to comply with the standard set out in M.D. 560, limiting the market for bidders and taking the risk of causing claims during the tender phase. To solve this problem, at clause 20 paragraph 2.1, ANAS declares that it will verify information contents through the use a BIM platform based on Autodesk authoring applications.

Table 7.3 Exchange data format

Model/Object/ Document	**Exchange Data Format**	**Exchange Open Data Format**
BIM model	.Rvt .Dwg .Nwd, Nwc	IFC 2x3, IFC 4.1 Landxml :bcf
Technical Drawing	.Dwg .Dwf .Pdf	.Dxf .Pdf
Other documents	.Xls	.Csv .Xml
Schedule documents	.Xls, Dcf	no
Ohter	.Txt, .Pdf	no

The information management model defined by EIR for project development follows the framework depicted in Figure 7.5. According to the Chapter 7 section 6.2, a framework has been introduced for interpolated BIM Uses, BIM objectives and LODs. The bidder, in response to ANAS' EIR, has to report this information in his BEP. Moreover, the bidder has to define how he intends to use the BIM model and develop modelling activities, developing a sort of table, identifying several milestones. These milestones identify moments for execution of model verification and validation activities, according to contract indications. In this way, it should be possible to map information process, roles and responsibilities and origin of information. The identification of outputs, which may be of different types (reports, technical drawings, documents, models or parts of models), is an essential step in organizing project management. At the moment, no single application is able to generate all information, hence the importance, during drafting of the Information Delivery Plan (IPD), of determining which platform will produce specific data on the basis of the WBS structure. For instance, in Figure 7.6, a table relating to one of the project pilots, based on the model structure, created according to the WBS, shows the type of model, the contents with PK indication, the design stage, responsibility, software used and data format.

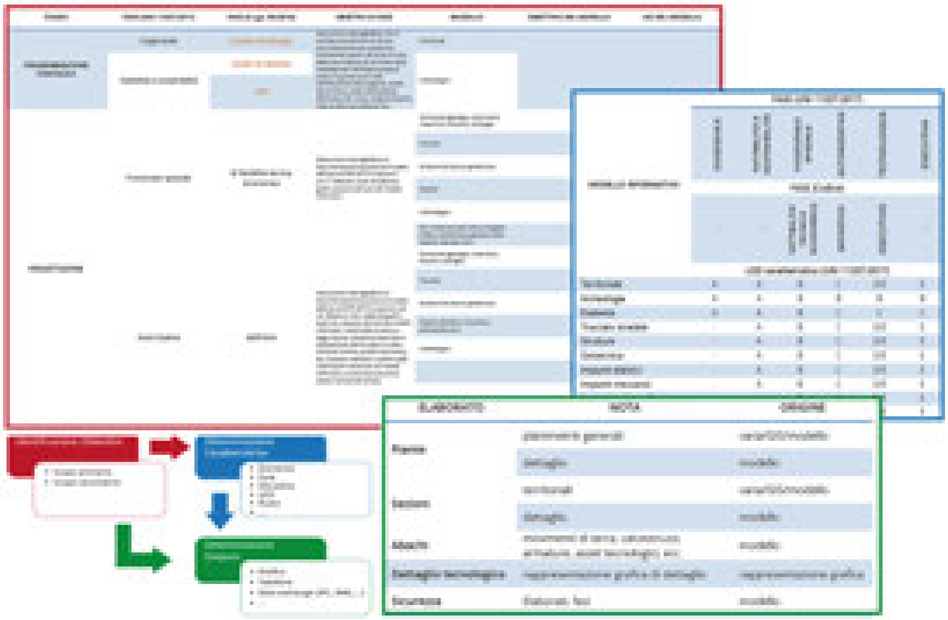


Fig. 7.5 information mode management framework

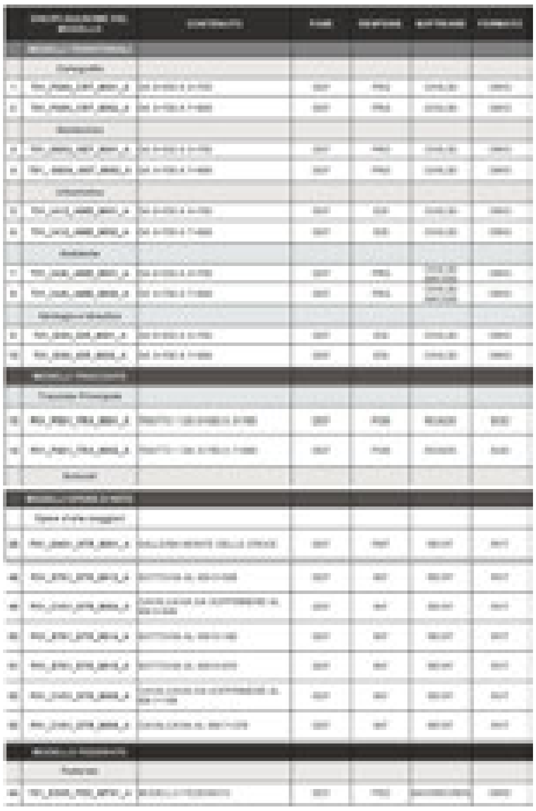


Fig. 7.6 Model granularity according to WBS

7.3 Conclusion

The EIRs for engineering and architecture services attached to the agreement framework published by ANAS in 2018 for `€ 240 million are an essential step of this research work, because in the Italian context they are the first instances of BIM procurement for a public administration. International literature in this regard does not provide significant examples. The contract forms, examined previously, are not applicable to Italian regulations, especially because most of those contracts are collaborative contracts, where the parties shared a common goal. Unlike in the Italian context, and compared also with British Protocol as CIC BIM Protocol, the form of contract has to be more detailed and restrictive. Furthermore, it is important to underline how those contracts published in 2018, are not subject to the obligations of M.D. 560/2017, so contractors offered the development of a BIM project as a rewarding requirement.

As mentioned above, this is reflected by the CRESME report that monitored procurement in the period 2017-2018. This depicted a substantial increase in BIM procurement as show in Figure 7.7. The data shows that in the first half of 2018 the percentage of the value of BM projects out of the total number of design calls was 12%; in the second half it was 20%; in the fourth quarter 30%, as shown in Table 7.4.

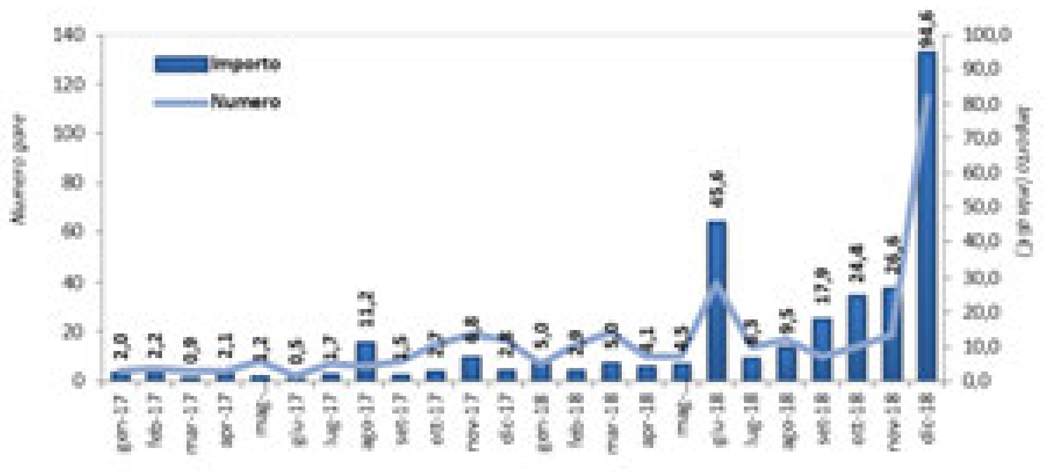
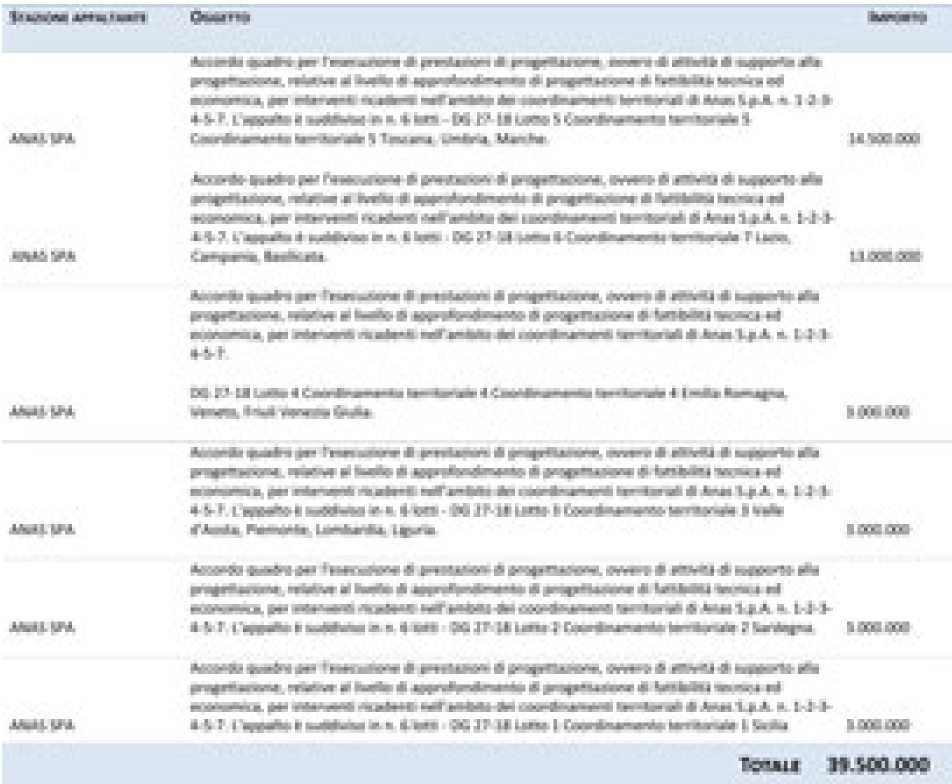


Fig. 7.7 BIM Procurement for Engineering and architecture service for the period 2017-2018. Soruce: CNAPPC-CRESME BIM Monitoring [53]

Table 7.4 Amounts based on tender for the EAS and BIM procurement for 2017-2018 (millions of euro) and-% incidence of BIM procurement on the total. Source: CNAPPC-CRESME BIM Monitoring [53]

	Toral EAS		BIM procurement		Incidence BIM procurement	
	2017	2018	2017	2018	2017	2018
Year	1.275	1.457	36	246	3%	17%
1°Sem.	419	568	9	67	2%	12%
2°Sem.	856	890	27	179	3%	20%
3°Sem.	554	479	12	146	2%	30%

For the amounts involved in BIM procurement, central administration plays a key role, but also public service managers, with 22 procurements worth `€ 71 million. In 2018 ANAS was the most important public service manager, with 6 project for an amount of `€ 39.5 million, corresponding to over 50% of the total for this category, as shown in Figure 7.8.



STAZIONE APPALTANTE	OGGETTO	IMPORTO
ANAS SPA	Accordo quadro per l'esecuzione di prestazioni di progettazione, ovvero di attività di supporto alla progettazione, relative al livello di approfondimento di progettazione di fattibilità tecnica ed economica, per interventi ricadenti nell'ambito dei coordinamenti territoriali di Anas S.p.A. n. 1-2-3-4-5-7. L'appalto è suddiviso in n. 6 lotti - DG 27-18 Lotto 5 Coordinamento territoriale 5 Coordinamento territoriale 5 Toscana, Umbria, Marche.	14.500.000
ANAS SPA	Accordo quadro per l'esecuzione di prestazioni di progettazione, ovvero di attività di supporto alla progettazione, relative al livello di approfondimento di progettazione di fattibilità tecnica ed economica, per interventi ricadenti nell'ambito dei coordinamenti territoriali di Anas S.p.A. n. 1-2-3-4-5-7. L'appalto è suddiviso in n. 6 lotti - DG 27-18 Lotto 6 Coordinamento territoriale 7 Lazio, Campania, Basilicata.	13.000.000
ANAS SPA	Accordo quadro per l'esecuzione di prestazioni di progettazione, ovvero di attività di supporto alla progettazione, relative al livello di approfondimento di progettazione di fattibilità tecnica ed economica, per interventi ricadenti nell'ambito dei coordinamenti territoriali di Anas S.p.A. n. 1-2-3-4-5-7. DG 27-18 Lotto 4 Coordinamento territoriale 4 Coordinamento territoriale 4 Emilia Romagna, Veneto, Friuli Venezia Giulia.	3.000.000
ANAS SPA	Accordo quadro per l'esecuzione di prestazioni di progettazione, ovvero di attività di supporto alla progettazione, relative al livello di approfondimento di progettazione di fattibilità tecnica ed economica, per interventi ricadenti nell'ambito dei coordinamenti territoriali di Anas S.p.A. n. 1-2-3-4-5-7. L'appalto è suddiviso in n. 6 lotti - DG 27-18 Lotto 3 Coordinamento territoriale 3 Valle d'Aosta, Piemonte, Lombardia, Liguria.	3.000.000
ANAS SPA	Accordo quadro per l'esecuzione di prestazioni di progettazione, ovvero di attività di supporto alla progettazione, relative al livello di approfondimento di progettazione di fattibilità tecnica ed economica, per interventi ricadenti nell'ambito dei coordinamenti territoriali di Anas S.p.A. n. 1-2-3-4-5-7. L'appalto è suddiviso in n. 6 lotti - DG 27-18 Lotto 2 Coordinamento territoriale 2 Sardegna.	3.000.000
ANAS SPA	Accordo quadro per l'esecuzione di prestazioni di progettazione, ovvero di attività di supporto alla progettazione, relative al livello di approfondimento di progettazione di fattibilità tecnica ed economica, per interventi ricadenti nell'ambito dei coordinamenti territoriali di Anas S.p.A. n. 1-2-3-4-5-7. L'appalto è suddiviso in n. 6 lotti - DG 27-18 Lotto 1 Coordinamento territoriale 1 Sicilia	3.000.000
	TOTALE	39.500.000

Fig. 7.8 BIM procurement for import over 1 million of euro in 2018

IIn conclusion, in trying to estimate the provisions provided by the ANAS framework agreement, it has been compared with other international contractual documentation, examined at the beginning of this Chapter, Paragraph 7.1, in relation to BIM procurement aspects. First of all, the ANAS contract framework is not based on the *"good faith"* and *"mutual co-operation"*. It does not include figures such as the *"Alliance Manger"* in the same way as the FAC-1 does, and it does not have a multi-part or poly-part contract structure, but it does identify an agreement between the contracting authorities and an economic operator, and in the case of a group of more than one economic operators it becomes group leader. The structure of the ANAS framework agreement is essentially based on provisions including general conditions and annexes, such as the general conditions setting out the commitments of contractors and sub-contractors. The annexes contain technical provisions setting out BIM requirements for managing the creation, transmission and sharing of BIM models between participants. In addition, the technical provisions refer to the BIM Guideline, i.e. a BIM protocol. It contains information related to CDE, roles and responsibilities for authoritative processes and information management.

IIn order to estimate contractual frameworks relating to BIM support in procurement, a set of metrics are used. Beginning with the report by the Centre of Construction Law and Dispute Resolution, King's College London [135], which reports BIM exploitation within procurement and contracts. ANAS contract framework has been compared, as shown in Table 7.5, with the other main examples. From the comparison, it is possible to notice how the ANAS framework provided several BIM provisions in line with the other contract forms. Nevertheless, some parts need to be added such as the involvement of contractors and sub-contractors/suppliers at early stages, or linking asset management through maintenance contracts. These absences are due to the necessity to improve a collaborative approach, overcoming the historical limitation of traditional procurement based on Design-Bid-Build, where each phase is negotiated with different contracts.

Table 7.5 EIR's Contract overview

	JTC 2011	NEC 2013	PPC 2000	CPC 2013	ANAS	FAC-1
BIM provisions in contract terms	yes	yes	yes	yes	yes	yes
Requires addition of CIC BIM Protocols to all contracts	yes	yes, with amend-ments	no	yes	ANAS Guide Line	no
Early warning system to support BIM clash detection	no	yes	yes	no	yes	yes
Direct mutual intellectual property licences among team members	no	no	yes	yes	no	yes
Provision for early contractor involvement to bring in pre-construction phase BIM contributions of main contractor and sub-contractors/suppliers	yes	yes	yes	yes	no	yes
Agreed mutual deadlines for specific activities	yes	yes	yes	yes	yes	yes
Link to asset management through corresponding repair and maintenance contract	yes	yes	yes	yes	no	yes
Provision for collaborative working	yes	yes	yes	yes	yes	yes
Provision for role of BIM Information Manager	no	no	no	no	yes	yes
Corresponding main contract, sub-contract and consultant appointment forms	yes	yes	yes	yes	no	yes

Chapter 8

Visual programming for infrastructure project

This chapter aims to introduce the concept of Visual Programming Language (VPL) and Parametric Design. The exploitation of algorithms to create associative relations between geometrical and physical aspects allows the designer to maintain different levels of linked information. The integration of VPL and parametric modelling with BIM makes it possible to overcome the limitations imposed by BIM tools when it comes to modelling complex geometry or Civil works. Starting with a brief introduction, the chapter shows the use of algorithm design to model tunnels and bridges, combining the positive aspects of BIM tools and algorithm modelling.

8.1 Parametric Design

The traditional drawing is an additive process that manages complexity as subsequent addition and overlapping of signs traced on paper. There are no associative relations that can guarantee internal consistency, which depends on the designer on the basis of a codification of standard and conventions. Limitations include detachment between the act of drawing and the cognitive mechanism in the creative process, which exploits the creation of interrelations rather than adding information. The other limit of traditional drawing is a lack of interaction with the physical aspect generated by the forms in the real world. For instance, it is possible to manage between interaction with force, project constraints, thermal properties, solar incidence and so on. However, early CAD models failed to solve this point of weakness, producing more than anything a translation of additive logic within the digital space [163].

BIM parametric modelling overcomes the limitations of traditional drawing as an additive process, by introducing parametric relations through geometrical parameters that define the geometric shape. Furthermore, it also adds attributes that may enrich the significance and characterization of objects such as materials, physical properties, producers and so on (Figure 8.1). In this way, elements designed in a BIM environment hold all the information that can be used to reconstruct the meaning of elements and much more, while avoiding the cognitive process necessary to translate the drawing convention into to a physical element.

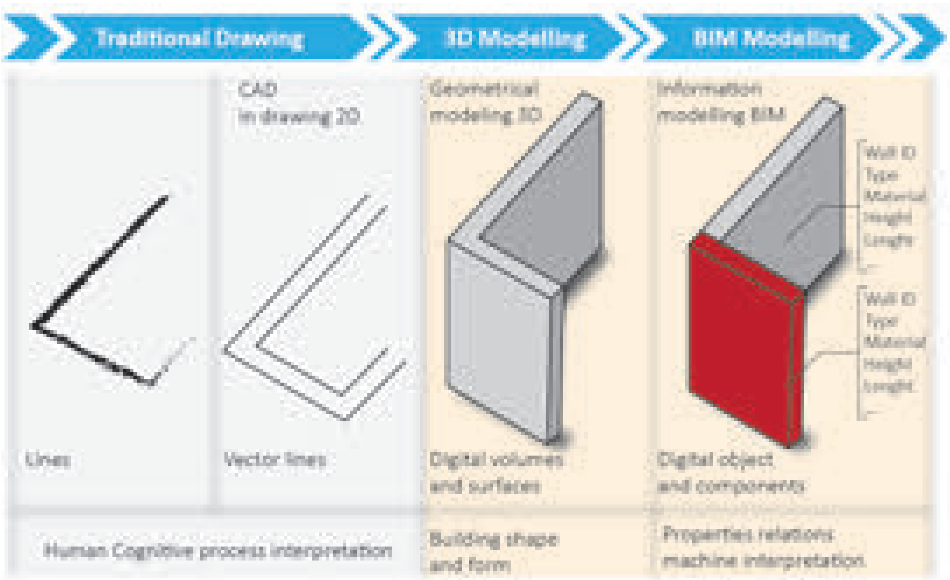


Fig. 8.1 Froma CAD to BIM

Before BIM, attempts to overcome the limitations of traditional drawings, began with studies about form finding, which aimed to investigate structural optimization through relations between materials, shape and structures. The process to develop these structures were physical models representing structural behaviour without the use of traditional drawings which cannot be used as tools to predict design outcomes. The pioneers in this work were Otto, Musmeci, Isler, Nervi and so on. They developed a new way to interpret projects, and increasing building complexity by linking shape and form through the idea that: "Form follow the forces" [163]. Structural optimization up until that moment was only mono-parametric but it marked the route to multi-parametric form-finding, which aims to let shape and form interact with other heterogeneous data, such as: geometry, dynamic forces, environment, social data and so on.

The first to use the definition of "Parametric Architecture" was Luigi Moretti in 1939. Moretti's research was carried out in collaboration with the mathematician Bruno de Finetti, within the Institution of Mathematical Research in Architecture (I.R.M.O.U). This research culminated in an innovative project for a soccer stadium, the form of which was derived from interaction between geometry and viewing angle and economic feasibility. The final geometry was a design using isocurve calculations that attempt the optimise the viewing position in the stadium.

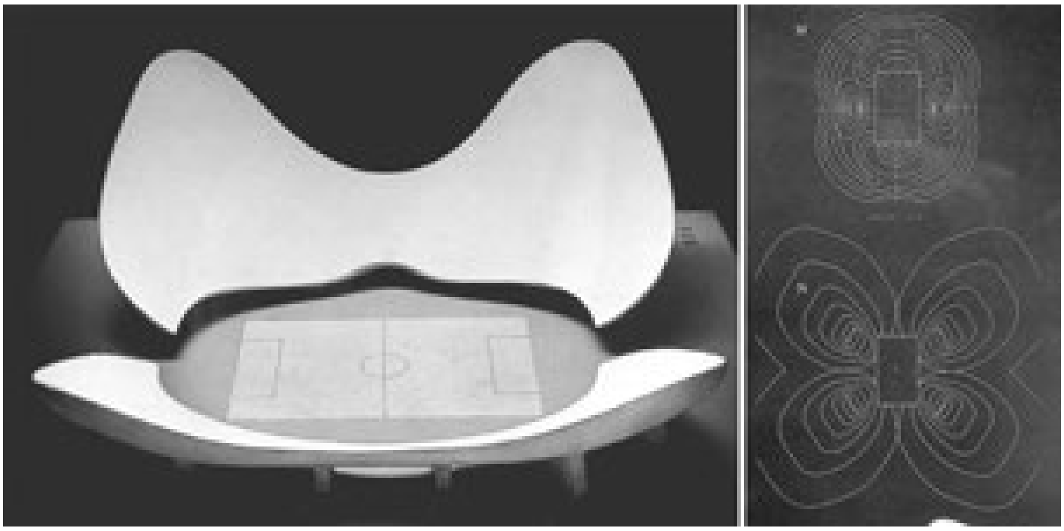


Fig. 8.2 L. Moretti soccer stadium

The advent of computers opened new frontiers to architecture and engineering design, offering the possibility of expressing parameters and their relations through a set of routines. In the wake of this new deal, Ivan Suntherland developed the design program, *Sketchpad*, for testing human-computer interaction, enabling users to design basic primitive items such as: points, lines, arcs, using a light- pen for input [163].However, this program did not enjoy the same success as *Autocad*, that in 1982 saw widespread uptake by architects and engineers, thanks to its ability to replicate repetitive tasks quickly and manage multiple drawing layers, thereby replacing the drawing board.

The first parametric software arrived in 1987, with Pro/ENGINEER. It was created for mechanical system design. The program allowed users to define input constraints which were associated with 3D parametric components. This reduced the cost of re-design and overcame the limitations of 3D modelling. At the end of '80s, there was a further innovation regarding the possibility to directly edit the software code though programming. In this way, it was possible to realize more sophisticated programs capable of managing complex functions beyond human capabilities by structuring routines and procedures. This approach is now known as *algorithm modeling*.

8.2 Algorithm modelling

The term alogithm coinde by 9th century mathematician Muammad ibn Mūsā al-Khwārizmī and used for the first time by Greek mathematicians in the sieve of Eratosthenes to find prime numbers, and the Euclidean algorithm for finding the greatest common divisor of two numbers [163]. A modern formalisation was proposed by David Hilbert in 1928, to solve the Entscheidungsproblem (decision problem). Later formalisations were defined to find effective calculability or effective method. Those formalisations included the Gödel–Herbrand–Kleene recursive functions of 1930, 1934 and 1935, Alonzo Church's lambda calculus of 1936, Emil Post's Formulation 1 of 1936, and Alan Turing's Turing machines of 1936–37 and 1939 [163]. Therefore, an Algorithm is a set of instructions used to return a solution to a problem, or to develop a specific task. Starting from an initial input, the instructions describe a computational process, that following a number of well-defined steps produces an output, as shown in Figure 8.3. In some cases, as shown in Figure 8.4, the outputs created may be used to analyse specific behaviour or perform specific tasks. The analysis output then became the starting input to runtime n-times in an iterative process, in order to optimise specific tasks using mono- or multi-objectives functions.

Fig. 8.3 Algoritm schema

In order to be executed by a computer, an algorithm uses specific computer languages and editors. These editors may be stand-alone or embedded in software applications. Examples of stand-alone editors include Python, C`, C++, and so on, while examples of editors embedded in software applications include programs such as Rhinoceros and Autocad, that allow the user to edit instructions and routines in order to automate specific tasks. Algorithms may be used to execute several procedures such as computational or decision-making calculations, but they may also be used to manipulate a standard set of primitive geometries. For instance, as shown in Figure 8.5, the creation of a line starting from a point has to follow a precise syntax, in this case the language used is Python. The script requires the user to set a starting point, and other conditions to validate the line generation.

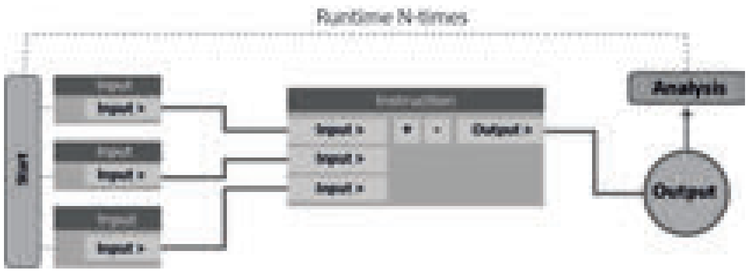


Fig. 8.4 Iterative algorithm process for optimization

The final output is not just a digital sign carried out by manipulating line tracing, but may be considered an interactive digital model that responds to input variations. In fact, if the coordinates of the starting point change, the line will change if the conditions are respected. The algorithm maintains the relationship that links line and point, not their location, thereby establishing an associative relationship between entities such as numbers, geometric primitives and data.

Of course, this approach offered new possibilities to designers to implement their workflow introducing new aspects into their project, while having more control and being able to manipulate data inputs while always maintaining control over final outputs and thus avoiding re-design or errors due to lack of updating. On the other hand, this approach requires the ability to translate the concept into a computer language, requiring a clear procedure for each step, especially in the case of complex geometric functions that have to be generated by gradual steps. As a result, script editing is a difficult operation not suited to everyone.

```python
import Rhino
import scriptcontext
import System.Guid

def AddLine():
    gp = Rhino.Input.Custom.GetPoint()
    gp.SetCommandPrompt("Start of line")
    gp.Get()
    if gp.CommandResult()!=Rhino.Commands.Result.Success:
        return gp.CommandResult()
    pt_start = gp.Point()

    gp.SetCommandPrompt("End of line")
    gp.SetBasePoint(pt_start, False)
    gp.DrawLineFromPoint(pt_start, True)
    gp.Get()
    if gp.CommandResult() != Rhino.Commands.Result.Success:
        return gp.CommandResult()
    pt_end = gp.Point()
    v = pt_end - pt_start
    if v.IsTiny(Rhino.RhinoMath.ZeroTolerance):
        return Rhino.Commands.Result.Nothing

    id = scriptcontext.doc.Objects.AddLine(pt_start, pt_end)
    if id!=System.Guid.Empty:
        scriptcontext.doc.Views.Redraw()
        return Rhino.Commands.Result.Success
    return Rhino.Commands.Result.Failure

if __name__=="__main__":
    AddLine()
```

Fig. 8.5 Python script for line between two points

In recent years many software houses have developed visual tools to facilitate script editing even for those who do not possess programming skills. The associative rule and dependencies are translated by these tools into a graphical method based on node diagrams. As with traditional scripting, visual scripting is based in two environments: the visual editor and 3D modelling environments.

As shown in Figure 8.6 in the visual editor there are nodes and link connections than contain the instructions for creating a line between two points. The inputs are the x, y, and z coordinates of the start and end points, which may be used as inputs for the node that contains the instruction to generate the line. The final output is a line between two points that can be modified on the basis of the relationship between the coordinates of points.

It is clear that unlike with the previous example, a visual editor can be used to simplify the scripting phase, without requiring any particular programming skills. Nevertheless, for very complex operations one of the main problems afflict this approach is the large number of nodes and connections that have to be managed in order to obtain the final output. Moreover, the visual editor always runs the entire script and for complex script there is a big use of resources from a computational point of view. Traditional programming, on the other hand, enables the re-call of sub-packages or parts of programs, thereby making computing more agile and more efficient.

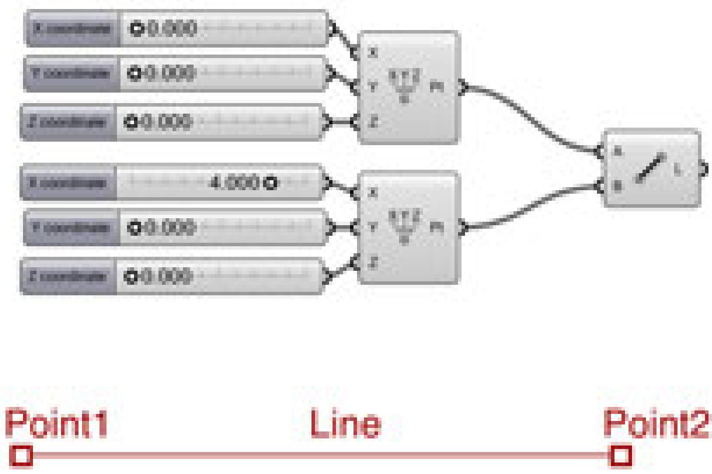


Fig. 8.6 Visual scripting for line between two ponts

Nevertheless, designers are now able to harness the potential of computational design without having to write code. Computational design is a powerful concept, and it has had an incredible impact in the AEC sector, in terms of exploration of new forms and shape optimisation. Several studies have been conducted in the last decade to investigate shape morphology in the fields of architecture and structures, thereby opening new horizons for architects and designers.

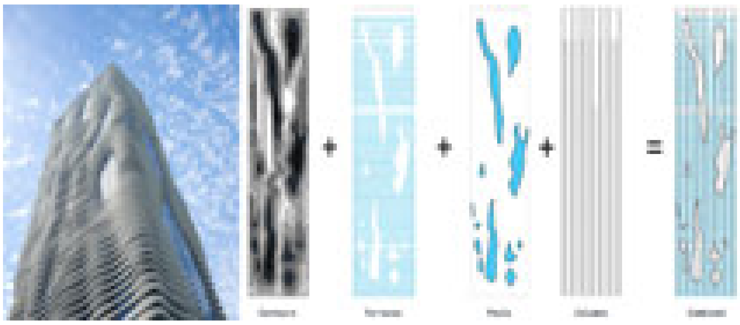


Fig. 8.7 Studio Gang‘s Aqua Tower Chicago, Illinois, 2009

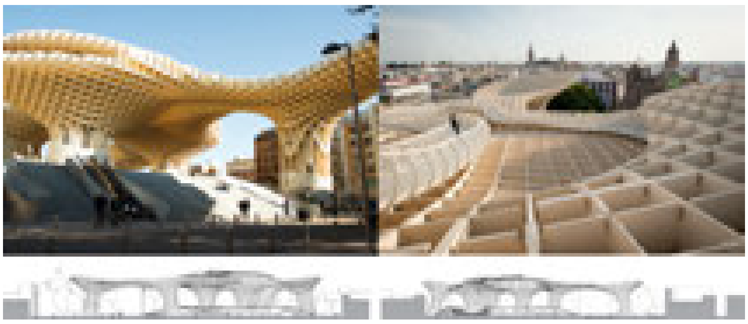


Fig. 8.8 Metropol Parasol Jürgen Mayer H. + Arup Espacio Metropol Parasol, Plaza de la Encarnación, Siviglia, Spagna, 2004-2011

In this research, the visual algorithm has been used to create relations between parametric BIM objects and their position in the project, in order to overcome the limitations of BIM environments in the management of civil design information. Two embedded applications have been tested, namely Dynamo and Grasshopper. Dynamo is a plug-in for Autodesk Revit, providing a visual editor for algorithm generation that which for 3D environments relies directly on Revit. On the other hand, Grasshopper is a visual editor that for its 3D environment relies directly on Rhinoceros, and thanks to specific nodes is also able to connect to the Tekla environment.

The approach followed in these example is to connect road corridor information with BIM parametric objects. The connection is made through an algorithm that starts with a road corridor and transforms this information into geometrical information, after which the algorithm divides it into a list of curves and points. The BIM parametric object can then be placed in the correct location thanks to the relationship between the list of curves and points with the placement points characterising the objects.

In this way, after the placement phase, the algorithm can be used, for example, to model reinforcement rebars for tunnelling, which given the lack of appropriate tools would otherwise require model manipulation or structural analysis, with the outputs used for form-finding optimisation.

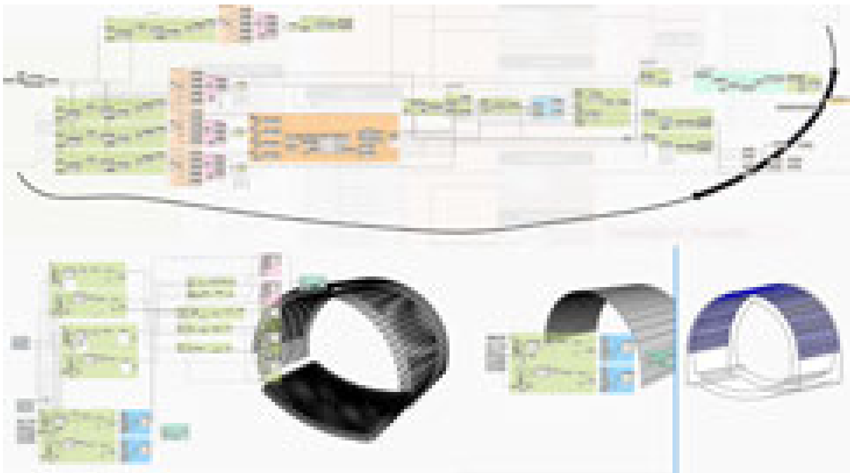


Fig. 8.9 Dynamo algorithm for Tunnel desing

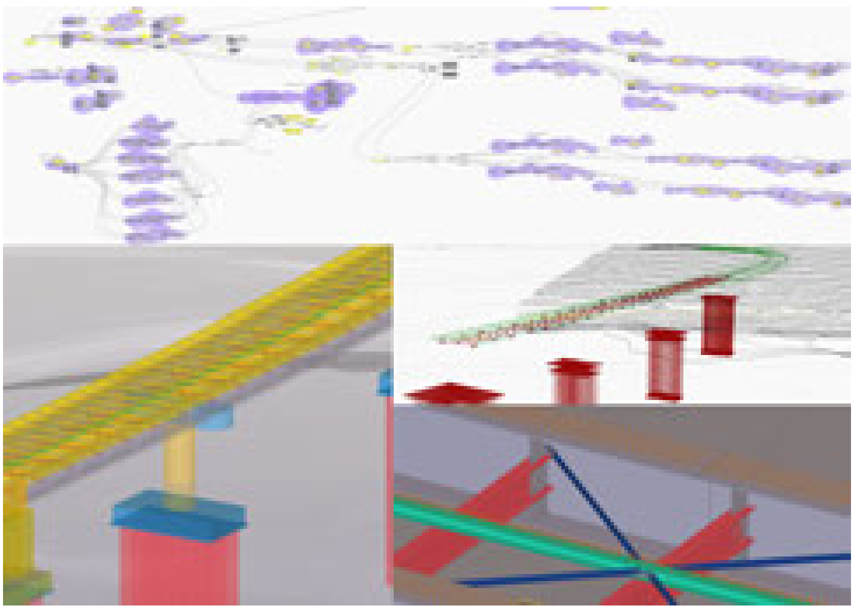


Fig. 8.10 Grasshopper algorithm for Bridge desing

Finally, these two examples will examined in more detail in the Chapter 9, below, demonstrating how visual scripting has now become an essential resource iin civil design, by helping to save time in the re-design phase while increasing control during the various design stages, thanks to the relationship created between the road corridor and BIM objects, and keeping the project up-to-date with the last review. As shown in the example, the algorithm may become very large and complex, making comprehension difficult especially for those who do not design the script. This makes it essential to execute the algorithm by phase, and to take note of inputs and outputs. Thanks to visual editor programs, even people who do not have particular computing skills may use algorithms, although they may not achieve the functionality of a real program with traditional scripts. In fact, in many cases this type of script, for a large amount of data, is too resource-intense from a computational point of view, and risks slowing down the process.

Chapter 9

BIM Use Cases

This chapter brings together several BIM Uses case studies developed during my research period thanks to partnership with ANAS, Regione Piemonte and to the work done in collaboration with a fellow Masters student in Civil and Building engineer at the 'Politecnico di Torino'. The main aims of these applications was to define and test a tailored workflow for infraBIM, going on to integrate BIM and GIS environments, in order to obtain a real Product Information Model (PIM). Taking into account the fact that most BIM tools are not suitable for infrastructure design, especially for certain disciplines or for preliminary phases, when the project is still on a large scale and the use of GIS tools is essential. For each case study, a short background will be provided, as presented in the literature review, after which the case studies will be described according to the research conducted on the different topics.

9.1 BIM applications

The main case study chosen for application of infraBIM workflow is the Demonte project *S.S. 21 "della Maddalena"*. The project has an overall lenght of 2,72 Km, starting from the current road S.S.12 *"della Maddalena"* located close ti the village of Demonte. The project derived from the necessity to redirect the heavy traffic coming from Vinadio, avoiding the pass in the historical center of Demonte. The project stemmed from the need to redirect the heavy traffic coming from Vinadio, to prevent it passing through the historical centre of

Demonte. This project is particularly suitable for testing BIM methodology for several reasons, one being the relatively small size of the road, but at the same timeit involves many works that can be characterised an infrastructure projects such as roundabouts, bridges, tunnels, culverts, retaining walls and so on. The total value of the works has been estimated at over `€ 50 million and the timing for its feasibility is planned after 2020. So it falls within the scope of M.D. 560/2017, under which BIM becomes mandatory for projects worth over `€ 50 million.

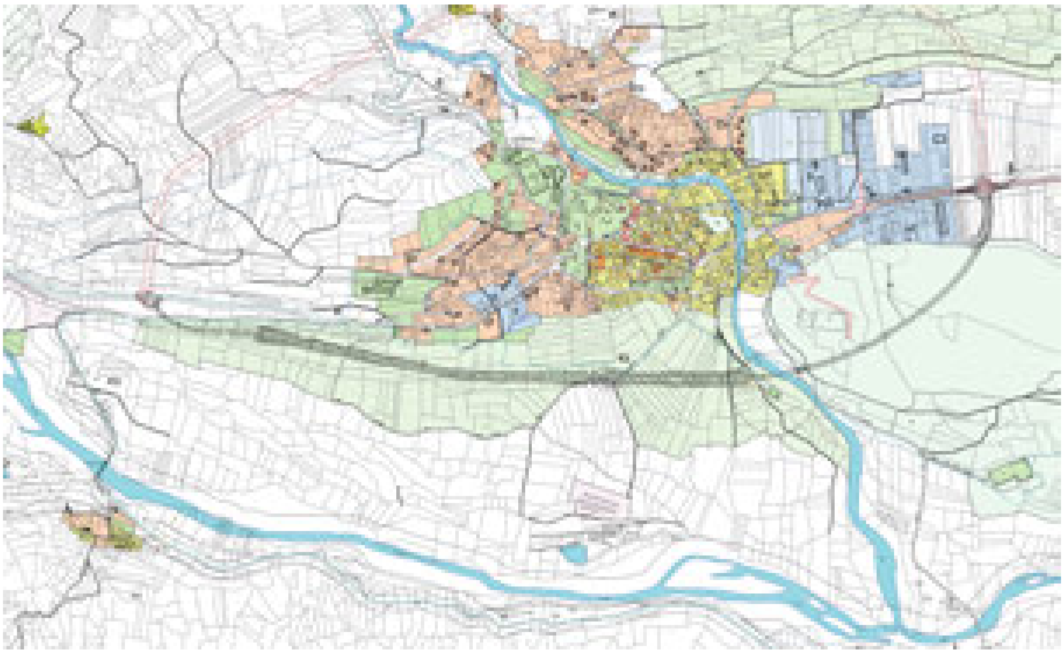


Fig. 9.1 Demonte Project planimetry

Other case studies, which will be presented in relation to specific topics, include a Viaduct on the Asti-Cuneo motorway, built by Regione Piemonte. This pilot project was used by Civil and Building engineering students on the course *"BIM and InfraBIM for built heritage"* at Politecnico di Torino. This small case study was used to develop a workflow tailored for structural design, while testing the interoperability process. Starting from a mathematical model for structural analysis, the aim was to arrive at a definition of a BIM Model for the construction phase. Thanks to several interoperability tests, benchmarking analysis was conducted, in order to evaluate the best options for integration of BIM and FEA software.

Fig. 9.2 The Viaduct on the hyghway Asti-Cune

9.2 BIM for Structural Desing

9.2.1 Background and previous works

The structural BIM design is a topic covered widely international literature, especially in the interoperability area. The integration between BIM authoring and Finite Element Analysis (FEA) specific software for structural analysis, continues to remain an unsolved problem. There are several reasons for this situation, and without doubt relate to the lack of an appropriate exchange data format able to transfer both geometry and property information to FEA software. The IFC format often is not able to communicate this kind of information, or it is not recognised by FEA software. Therefore, software houses use a direct link to overcome this problem, and in many cases this type of connection allows bi-directionality. Jeong et al. [104] [105] [103] proposed a study, shown in Figure 9.3, designed to integrate the BIM open data model, based on Open BIM Bridge Standard (OpenBrim) with the Sensors Health Monitoring (SHM), to enter data into an FEA software program like CSI Bridge in order to analyse the stresses and displacements. In this case the connection was created through an Application Programming Interface (API). APIs are programming interfaces used to create custom codes, exposing the source code of the software to increase additional features and create links between software, automating repetitive tasks [57]. In this way it is possible to avoid loading sensor data handling operations or the re-design of geometrical models.

Shim et al. and other authors introduced the concept of Digital Twin Model (DTM). The DTM is a virtualised version of a physical entity in the real world, a digital replica that can be an asset, process, system, or even a service [153] [55] [59]. The concept of a digital twin in other sectors like Power, Aerospace and Automotive for instance, is widely used to prevent technical errors or to simulate behaviour or performance to improve efficiency. Indeed, the Gartner Hype Cycle placed the digital twin among the top 10 strategic technology trends [153]. At the basis of the DTM application, but at the same time also for the example mentioned above, the essential step in building the digital twin is the inventory of elements and information definitions.

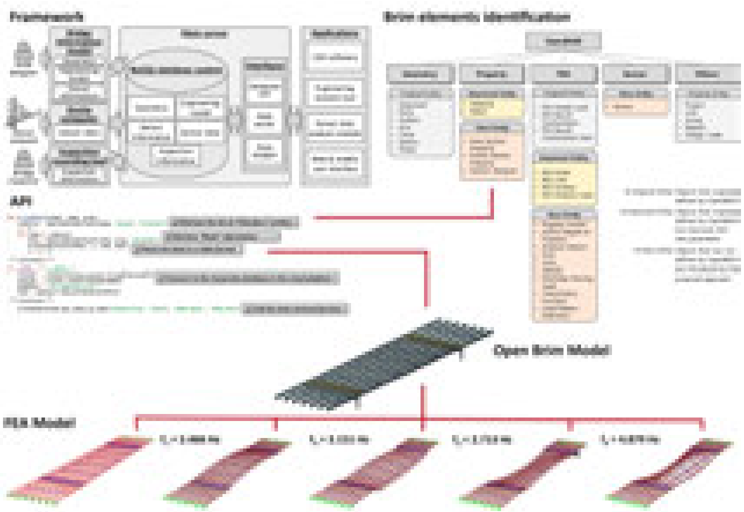


Fig. 9.3 Open BIM Bridge for Sensor Health Monitoring. Soruce Jeong et al. [104][105][103]

The integration of SHM and BIM for structure monitoring requires a platform of data aggregation of the results. In this sense, the study provided by Delgado et al. takes its cue from previous studies and in addition inserts a game engine such as Unity, as a graphic user interface (GUI) to visualise time-series data. Game engines are software programs mainly dedicated to video games development, however they also have widespread application in the scientific field, thanks to several functionalities such as a rendering engine to visualize 2D and 3D models, a physic engine able to simulate physical phenomena, interaction modules to provide an interaction with users, and networking modules to allow communication between server and client applications [57] [60].

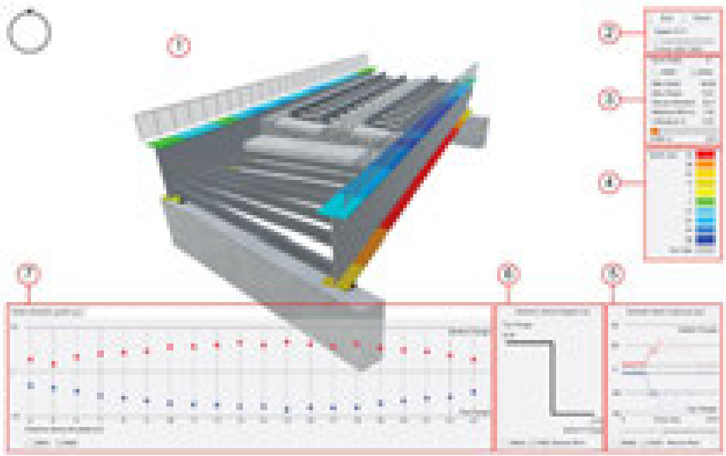


Fig. 9.4 GUI interface for BIM SHM. Source Delgado et al. [57]

The condition for using a BIM model for maintenance and especially for monitoring is to have a great amount of information, which has to be composed not only of geometrical data but also of other information from reports, photos, technical drawings and schedules, tests on materials and so on. For these reasons, image-based and close-range technologies are being increasingly used to map the 'as-is' condition, giving a time step of the bridge. Shin et al. and Leo-Robles et al., in their study proposed the use of image-based technology to acquire the shape of an element and of any damage. Then, using a reverse engineering process, it is possible to obtain several different types of information such as a 3D model, orthophoto, plan, section and so on. Furthermore, thanks to the RE and vector graphics environment, information relating to crack damage was recreated [153]. This approach is especially useful for Heritage BIM (H-BIM), as shown in 9.5,where the point cloud in addition to being a survey tool can also be used to analyse the verticality of a bridge part in order to estimate instability problems. By defining a plan pass for a point cloud portion, it is possible to compute the distance between the plane and point cloud [116].

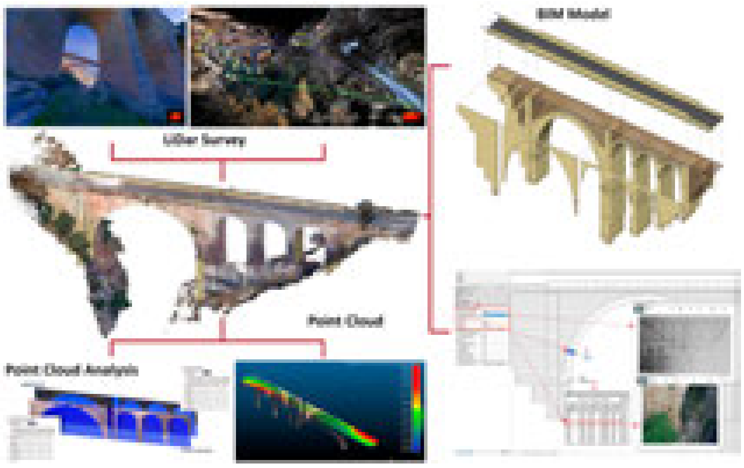


Fig. 9.5 Heritage BIM. Source Leon-Robles et al. [116]

In conclusion probably the application of BIM to bridge design is quite similar to building modelling, given the vertical development of the structure and the use of standard components such as piers and beams. At the same time, it does not apply for historical bridges that require suitable elements created case by case. The integration of IoT and BIM modelling to create the digital twin will be one of the main topic ins coming years, in order to provide owners with a system capable of reading structural behaviour and thanks to machine learning applications, also capable of providing essential information about the status of the bridge, thereby preventing maintenance emergencies. The creation of API seems more appropriate for roads in order to overcome the problem of data exchange between BIM and FEA software, but it remains a customised solution, requiring computer skills and a great deal of effort, and it could be a point of weakness, especially for SMEs.

9.2.2 BrIM: the case studies

Cant Bridge

The Cant bridge is located in the first parcel of Demonte project. The bridge is composed of 3 curved spans, with a distance between structural bearings of 35 [m] + 50 [m] +50[m] respectively.

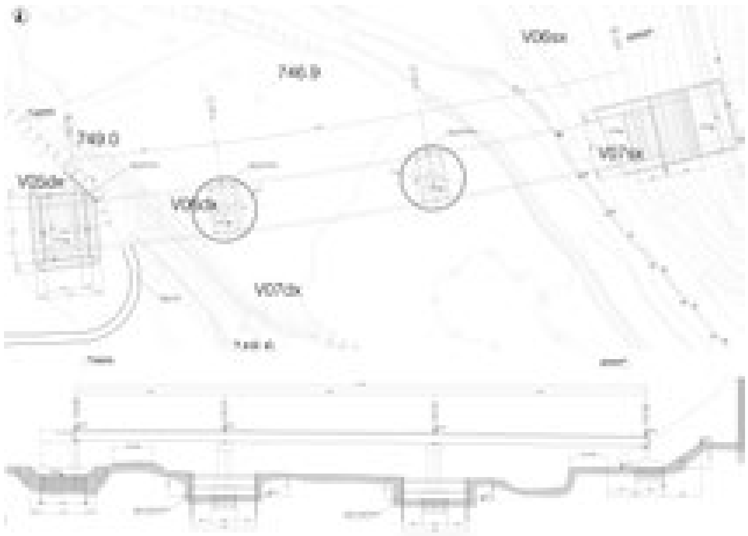


Fig. 9.6 Cant Bridge traditional project

The section is mixed concrete-iron with a double *T* sections. The main beams have an high (H) of 2.20[m], located at a distance of 8.50 [m]. The main beam are linked each other with cross beam having an high section (H) of 1[m], located at a distance of 5.0 [m]. In the middle of the deck there is a beam of supporting of section type HEB500. The deck is realized using prefabricated concrete slabs, which constitute a self-supporting formwork reinforced with electrically welded metal pylons. The thickness of the slab is constant throughout the cross section and is equal to 30 cm (the *"predalles"* with thickness 6 cm). The slab is connected to the underlying steel beams by means of electro-welded Nelson type connectors on the flat upper bands of the beams. The reinforced concrete slab collaborating with the beams guarantees, along with the beams, load distribution across all the beams of the deck. The foundations for both shoulders and piers are indirect on micro-piles.

The aim was to test Bridge Information Modelling (BrIM) to develop the main part of the project by assigning phases, cost value, detailed design, creation of technical drawings and sharing information by means of integration with FEA software. The BIM authoring tools chosen were Autodesk Revit and Trimble Tekla Structure. Taking into account the major capabilities of software to manage and develop building projects, the use of Visual Programming Language (VLP) has been necessary to improve the standard modelling tool provided by software normally. The workflow proposed in this study, shown in

Figure 9.7, begins with collaboration with the road discipline that provided road alignment as a starting point for modelling. Once the structural layout was defined, typically a single wire 2D model, it was imported into a BIM environment to be processed. The main difference in the two workflows is that in order to use the VLP programming, Tekla needs a further application, in this case Rhinoceror 3D as a bridge for communicating geometry and data with the Grasshopper VLP *add-in*. Meanwhile, Revit environment already has an integrated VPL tool, called Dyanmo. The focus of this approach is to reduce the time due to design and re- design of bridge elements, thanks to programming that interpolates the spatial information provided by road alignment with the structural layout. In this way, the model can be updated while avoiding the waste of time in re-modelling the structure. Without this approach, the time required for modelling and re-modelling increases critically. Nevertheless, this approach is based on the use of third-party and *add-on* applications that exploit a direct link among authoring tools. Therefore, compared to the IFC format, this ensures the maintenance of information about sections and materials, properties, joints and bearings, load definitions and so on.

Basically the examples follow the same methodology derived from the workflow process, described at Chapter 5. In this part the workflow demonstrates the possibility of modelling parts such as bridges with a high level of integration. To reach this goal, in addition to the definition of a tailored script, thanks to the use of the Grasshpper or Dynamo add-on, it has been necessary to define appropriate parametric objects and attributes. Parametric objects, defined in greater detail in Chapter 7 6.3, are developed in different way, based on to script methodology.

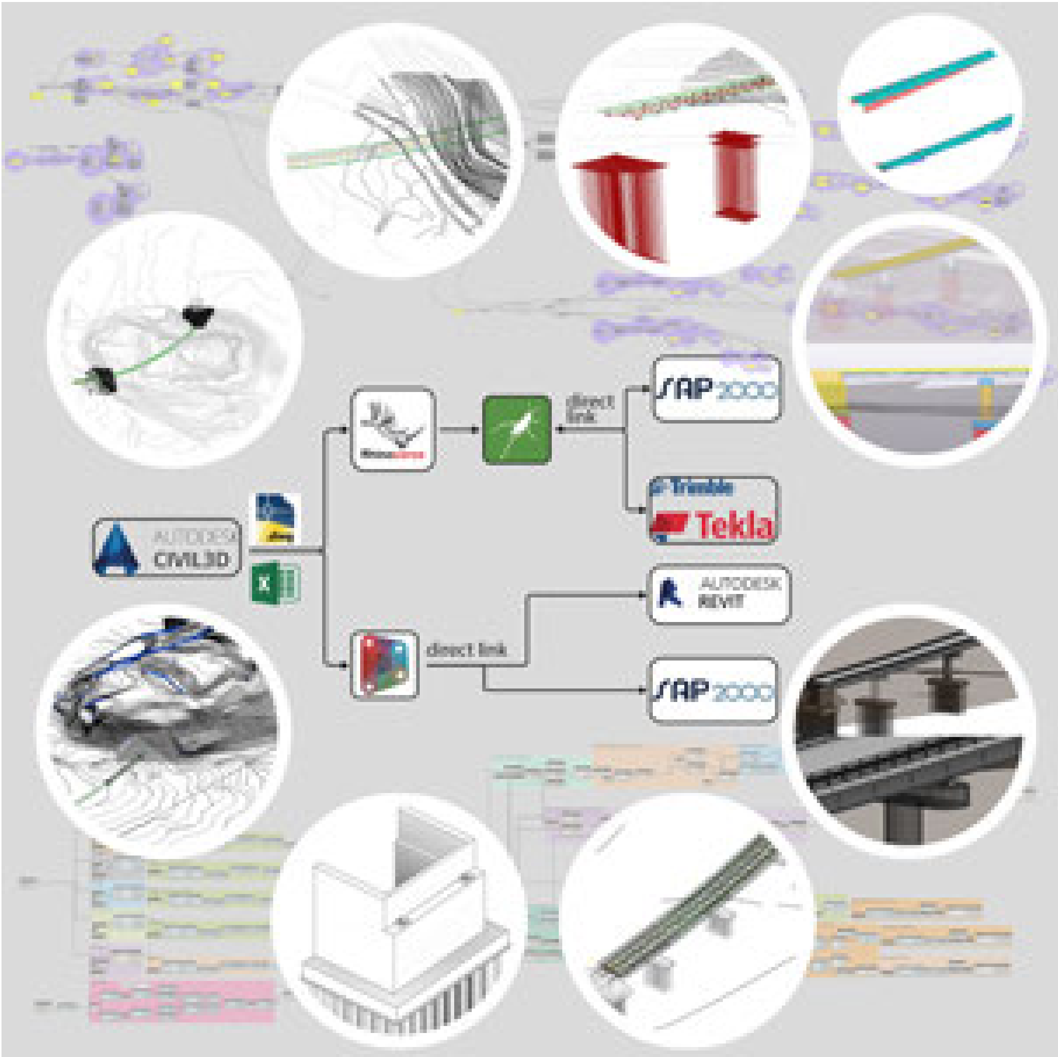


Fig. 9.7 BrIM workflow

After the modelling phase it is possible to connect the model with timing and cost information. As shown in Figure 9.8, the parametric model contains WBS, phase and cost code. the parametric model contains WBS, phase and cost codes. These parameters can be used by other software to execute 4D simulations and Quantity Take Off (QTO) analysis, for instance. The advantages to using this type of model information with time and cost data is that project errors can be reduced. The 4D simulation is created by linking the model with time information, like Gantt.

The cost code refers to ANAS's pricelist, so quantities are calculated parametrically by BIM software, while the Cost estimation (5D) can be carried out using specific software like Primus or STR Vision, while maintaining data up-to-date and reliable.

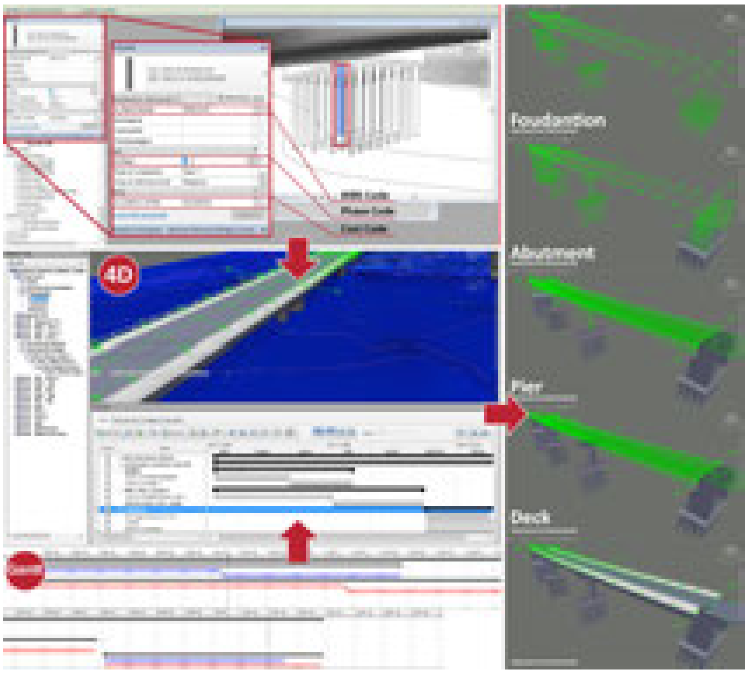


Fig. 9.8 Structural 4D modelling

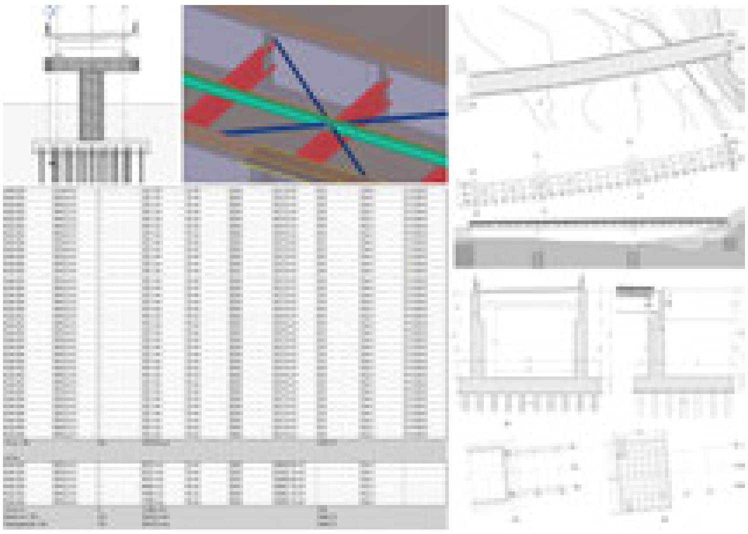


Fig. 9.9 Strucutral documentation

Viadut Asti Cuneo

The case study relating to the Asti Cuneo Viaduct, which was built during my research activity - as part of the Course Course of *"BIM and InfraBIM for built environment"* was suitable for testing the interoperability process, with a large number of applications for BIM Authoring and Structural Analysis. The case study, developed by Regione Piemonte, is located on a stretch of the Asti-Cuneo motorway. It has a total span of 80[m] with a distance between structural bearings of 30[m] + 50[m]. The deck section is a steel-concrete mix and the main beams have a IPE high section of 2.3[m], located at a distance of 4[m]. The main beams are connected to one another with cross beams and bracing having a double-L cross-section of 120x10.

The interoperability test was conducted by testing several applications with three type of exchange: i) IFC (the open standard for BIM); ii) Add-on; iii) Direck link. The evaluation scale varied from 0 to 5 where the minimum refers to zero data, while the maximum indicates the importation of all information such as geometry, materials and section properties, along with other parameters, providing for operation and analysis.

Evaluation scale:

- - = where the test could not be conducted;
- 0 = failed import
- 1 = low import - Geometry presents uncertainties and errors almost no information is imported;
- 2 = Mediulm Low - Geometry is almost completed and few properties are imported;
- 3 = Medium Import - Geometry is imported correctly, with some properties;
- 4 = High import - Geometry is imported correctly, with section and matierial information and some attribute;
- 5 = Full import

Table 9.1 Benchmark tool

		BIM Authoring				FEA			
		Revit	Tekla	Allplan	Advance steel	Sap2000	Robot	AxisVM	IdeaStatica
Revit	IFC	-	3	1	0	1	0	2	0
	Add-on	-	-	-	3	3	3	-	-
	Link	-	2	-	3	2	2	3	3
Tekla	IFC	4	-	1	0	0	0	2	0
	Add-on	no	-	-	-	4	-	-	-
	Link	3	-	-	-	2	2	-	4
Allplan	IFC	3	3	-	-	0	0	2	-
	Add-on	-	-	-	-	-	-	-	-
	Link	-	-	-	-	-	-	3	-
AdvanceSteel	IFC	0	0	0	-	0	0	0	0
	Add-on	-	-	-	-	-	-	-	-
	Link	3	-	-	-	-	-	-	3
Sap2000	IFC	2	2	-	-	-	0	-	-
	Add-on	-	3	-	-	-	-	-	-
	Link	2	-	-	-	-	-	-	3
Robot	IFC	1	-	-	-	-	-	-	-
	Add-on	-	-	-	-	-	-	-	-
	Link	3	3	-	-	-	-	-	3
AxisVM	IFC	3	3	3	-	-	-	-	-
	Add-on	-	-	-	-	-	-	-	-
	Link	3	3	3	-	-	-	-	-
IdeaStatica	IFC	-	-	-	-	-	-	-	-
	Add-on	-	-	-	-	-	-	-	-
	Link	3	3	-	3	3	3	-	-

The results of the Matrix Interoperability evaluation indicate that at the moment, as shown in 9.10 when it comes to BIM authoring software, Revit and Tekla have major compatibility, providing different methods of communication with other software. This result is due to the activities of their software houses in creating a direct link capable of sharing most information. Furthermore, the possibility of using add-ons offering free implementation by the user enabled creation of custom nodes able to connect these applications to others with a high degree of accuracy of information. Meanwhile, in the FEA software, the highest ranking was obtained by IdeaStatica, which does not provide any add-on or connection through IFC, but thanks to the development of several direct link allows connection with both BIM authoring and FEA software.

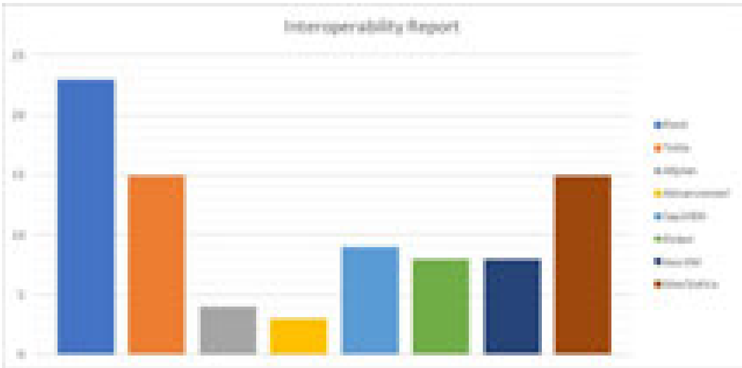


Fig. 9.10 Global interoperability report

The IFC format, on the other hand, according to the results shown in Figure 9.11,still does not seem able to solve the problems of communication relating to structural parts, displaying a lack of information, in the re-generation of geometry and in the transposition of structural axis, load joints, constraints, material properties and so on.

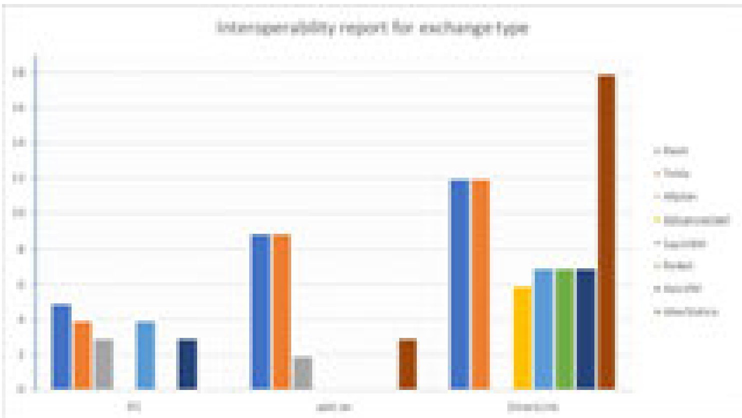


Fig. 9.11 Interoperability report for exchange type

In conclusion, BriM methodology is based on the use of VPL to reduce design time, but in particular it facilitates model updating during different design stages, thus avoiding time wasting. Moreover, thanks to the virtual community, a large number of custom nodes are available that improve the standard software capability. This is at the same time a point of weakness, because in case of software update, these solution are based on the improvement of community don't guarantee the continuity.

9.3 BIM for Hydraulic Desing

9.3.1 Background and previous works

Hydraulic analysis is a very complex and important phase of infrastructure design. It defines the shape of infrastructure, effects structures such as the height of the bridge, the shape of a pier, protection elements essential for safety, and the durability of an infrastructure. Furthermore, it has become an essential step in the assessment of flood damage risk. According to Amirebrahimi et al. [12], the possibility of integrating an effective flood damage analysis requires the integration of two sets of information: GIS information to store and analyse flood parameters (for instance depth, velocity, river power); and the BIM information that contains the geometrical components that clash with the flood outputs [102][175].

The combination of these two datasets provides several advantages, improving analysis and communication of results, given the possibility to visualise different layers in 3D environments, as shown in 9.12. Amirebrahimi et al. in their study propose a semantic approach that starts with the study area generated by the flood simulation; flood output analysis has been used to obtain the parameters relating the building, in this case the depth, which are then communicated using 3D visualization. From the intersection of BIM model with the flood analysis it has been possible to give an estimation of damages.

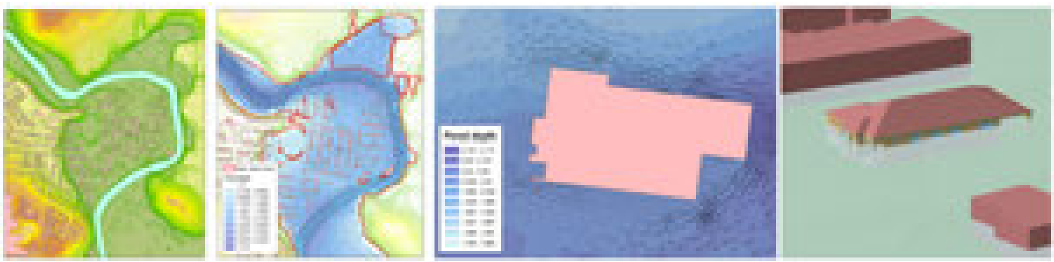


Fig. 9.12 Flood anlysis step by step. Source: Amirebrahimi et al [12]

Another application of the integration of BIM-GIS is provided by Lyu et al. [122], that test the integration these two datasets to face the problem caused by flooding in high dense urban areas, especially for underground facilities. The study about the Guangzhou metro system started from the study of spatial distribution of regional risk level. Finally, the results, obtained the risk level range, were integrated with a BIM model useful to monitor and to maintain the underground facilities.

Despite the great interest in GIS-BIM data integration, in international literature it is quite difficult to find studies that focus on the integration of BIM and GIS data for hydro-geological and flood analysis in the transportation sector. The reasons for this absence probably lies in the approach that considers these elements separately and not in an integrated manner.

9.3.2 HydroBIM: the case studies

Demonte Project

In this section, the case study used to test infraBIM methology for the hydraulic discipline is the Demonte project, involving a river crossing at PK km 1 + 875.00 at the level of the Cant river. The Cant river is a left tributary of the *Stura* di Demonte whose catchment area, called *"Vallone dell'Arma*, extends for about 70 km ^{2} and reaches the valley bottom near the village of Demonte, with a closed section at an altitude of 724 m above sea level. The river Cant starts out with the name of Rio Cavera near the Colle Valcavera, at an altitude of around 2350 meters. As it descends towards the south-east, it collects various tributaries and follows the *"Vallone dell'Arma"*, the main lateral valley of the *Val Stura.* Downstream of the hamlet of San Giacomo it is called the torrent Cant. At the Fedio locality it is blocked by a dam and forms a small reservoir located around 900 meters high. It finally flows into the Stura southeast of Demonte. The project is located at the confluence of the Vallone dell'Arma with the Valle Stura where there is the hill of the Podio di Demonte and the built-up area of Demonte.

Fig. 9.13 Hydro-morphologica Map

The characterization of flood flows for the Cant stream was conducted with reference to the studies developed by the Mountain Community of Valle Stura di Demonte within the framework of the drafting of the Inter-communal Regulatory Plan of the Mountain Community, in the 2003 Variant of adaptation to the PAI and other variants. In particular, for the definition of floods, the assessments defined the areas of instability of the P.A.I. approved by the Piedmont Region with D.G.R. n.11-12660 of 11/30/2009. The flow rate values were determined by setting up a hydrological model calibrated on all the Stura di Demonte valley basins and based on the following parameters:

- Extreme rainfall defined in relation to the data provided by the PAI in regionalization of parameters of extreme events, references to events with time return of 20, 200 and 500 years;
- Morphological parameters of the basin defined by the analysis of the Regional Technical Map in scale 1: 10000, the calculation of flood rates is performed at the closing section downstream of the town of Demonte;
- Project river bed graph obtained with the "frequency storm" methodology with duration 24-hour rain and 5-minute shower;
- Influx-runoff transformation method in accordance with the indications of the Directive2 of the IAP, with evaluation of the rational formula and the SCS method;
- 10% increase in the value of the reference flows to take into account the transport of suspended solid material and carried by the current;

Table 9.2 Reach Morphological parameter

Parameter	Value	Unit
Reach Area	70.46	[km^2]
Reach Boundary	46	[km]
Vector Lenght	9.1	[km]
Main Orientation	SE	-
Maximun Altitude	2620	[m] a.s.l.
Minimum Altitude	724	[m] a.s.l.
Altitude Average	1749	[m] a.s.l.
Reach Avergare Slope	45.3	[%]
Reach Avergare Side	35.6	[%]
Lenght Main Reach	21.10	[km]
Slope Main Reach	7.6	[%]

According to the parameters provided by PRGC and PAI, the flow rate was estimated using a logarithmic scale in order to analyse other flood rates, increasing the study of the river to have a better quality of results for improved safety. The flood flow rate is shown in Table 9.3

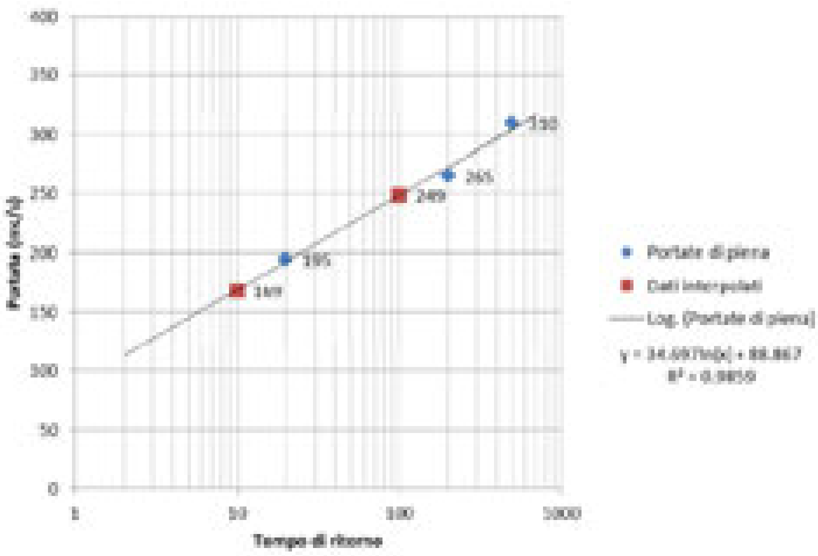


Fig. 9.14 Flow Rate River Cant

Table 9.3 Time of return and Flood Rate

TR years	FR [m3/s]
10	169
20	195
100	249
200	265
500	310

Considering the challenges involved in integrating BIM and GIS information for Hydraulic analysis in transportation design, the approach proposed, as shown in Figure 9.15, is to focus on the use of tools dedicated to flood analysis, such as Hec-Ras integrated with ArcGis to define hydraulic models. The outputs of the flood analysis are then stored in a geodatabase and later loaded into a Web- Service application like ArcGis Online. The map data are thus available for import into BIM authoring applications such as Civil3D for further processing and analysis, or Infraworks for communication of the findings.

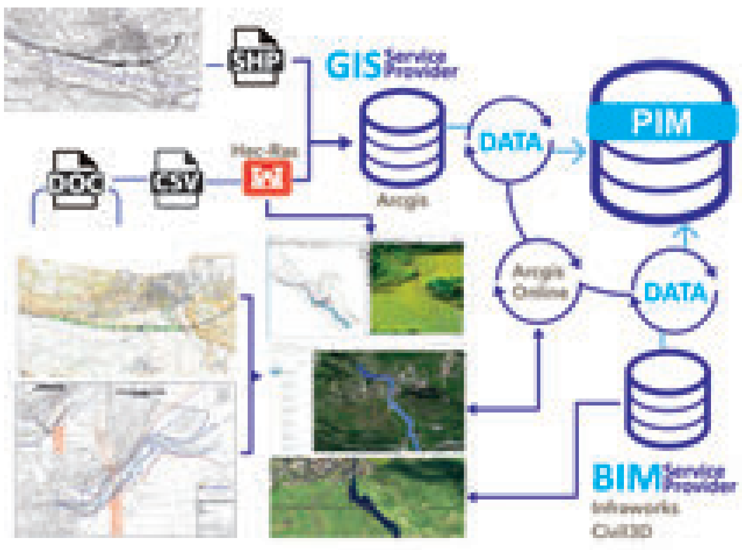


Fig. 9.15 Workflow Schema

The hydraulic model was developed using ArcGis, Figure 9.16 ccollecting data from several SIT datasets, in order to model the geometry related to reach, cross-sections, banks, flow path, flow rate tables and structures such as bridges. The geometrical data was then exported into Hec-RAS for flood analysis. The design parameters were derived from the technical report provided by ANAS, Table 9.3. Time of return and the flow rate were assigned, and in the same way, the Manning' coefficient, representing the depth roughness, has been set at equal to $0.045[m^{-1}\ s_{1/3}]$ in the river bed, i.e. with reference to a value for a mountain reach characterized by sediment and vegetation and $0.07[m^{-1}\ s_{1/3}]$ for a river back.

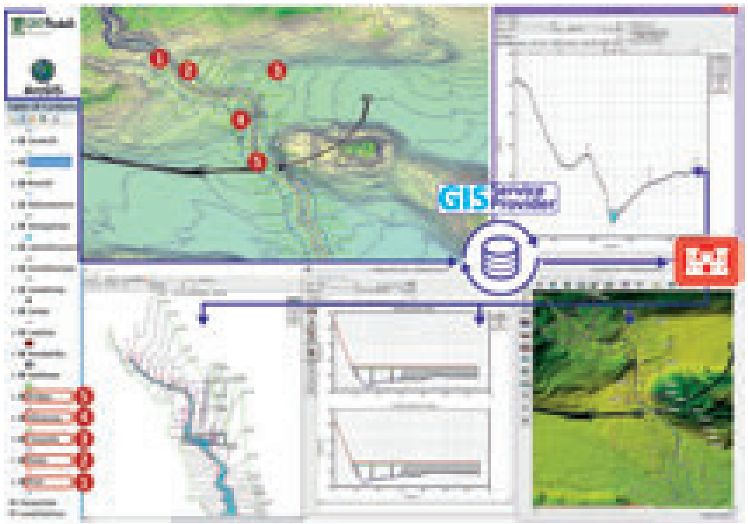


Fig. 9.16 Arcgis geometrical model and import into Hec-Ras

Once the Hec-Ras model has been regulated, it is possible to carry out flood analysis. Hec-Ras provides several methods of calculation. In this study, a m ono-dimensional steady flow analysis has been chosen. The Hec-RAS mono-dimensional method is based on the Saint Venan Equations that are obtained basic assumptions about the hydraulic process [142]:

- Flow is one-dimensional; the quantities can be described as continuous and derivable functions of longitudinal position (s) and time (t);
- Fluid is uncompressible;
- Flow is gradually varied, and the pressure is distributed hydrostatically;
- Bed slope is small enough to consider cross sections as vertical;

- Channel is prismatic in shape;
- Flow is fully turbulent;

Tanking into account these assumption the Saint Venan Equation assume the following form:

$$\text{SVE} = \begin{cases} \frac{\partial Q}{\partial s} & \frac{\partial A}{\partial t} = 0 \\ \frac{\partial V}{\partial T} & V\frac{\partial V}{\partial s} = g(s_0 - s_f - \frac{\partial d}{\partial s}) \end{cases} \quad (9.1)$$

If we do not consider the temporal variation, it can be simplified as follows:

$$\text{SVE} = \begin{cases} \frac{\partial Q}{\partial s} = 0 \\ \frac{V}{g}\frac{dV}{ds} + \frac{dd}{ds} = \frac{dE}{ds} = (S_0 - S_f) \end{cases} \quad (9.2)$$

The equation can be simplified yet furhter by not taking spatial variation into account (Uniform flow):

$$\text{SVE} = \begin{cases} \frac{\partial Q}{\partial s} = 0 \\ S_0 - S_f = 0 \end{cases} \quad (9.3)$$

In this case the discharge constant has been assigned to the entire reach and boundary condition for water level. Assuming that the quantity does not vary in a longitudinal direction, so in case of uniform flow, the momentum equation became $S_0 = S_f$ and the boundary condition is called normal depth. In this case, the average slope of the longitudinal reach profile is equal $S_0 = 2\%$.

The steady flood analysis findings are shown in Figure 9.17, underlining the need to add levees, and in many case this is due to the fact that if the bed elevation at flood is lower than the water surface, HEC-RAS will consider water flowing onto the flood plain. So further manipulation of the hydraulic model is required to correct this type of error.

Without going to deeply into the technical analysis provided and verified by ANAS, the aims of this analysis is to understand how to share findings obtained with software dedicated to hydraulic analysis within a BIM process. As shown above in Figure 9.15 the information processed in Hec-RAS, generated in ArcGIS, can be bi-directional, thereby enabling the results obtained from the analysis to be imported for further study and communication.

The proposed workflow aims to use Arcgis to share the findings as a bridge towards direct conversion into a shape file or towards the publication of information through the use of the Web-Service application Arcgis Online using BIM authoring software such as Infraworks or Civil3D, as shown in Figure 9.18. Data sharing with other applications provides process optimisation, with the steady flow model re-imported into ArcGis to visualise outputs such as the depth map, velocity map, stream power map, an inundation boundary. These data are of several types such as geometrical data, raster data, table data and so on. It is necessary to adopt the right strategies to exchange this information through the use of appropriate exchange formats, depending on the aim of the design process. In the case study, one of the aims is to use this information for the preliminary design phase and to communicate analysis results.

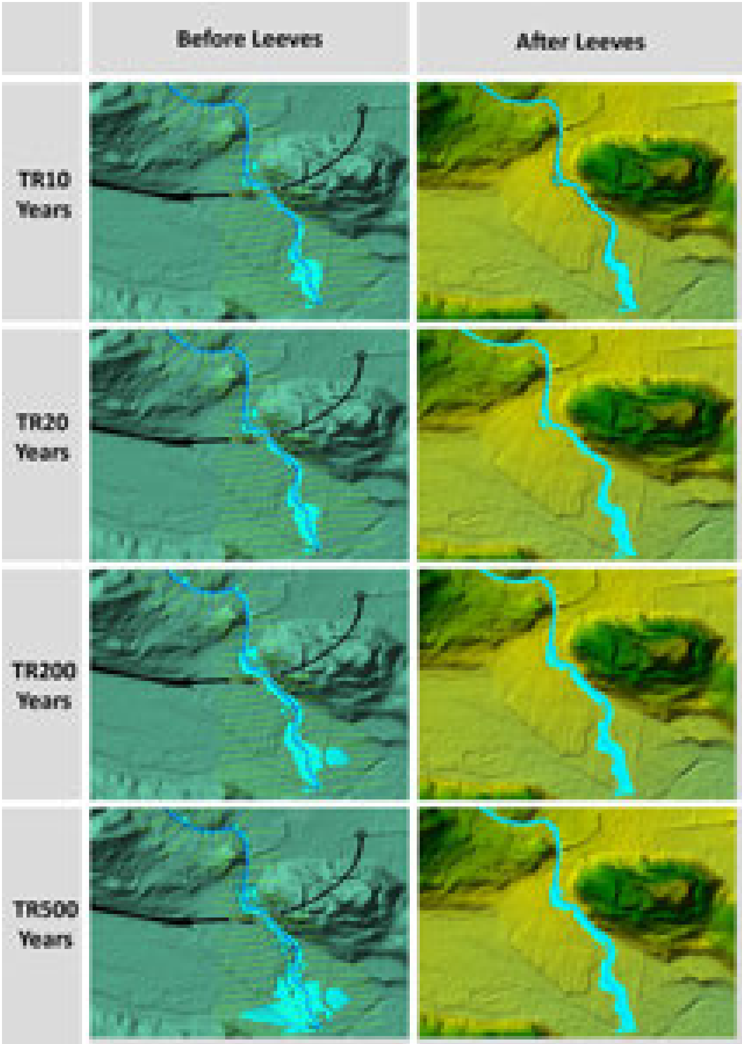


Fig. 9.17 Steady Flow Analisys

The idea is to export the inundation boundary, which is a polygon feature in the GIS environment, into Infraworks, which is a useful tool for integrating several types of data. The inundation boundary has been cconvered to a GeoJSN format, to facilitate the exchange process. The Jason format is a common exchange data format for web service applications [39], used to publish contents and make them available. Once published, the information can be imported into other 3D modelling environments such as Infraworks, to create scenarios useful to communicate the project. In this case, the inundation boundary for each TR (10,20,200,500) has been imported into the Infraworks model, as shown in Figure 9.18. The geometry imported into infraworks have to be mapped according to the application feature, which in this case was assessing the *"Water Area"* and the geographic protection. The advantages of this approach are that it enables improved communication of the project especially in the preliminary phase, by using a 3D environment to generate a 3D mock-up, which can be easily understood even by non-experts. Similarly, the same information can be imported into Civil3D with a direct link between Hec-RAS, in order to use a BIM application to improve project development. In this case, the connection with Civil3D is useful for a better definition of the alignment and works design, such as bridge height, because the user has a clear reference to the high-water level during a flood, along with water velocity and power. This data is essential for evaluating the relationship between the reach and the bridge and from this interaction we can define the design parameters.

Fig. 9.18 Hydraulic integration map

IIn conclusion, the integration of GIS information with BIM enables us to increase project comprehension, providing results that become inputs for other disciplines, thereby also helping with communication of the results. At the same time, integrating GIS and BIM data improves the richness of the project with respect to a traditional basic CAD approach, where geometrical and data information are separate. In this way, data referring to the flood area can be improved by monitoring, georadar use, and updating. This increase in information can be shared through other systems that in turn update their data and analysis.

9.4 BIM for Geotechincal Desing

9.4.1 Background and previous works

The integration of sub-surface data into a BIM process derives from the need to integrate the information derived from site investigations, labour tests, georadar usage and so on. In the traditional approach, all this data, following acquisition, passes through several stages of manipulation and interpretation for the creation of different tasks such as geological maps, data analysis and geological modelling. All these steps, usually, are carried out manually with a great deal of effort required from geologists and geotechnical engineers [173] [94]. It is clear that data interpretation cannot achieve as high a degree of accuracy as geological maps. This is due to the complexity of operating in a similar field and also to the fact that there is not a great deal of interest in investing more money and work to increase the quantity of data. Nevertheless, the aim of this Section 9.4 is to investigate how to improve data collection within a BIM-based system, in order to reduce manual operations and to provide a workflow of data integration that can facilitate the sharing of sub-surface data.

A review of existing literature reveals that various approaches have been proposed, such as 3D-GIS, GeoBIM, 3DGEM, and the Hybrid ground data model. Hack [94] proposed an Intelligent Decision Support System (IDSS) that integrates 3D modelling, visualisation and artificial intelligence technology for decision-making in tunnelling projects. The aim of the study is to provide a scenario for choosing the type of Tunnel Boring Machine (TBM) to use, and to forecast its performance. In this way, it should be possible to anticipate problems. Sub-surface modelling began with the acquisition of geological data, boreholes, Cone Penetration Tests (CPT), and interpreted geo-technical profiles based on CPT and seismic data. From the interpretation of data, a 3D lithostratigraphic model was created. Once the 3D volumetric model was created, it was imported into FE software to evaluate sub-surface behaviour during construction in order to analyse vertical displacement, thereby helping to identify potential areas of risk due to surface loading, in consideration of the fact that the tunnel passes below an urban area. The results were the imported back into the 3D GIS system to collect data.

According to the author, the main problems of this approach were:

- The exchange data format are not already suitable to asses a complete conversion;
- The correctness of the model cannot be assessed;
- The sharing of information toward other application is very complex and it requires, when it is possible, a simplification;
- More information, typical of geology such as velocity scales in seismic or resistivity scales are not be able to manage in GIS system and as consequence they are be able to process in specialized geophysical programs;

Tegtmeier et al. starting with CityGML schema, developed the concept of an integrate model, named 3D-GEM, to represent geotechnical sub-surface information [164]. The model aims to harmonize and collect geometry and semantic information about geo-technical objects, on the basis of an existing frameworks like GeoSciML, Geotechnical Exchange Format (GEF) and Observations and Measurements O&M [176]. The generic CityGML schema was improved adding the GeoSciML class and subclass such as *GeologicFeature*, *GeologicUnit*, *GeologicStructure*, *GeologicEvent* and *GeomorphologicalFeature*.

Another extension of BIM to geological information is proposed by [177]. The GeoBIM concept is defined by a different objects known as *Subsurface-GeoObjects ('S_GO')* that describe the sub-stratum in terms of its location, 3D shape, composition, structure, physical properties, and dynamics, and also adds other properties associated with materials, engineering behaviour and so on. According to the author, the GeoBIM approach should facilitate the interoperability of data thanks to exchange through the use of open standards in order to enable engineers to improve infrastructure quality.

The ground surface is a very complex element to describe and understand, so for this reason we use a simplification of the real world. It can be represented by two types of model, as a boundary representation or voxel model

[Hegemann et al.]. The B-rep model is useful to represent geometrical ground data, mainly the horizontal layer where each homogeneous layer of material is portrayed as a single region. The geometrical representation is defined by a set of surfaces capable of describing the boundary between different regions. The voxel model, on the other hand, is a geological representation, based a discretization of the soil volume into 3D cubes. Each voxel is associated with a material identifier, and defines a homogeneous region of material. Starting from these two representations, Hegemann et al. proposes a model, known as a Hybrid ground model, that consists of a model made up of two sub-models, composed of the surface boundary representation (B-Rep) and a volume model (voxel) representing point data [Hegemann et al.].

9.4.2 GeoBIM: the case studies application

Demonte project

The integration of sub-surface data acquired during site analysis into a BIM-based approach was tested by the integration of BIM and GIS systems. The case study used is an ANAS project, the Demonte project. In this case the idea was to collect all information into a GIS system, creating a geo-database, in order to interpolate this information for a preliminary analysis and sharing with a BIM system, starting from the acquisition of data, obtained by site analysis such as boreholes, cone penetration, geophysical analysis, reports and so on.

Fig. 9.19 Geomorphological section

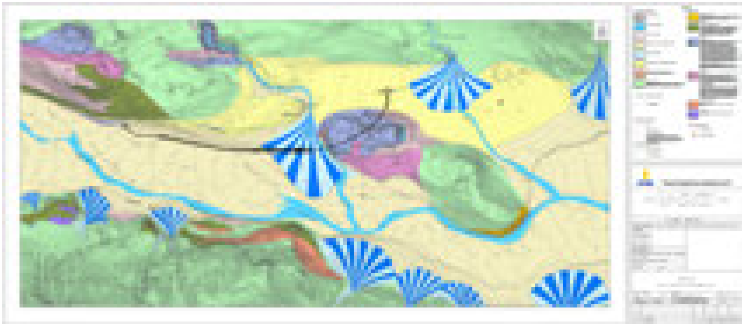


Fig. 9.20 Geological Map

The geological context is that of the Maritime Alps, deeply shaped by the quaternary glaciation activity before current fluvial activity and slope morphogenesis prevailed over the other modelling agents. The geological structure consists of formations with differing degrees of erodability, belonging to the main geological types found in the Western Alps. Furthermore, tectonic action has deeply influenced the geomorphological evolution of the Stura Valley. The presence of indigenous soils of the Massif Cristallino dell'Argentera, of sedimentary covering formations adhering to the Massif, sedimentary formations not belonging to the Massif and of areas adjacent to the Brianzonese tectonic / sedimentary units can be found. In addition to glacial and tectonic action, another important morphogenetic agent is certainly the fluvial one. In fact, the extension of river morphotypes is comparable to those of glacial origin.

Thanks to the technical documentation provided by ANAS, it was possible to obtain important information about the location of the borehole, and the type of subsurface soil. As shown in Figure 9.21 and Figure 9.22, the boreholes required by ANAS were made along the length of the project. For each borehole a report was produced - Figure 9.23 and Figure 9.24 - describing the soil layer, material, depth, hydro depth and so on. This information is very relevant, because in order to develop a Geo-BIM model, the first step is to create a geo-database where all information is collected and then interpolated and shared. In the traditional approach this information is isolated and handled by geological engineers to produce the main outputs such as full reports, laboratory analysis, cross sections, and drawings of the sub-surface (Figure 9.19).

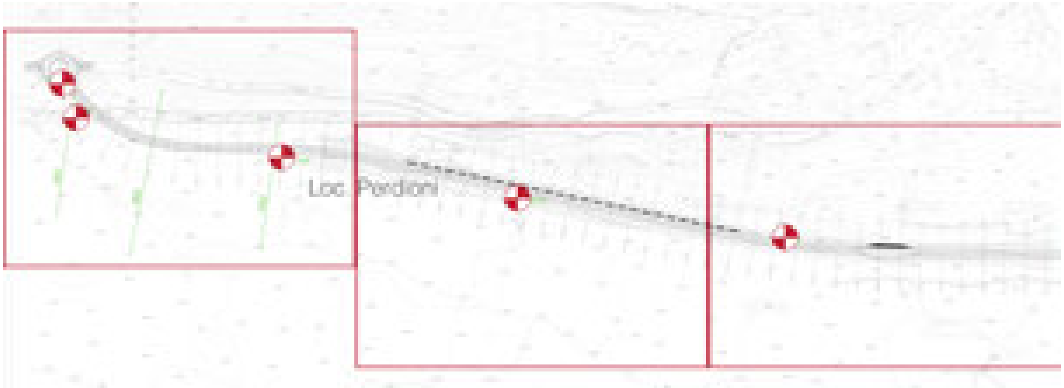


Fig. 9.21 Boreholes Location

Fig. 9.22 Borehoels Location

Fig. 9.23 Borehole box

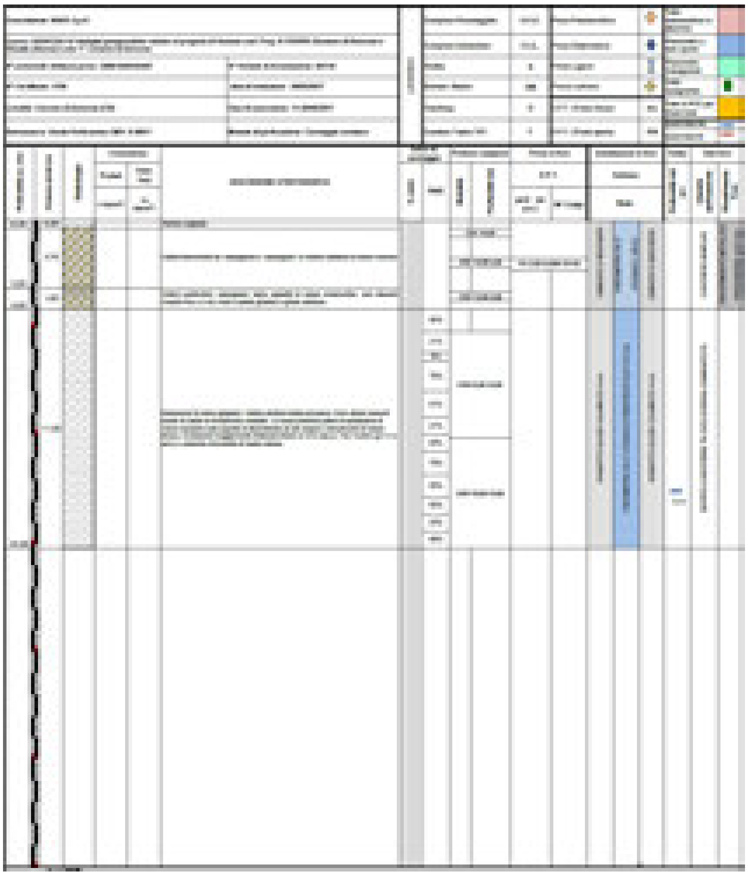


Fig. 9.24 Borehole sheet

Starting with traditional data, a BIM-based approach is proposed, involving integration with the GIS and BIM platform. The proposed model, shown in FIgure 9.25, describes the methodological approach to convert information, using GIS software and plug-ins such as ArcHydro to convert traditional data into geo-referenced information in a geo-database capable of managing and collecting data deriving from site analysis and geographic data loadable through a Geo-Portal. Once the information is organised in an appropriate manner, it is possible to interpolate the data to create sub-surface layers, *"GeoSection"*, *"GeoVolume"* and so on. The results and the data are shared using web-services, in this case provided by the Arcgis platform, and are then exported into BIM-based software such as Civil3D and Infraworks.

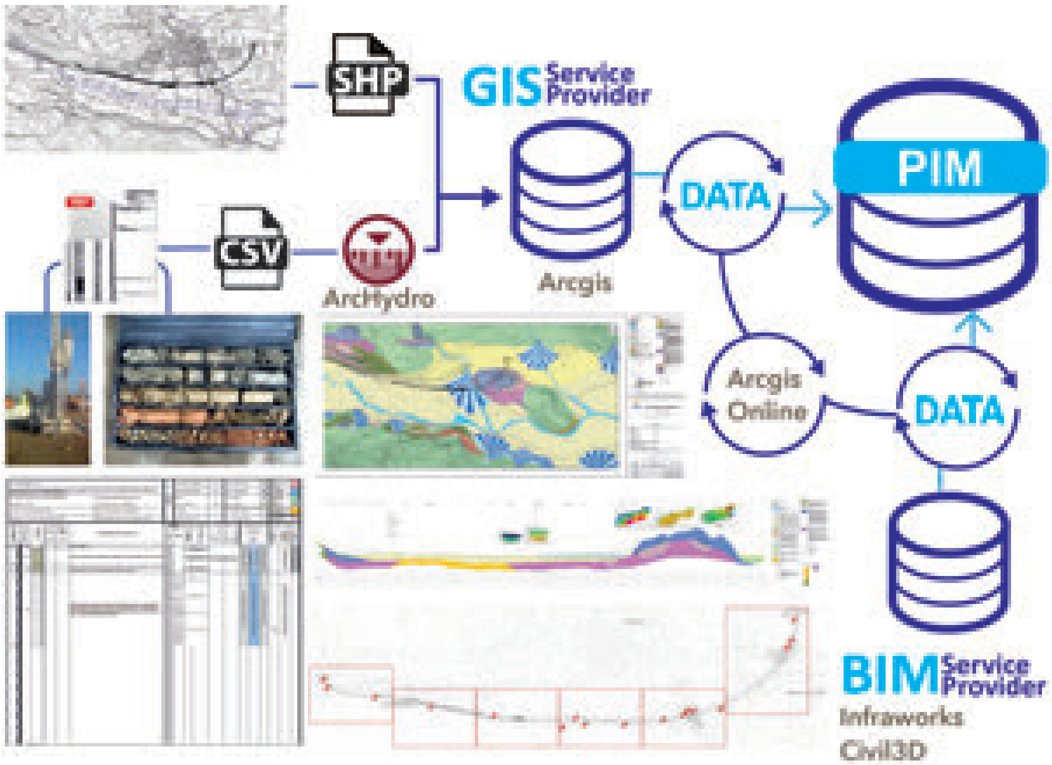


Fig. 9.25 Workflow schema

For sub-surface analysis, the ArchHydro Groundwater plug-in for Arcgis was tested to create the sub-surface model. The ArchHydro plug-in requires a precise data structure, Figure 9.26 [1], composed of tables of data and raster data. Starting from the data provided by site analysis, the well and borehole information was converted into tabular for, as shown in Table 9.4 and Table 9.5(.txt, .csv). Once the well and borehole features are created, the data can be interpolated to create surface georasters for each homogeneous layer of soil. The georaster plug-in is then able to create geo-sections and geo-volumes.

[1]The schema is an online resource available https://www.archydrogw.com/Arc_Hydro_Groundwater_Data_Model, last view August 2019

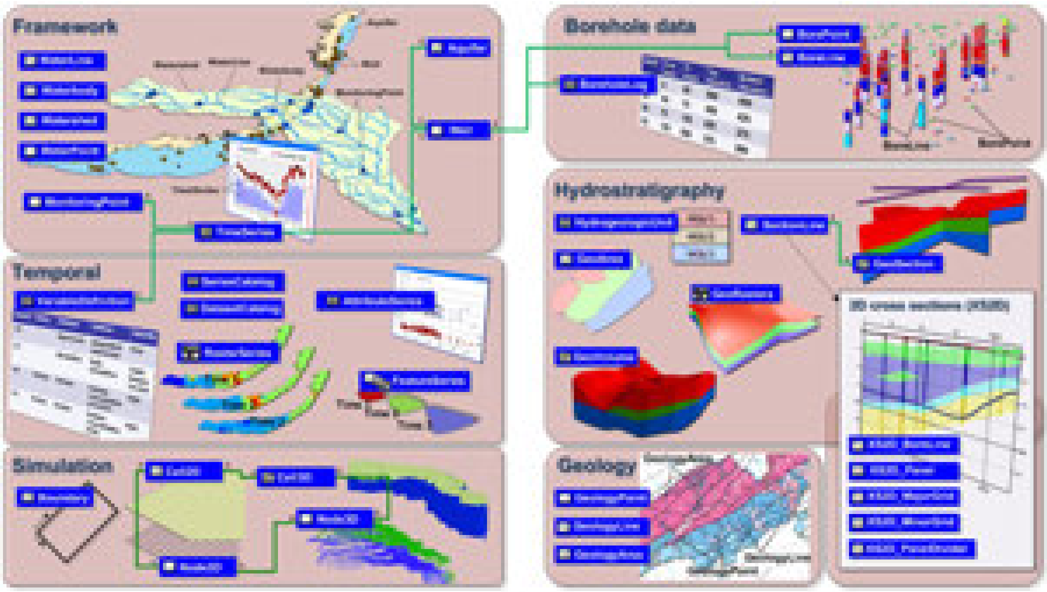


Fig. 9.26 Arc Hydro Groundwater Data Model.

Table 9.4 Well Location

Well ID	**Coordinate** North	East	**Ground high** [m]	**Final depth** [m]	**Orientation** °	**Grade** °
BH-01	4908140	1362846	760	35	0	90
BH-02	4908073	1363097	748	33	0	90
BH-03	4908021	1363388	747	21	0	90
BH-04	4907922	1364153	740	50	0	90
BH-05	4907921	1364563	747	35	0	90
BH-06	4907957	1364672	749	70	90	0
BH-07	4907921	1364848	808	60	0	90
BH-08	4908286	1365198	747	60	90	0
BH-09	4908328	1365219	745	50	0	90
BH-10	4907972	1364704	769	55	0	90
BH-11	4907938	1364670	748	55	0	90

Table 9.5 Boreholes

Well ID	**Star Layer** [m]	**Depth Layer** [m]	**Soil Type**
BH-01	0	1	DR
	1	4	UGm1
	4	15	UGm2
	15	25	UGm3
	25	35	Ugm_i
BH-02	0	1	DR
	1	2	UGm1
	2	23	UGm2
	23	30	UGm3
BH-03	0	1	DR
	1	5	UGm1
	5	10	UGm2
	10	14	UGm3
	14	21	Ugm_i
BH-04	0	1	DR
	1	20	UGm1
	20	30	UGm2
	30	40	UGm3
	40	50	Ugm_i
BH-05	0	1	DR
	1	20	UGm1
	20	30	UGm2
	30	40	UGm3

Continued on next page

Table 9.5 – *Well Location*

Well ID	**Star Layer** [m]	**Depth Layer** [m]	**Soil Type**
	40	50	Ugm_i
BH-06	0	1	DR
	1	4	UGm1
	4	8	UGm2
	8	12	UGm3
	12	70	Ugm_i
BH-07	0	1	DR
	1	4	UGm1
	4	8	UGm2
	8	12	UGm3
	12	70	Ugm_i
BH-08	0	3	DR
	3	17	UGm1
	17	40	UGm2
	40	50	UGm3
	50	60	Ugm_i
BH-09	0	1	DR
	1	20	UGm1
	20	30	UGm2
	30	40	UGm3
	40	50	Ugm_i
BH-10	0	5	DR
	5	25	UGm1
	25	35	UGm2

Continued on next page

Table 9.5 – *Well Location*

Well ID	**Star Layer** [m]	**Depth Layer** [m]	**Soil Type**
	35	45	UGm3
	45	55	Ugm_i
BH-11	0	5	DR
	5	25	UGm1
	25	35	UGm2
	35	45	UGm3
	45	55	Ugm_i

The table refers to wells and boreholes, which were converted into a textual format, Figure 9.27 , so that they could be loaded into the software to create the feature – a point in this case - used to interpolate data and create the sub-surface layer, as shown in Figure 9.28. The Borehole table shows the depth of each soil layer, and is linked to the Well table by the relation with the field *"WellID"*. Handling the borehole table, borelines have been created with the classification of each soil layer. Using the Borehole editor, it is possible for each borehole to manage the parameters with information relating to the *"TopElevation"*, *"BottomElevation"* and *"HGUID"* the index that identifies the geological unit.

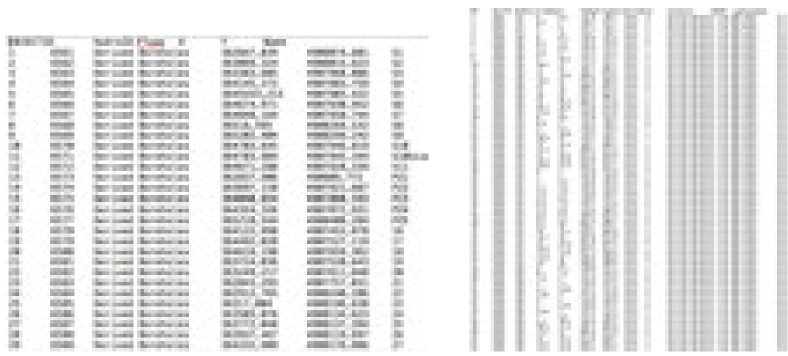


Fig. 9.27 Conversions Well and Borehole table into .txt file

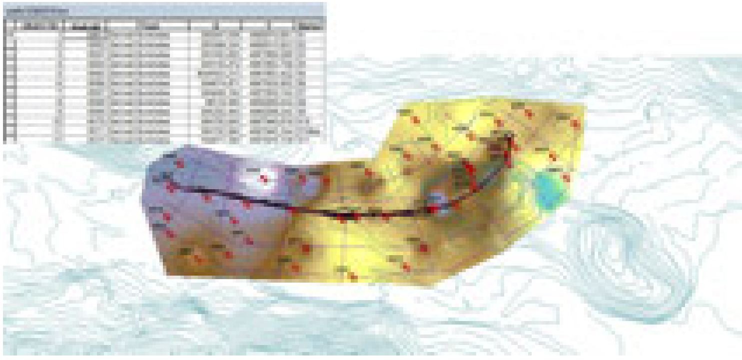


Fig. 9.28 Well location

As mentioned, the borehole data is organised into strata and horizons[63]. The concept of horizon is essential for representing the top of each stratigraphy unit, such as the interface between two adjacent geological units. Each horizon is represented by x, y and z coordinates and a unique identifier (HorizonID), numbered according to the depositional sequence.

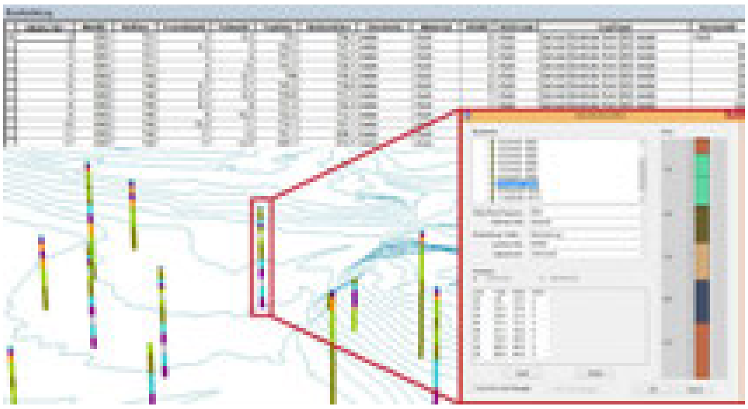


Fig. 9.29 Boreline stratigraphy

Once the preliminary data has been organised, it is possible to interpolate the horizon elevation of each stratum according to boreholes to create the sub-surface. The interpolation created is a reasonable estimation of the value of a continuous field. In this study, inverse distance weighting (IDW) has been used. The IDW is a deterministic approach, widely used in GIS analysis, that determines cell value using a linear weight combination on the basis of a set of simple points. The method uses the Tobler law, assigning a weight as a function of the distance of a known measured point from the output unknown measured cell [44] [63]. The IDW interpolation giving a spatial interpolation of each soil layer can be visualised as shown in Fugure 9.30. The raster is composed of a dataset stored in a Geodatabase that can index, store and attribute raster datasets, where elevation, deposition sequence and identifiers of the stratum material are stored and made available for further analysis.

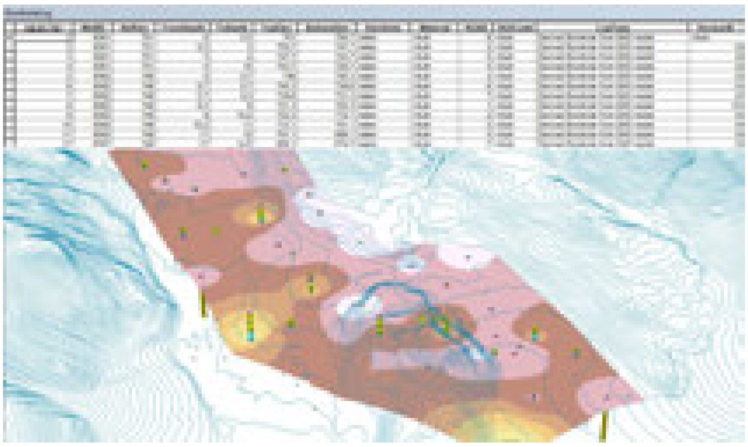


Fig. 9.30 Raster Interpolation

The dataset put together for each horizon is useful also for post-processing other data products, such as the cross-sections that portray the sub-structure of soil, along a vertical plane. The 2D vertical section is created by interpolation of geological units, stored in a raster data set. The parameters *Cut* and *Fill* are options available in the *Georaster* dataset. These two parameters manage the priority between strata, which may be clipped or filled, as shown in Figure 9.31. Once the clipped and filled area has been set based of geological interpretation, georaster interpolation can be used to extrapolate the geo-sections. The advantage of this system is that it is able to improve by continually adding more data. Furthermore, it is possible to plot the results by adding other types of data, like boreholes, water levels, water quality, updated surface terrain models, observed faults, well construction, and many other GIS-based datasets [158].

Fig. 9.31 Cut and Fill option

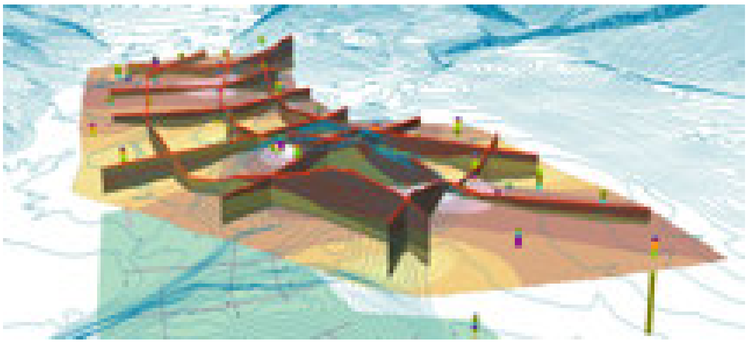


Fig. 9.32 Geo-Section

All information, at this point, is stored into a geo-database (.gdb, squlite, ODBC, mySQL) ready for sharing. In this study, In this study, the proposed approach is to share information using a web-service provided by ESRI, in the form of the web portal Arcgis Online. Thanks to the web portal, information can be loaded, while maintaining all information and assessing data reliability. This information is available for other supports, where designers can continue with the design process.

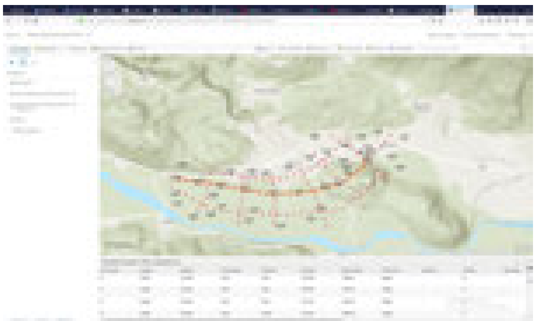


Fig. 9.33 ArcGis Online Map

Fig. 9.34 Arcgis Online connection map

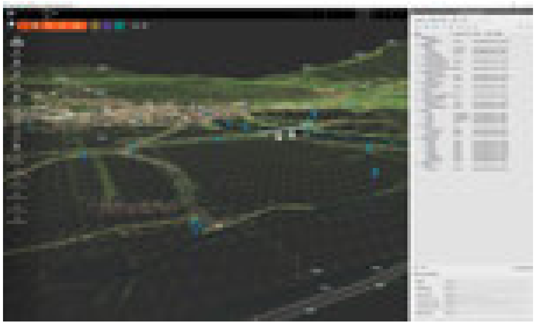


Fig. 9.35 Arcgis Online connection to Infraworks

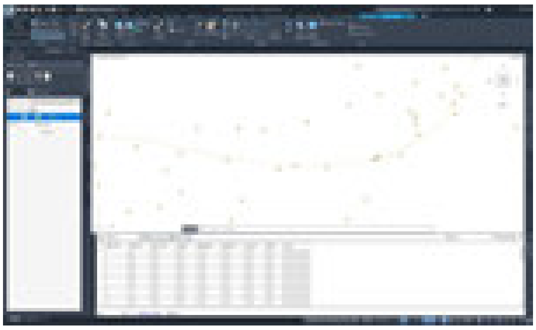


Fig. 9.36 Civil3D map acquistion by web-service

In conclusion, the integration into an infraBIM process of data derived by spatial analysis produced using GIS software also requires improvements, especially for certain disciplines such as geology and geo-technical. The proposed system has several advantages, the main ones being related to the creation of a database of geo-referenced, non-disconnected data. In this process, the use of a web-application like Arcgis Online offers the possibility to share some information, after analysis in BIM authoring software, such as Infraworks or Civil3D. At the same time, this approach assesses the availability of data and updating of information, which can be manipulated and then published for other disciplines. Compared to the traditional approach, the digitalization of data that normally remain separated from the project enables greater control of the design process, by keeping the information in a database system that is always up-to-date and can be used for further analysis or for process development.

9.5 BIM for Tunnel modelling

9.5.1 Background and previous works

The BIM model for underground facilities like tunnels is very complex from several points of view. Currently, BIM software is unable to effectively model tunnel geometry, due to a lack of dedicated elements, and the weakness of BIM tools such as Revit or Tekla when it comes to modelling geometry along an alignment. These software programs were developed for architecture and building engineering and not for civil works. In order to overcome these problems, Staschelt et al. [157] roposed a tunnel product model (TPM), as shown in Figure 9.37, which is a set of information composed of a Ground Data Model (GDM), Tunnel Model (TM) and Tunnel Boring Machine (TBM). The TM absorbs the data relative to tunnel alignment, lining segments and annular gap grouting. Meanwhile, the TBM model provides information about the dimensions and characteristics of each machine component shield. All this information was shared through IFC, continuing the study proposed by Yabuki et al [172] that developed a tailored IFC-shield Tunnel structure capable of collecting information about soil layers and cave boundaries. Still with reference to IFC structure development, Borrman et al. [35] [33] [9] [34] [35] provided a semantic approach based on a multi-scale extension of IFC mapping the tunnel information on a LOD scale.

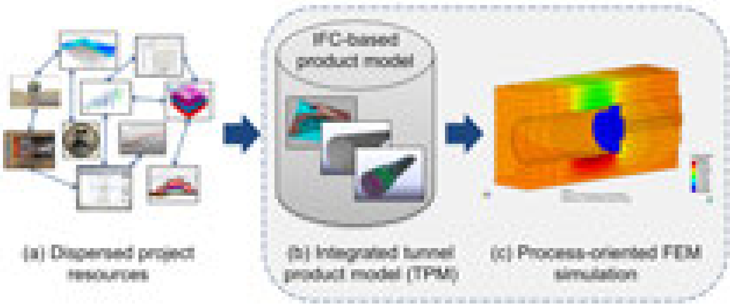


Fig. 9.37 Tunnel Product Model method. Source Staschelt et al. [157]

According to Borrmann et al., the use of BIM methodology improves the stepwise development of projects during the design phase. For this reason, according to the philosophy of BIM methodology as an evolving model, the concept of LOD plays a key role in defining the hierarchical structure of data in order to collect information from from the rough phases through to the finer phase, by spreading the data automatically and thus reducing the effort required for re-processing.

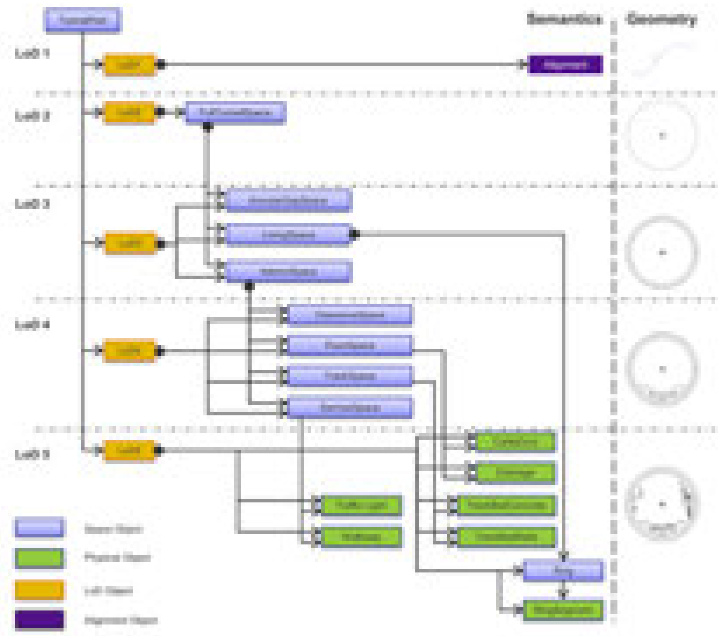


Fig. 9.38 Shield Tunnel Product Model. Source: Borrmann et al. [32]

Starting from previous studies, Osello et al. [139] tested BIM methodology to provide a workflow tailored to FEM analysis. Given the lack of an open data exchange format, such as IFC, required to ensure the correct conversion of data, the study proposed the use of a proprietary format, such as DXF, to translate at least the geometry data, thereby avoiding re-design operations in FEM software. In this case, a very detailed BIM model, drawn up for executive design, was exported to share cave geometry with a dedicated FEM software, such as RS3 by Rocscience.

Fig. 9.39 BIM methodology for Tunnel Information Modelling. Source Osello et al. [139]

In conclusion...

9.5.2 Tunneling BIM: the case studies application

Demonte project

The tunnel project consists of a single-arch road tunnel with a total length of 647.61[m], consisting of 48.3[m] of artificial tunnels and 599.31 [m] of excavation of natural material. In addition to this work, an exit tunnel with a length of 174.98m will be built, of which 163.48m will require excavation through natural material and the remaining 11.5m will be made through an artificial tunnel. The tunnel has a maximum coverage of about 75m; at the central part of the work the exit tunnel is predicted to have a maximum coverage of approximately 66m.

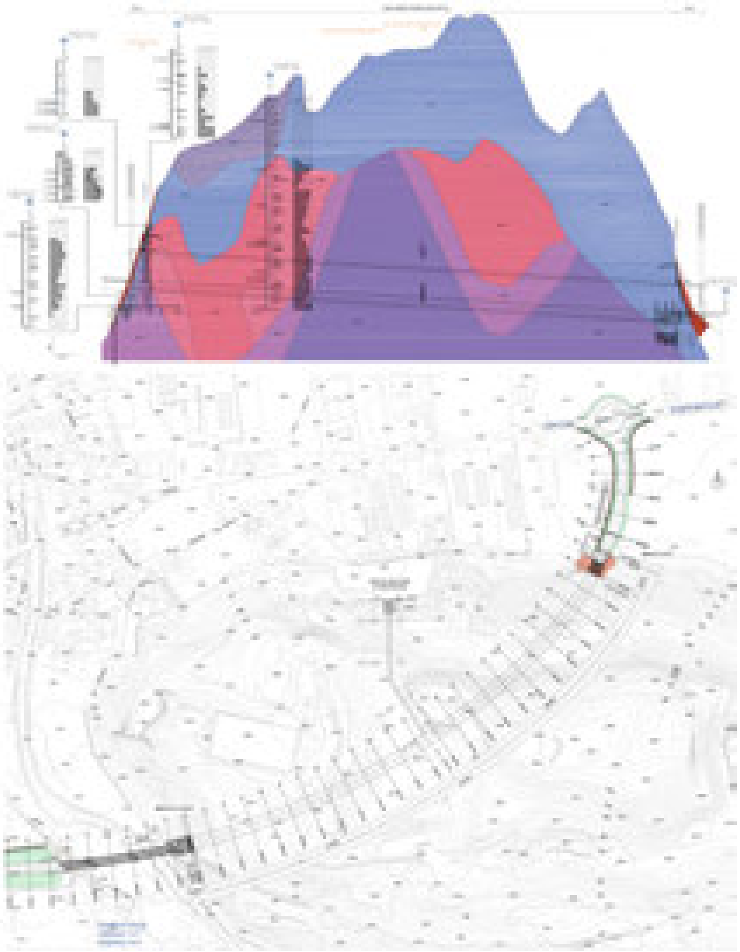


Fig. 9.40 Demonte project, Geo-section and planimetry

Based on the geo-mechanic study, the project sections are B, C1 and C2. Section B type sections are those where the rock mass has the best mechanical characteristics (UGm1 and UGm2). Section C2 on the other hand refers to areas where the cluster is poorer (UGm_i), therefore for this section consolidation of the excavation and boundary front are provided, by means of jet grouting columns and a support consisting of metal inserts. The Section C1 designation is used in conditions of intermediate rock mass (UGm3) and involves consolidation of the front with fiberglass pipes and a shell support consisting of metal inserts.

ITo tackle such a complex modelling problem as a tunnel, Revit software was chosen, taking into account the possibility of integrating it with BIM environments developed using Dynamo, i.e. a visual programming language needed to overcome the limitations imposed by Revit modelling. The first step in developing an effective script with Dynamo is to create a mind map of the script process in order to identify the information flow, depicting inputs and outputs. The results derive from a step-by-step process based on function and script blocks that run a single objective, producing elements that can be useful for the next step

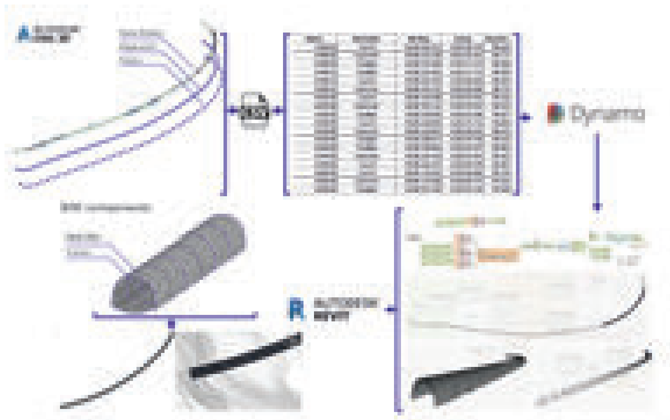


Fig. 9.41 Tunnel workflow

In this case, the starting input is a road alignment shared by Civil3D. The road alignment can be exported by Civil3D as a 3D spline or as a point report. Depending on the type of input, development of the script may change. The 3D spline is easier to process and has forced constraints, but it is more difficult to keep up-to-date, while the point report requires more manipulation in the preliminary phase, but it offers greater reliability during later development phases of the project. After processing the points report, adaptive components were developed in order to place the elements along the road alignment.

The road alignment report is organized in columns: i) Station (Pk); ii) Description; iii) Points coordinates (Northing, Easting and Elevation). The parsing process aims to define the rules necessary for the program to read the file and encode the data, Figure 9.42. The script accesses the file path directory, enabling the information to be modified and updated all the time. Each time the program computes the entire process by reading the file report. Thus, if the road corridor is changed, the report is updated and so is the tunnel corridor.

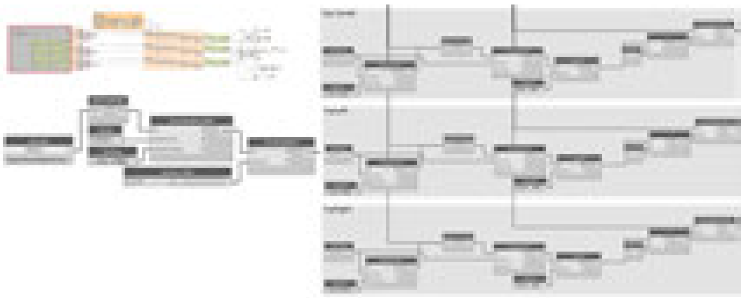


Fig. 9.42 Dynamo script parsing road point

The program reads the alignment report and translates the cell contents into *"string data"*. In this way it is possible to define a script to search the contents using a guide parameter (for instance *TopLeft*, *TopCenter*,*TopRight*). The nodes used for these operations are *“String.Contains”*, *“String from Object”* and *“List.FilterByBoolMask”*. The chain of these nodes aim to compare table data with a mask returning the filtered data. The outputs from this process generate a List of values organised in a sub-list, as shown in Figure 9.43. The concept of sub-list mentioned in Chapter 8 plays a key role in the development of scripts, selecting and organizing data. The program groups and sorts the data derived from the report according to the *"Descrition"* field. Each sub-list is composed of five items, as shown in Figure 9.43. The program then creates a selection, for instance with the item "0" in all sub-lists. By parsing the geographic coordinates using the *"Point.ByCoordinates* ode to re-build the points, and then using them as inputs with the *“NurbsCruve.ByCoordinatesPoints”* node, it is possible to generate the curve in the workspace.

Fig. 9.43 Dynamo Parsing Alignment

The interpolated curve will be used as a reference to locate the BIM components. The approach proposed in this application is based on the use of particular BIM components, named *"Adaptive Family"*. The adaptive families are able to adapt their geometry according to reference points, a property which in this case is very useful, because it allows components to be placed along the alignment, thanks to the Dynamo program. Furthermore, adaptive families have more capacity from a geometrical point of view, enabling the modelling of complex geometric shapes such as tunnel sections.

The tunnel section was created starting from a parametric profile and evolving into an adaptive family template, as shown in Figure 9.44. In order to solve the problem of planar sections, especially when the sections have to be located in a curve stroke, the family is based on three reference points, useful for placement in the next step. The parametric profile is characterized by geometrical parameters that can modify the section geometry according to project needs. The methodology to develop tunnel sections exploits the possibility of nesting one family within another to facilitate the creation of complex components. Before introducing the profile section, a spline based on three reference point is created to generate a spline curve, highlighting the normal plane. The section is loaded by placing the profile on the point reference, while maintaining the normal plane of the sections

To complete the creation of the tunnel section, an elevation of the section geometry has to be conducted. Once the elevation has been completed, the solid geometryis subtracted to obtain the final component. The geometrical parameter defined for the section is matched to allow geometrical adaptation to project needs. Additional parameters are defined by the list supplied according to ANAS requirements.

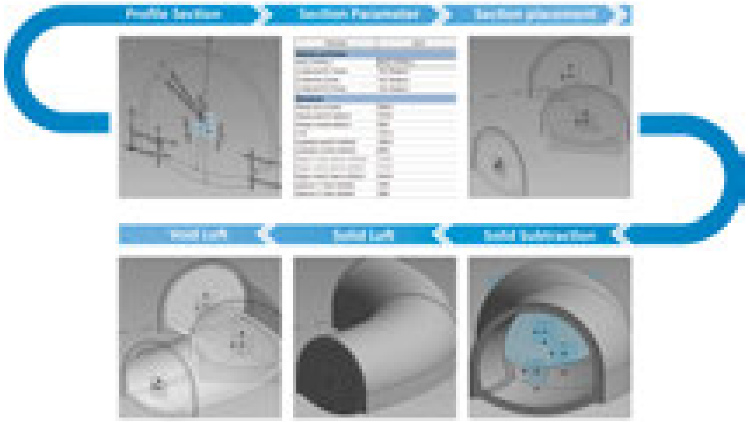


Fig. 9.44 Tunenl section component

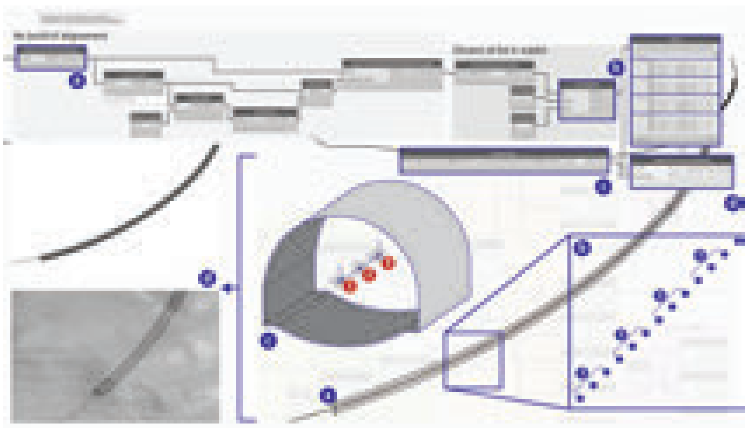


Fig. 9.45 Tunnel BIM model

Once library of BIM objects has been prepared, the script has to handle the curve, Figure 9.45[a] dividing it into points at a distance that depends on project parameters. In this case, we suppose that the work should advance by nine meters a day. So, taking into account that the tunnel section components require three reference points, the curve has been divided into segments at a distance of around 4.5 meters, as shown in Figure 9.45[b]. Dividing the alignment into segments, we obtain a list of points, which are grouped into a sub-list with a lengthsfor three items and an offset for two items. In this way the end point of one section will be the starting point of the next section, as shown Figure 9.45[b]. Once the sub-list has been obtained, it is possible to place the object using the *"AdaptiveComponent.ByPoint* node, which requires the reference point just created and the family section, Figure 9.45 [c][d]. Once this section is accomplished, it is possible to run the script and the tunnel section will be placed along the alignment.

In conclusion, the methodological approach proposed for the modelling of tunnels and underground facilities is based on the use of Visual programming to force the software to model elements in an automatic way. Otherwise, without the use of Dynamo, the designer would waste a great deal of time placing the elements, with enormous problems caused by the fact that software programs like Revit are good at managing horizontal information but they are based on vertical levels. Other advantages of this approach relate to the ability to accept updates to road projects. Indeed, thanks to alignment report processing, it is possible to update every change without to re-modelling the tunnel by hand, thereby saving time and leading to greater control over the project.

9.6 Conclusion

In conclusion, to summarize the case studies proposed in this Chapter, it can be stated that considerable integration of different applications is required in order to apply BIM methodology to infrastructure projects. This has to be inserted within a workflow to perform the design process. These case studies have shown that integration between the BIM and GIS environment is essential, producing numerous advantages in terms of communication and storage. Moreover, the use of on-line applications can be useful for sharing information between different stakeholders and technical disciplines. Other case studies, related to bridge and tunnel modelling, highlight the need to improve standard applications, using visual script to perform modelling activities, thereby avoiding manual work by BIM modellers. At the same time, the use of algorithms makes it possible to facilitate update operations, thereby saving time and costs. Finally, the interoperability process was tested to assess the quality and quantity of data shared, highlighting that full integration of applications is still far away, especially for open data formats.

Chapter 10

BIM Maturity

This chapter aims to try to assess the initiative proposed in this research, in order to evaluate, using different methods, the state of adoption of BIM Methodology. Thus it would be useful to understand which initiatives should be promoted in the future and to plan these according to the DM provisions and company objectives. At the moment there are several studies that provide Maturity Capability models, however only some are able to perform an assessment for a Contracting Authority like ANAS.

10.0.1 BIM Maturity Capability Model

The perception of BIM in the AEC context has changed over the last decade. It is no longer considered just a modelling tools, but is now recognised as a process based on Information Technologies (IT), in turn based on the collaboration and cooperation required at organisational level and from the whole supply chain [169] [159]. So the challenge for BIM has shifted from overcoming technical difficulties to being integrated into working practice. In order to address this challenge the AEC sector (firms, owners, contractors and so on) find the need to evaluate the current status of BIM implementation in its organisations, in order to identify the path to follow to improve the BIM Maturity Level [124] [108] [4] [6].

Driven by this necessity, several BIM maturity measurement tool have been created. From the literature review, the large number of tools described can be reduced in number, as reported by with Wu et al. [169]. TThe models retained are:

- **NBS CMM** proposed by the Nation Institute of Building Science (NIBS) in 2007. The model is composed of 11 areas;
- **IU BIM Proficiency Index** proposed by Indiana University in 2009. The model is composed of 8 area, 32 measurement and 5 maturity levels;
- **BIM quick Scan**, in 2011. The model is composed of 44 measures on the basis of questionnaire;
- **VDC Scorecard** proposed of Stanford University, in 2012. The models is based on 4 areas and 74 measures;
- **Organization BIM assessment**, proposed of Pennsylvania State University, in 2013. The model is composed by 6 areas, 20 measures and 5 maturity level;
- **BIM Maturity Measure**, provided by Arup in 2012. The model is derived from studies carried out by CIC Research Group and Department of Architectural Engineering of Pennsylvania State University. The model is composed of a dedicated area for project measurement and n-areas for the disciplines involved in the process. There are 12 measurements per project area and other disciplines are divided, with 6 levels of maturity;
- **BIM Cloud Score (BIMCS)** proposed by Du et al. [64], in 2014, is a third-party server-based application that can perform benchmark analysis of models using cloud computing. It measures 6 main aspects and 19 quantitative measurements;

Basically it is possible to sub-divide measurements into question categories, where the degree of quantification, based on a target, determines the level of maturity. The question categories include:

- **Process** questions relate to coordination among disciplines and stakeholders, the grade of IFC support in the delivery, design, use and re-use of information;

- **Technology** measures the level of accuracy of the model, data richness, model used, quality of interoperability process, if data are received and used in O&M phase;
- **Standard oriented** refers to evaluation of BIM standards implementation, such as BEP, EIR and Guide Line;
- **Organization** : measures BIM goals and business targets, the cost of BIM, company commitment level regarding BIM implementation;
- **Human** evaluates whether or not roles and responsibilities are defined, the capability of the design team, whether training and dissemination is expected for employers, the number of employers involved in BIM activities and whether a dedicated BIM space is provided;

10.0.2 ANAS BIM maturity

On the basis of the BIM capability models analysed, three models have been chosen to assess the ANAS maturity level. Taking account of the activities proposed in this research paper, the aim is to test these capability models and at the same time estimate the actions provided to return a level of maturity and address the future steps involved in BIM implementation. Furthermore, not all models are tailored to assess organisational level, for instance the BIM Maturity Measure proposed by ARUP is mainly focused on the evaluation of project development. It is used to assess project workflow among the different disciplines, without considering process organisation.

The result obtained from the models point out a maturity level for ANAS consistent with the expectations of BIM adoption level described in the Chapter 5. The highest score has been reached by the BIM Maturity matrix, shown in Figure 10.1 (Appendix C.1) which mapped the process at organisational and discipline level, dividing the scope into primary and secondary aims. Process organisation achieved a score of almost 70% and the average maturity level by discipline is around 60%, even though this approach is tailored to assess private companies and not public administrations. Meanwhile, the second model, shown Figure 10.2 (Appendix C.2) provided by NIBS, propose a set of questions that are related to BIM implementation at organisational level, for iinstance it estimates the process of change management, the definition of roles and responsibilities, the business process and so on. The model result gives a score defined as *"Minimum BIM"* - this is due to low scores achieved for some aspects such as *Life Cycle View* where at an organisational level at the moment there is not a great deal of sensitivity or vision. The story is the same with the business process, where only some business processes are designed to collect information to maintain BIM organisation.

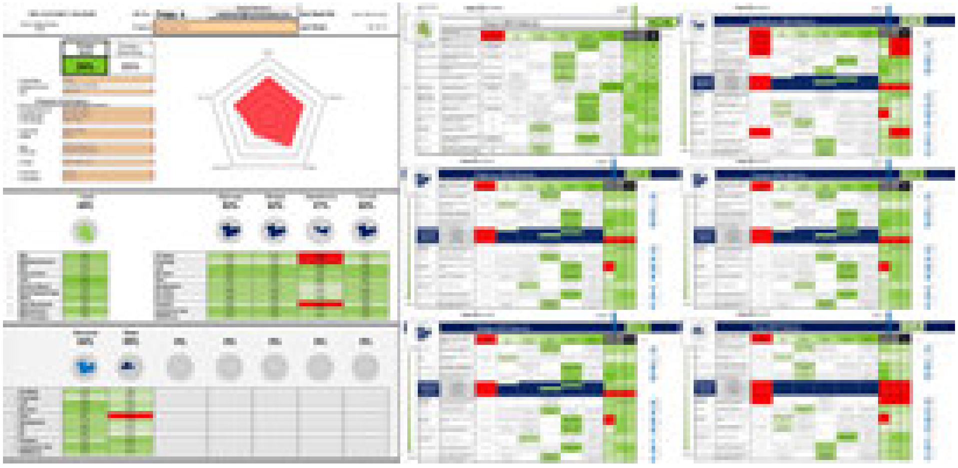


Fig. 10.1 Arup BIM Maturity Matrix

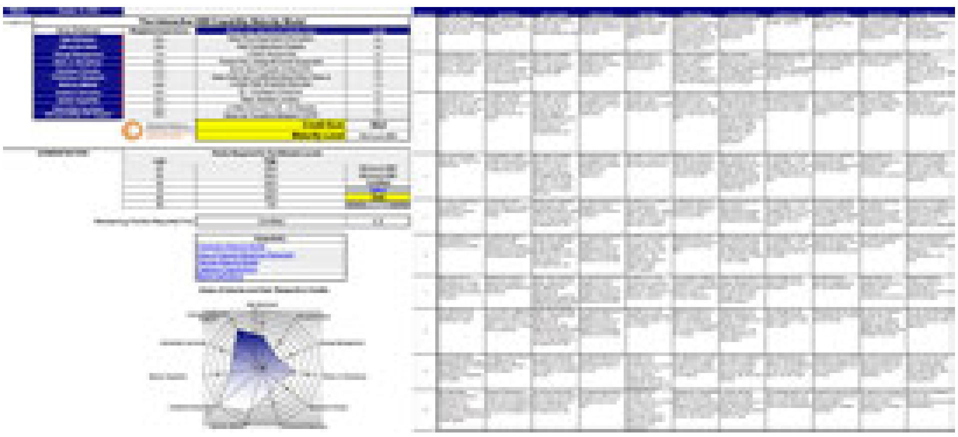


Fig. 10.2 NIBS Maturity Assesment

Fig. 10.3 Penn BIM Maturity Matrix

The last model, proposed by PENN and shown in Figure 10.3 (Appendix C.3), seems to be the most useful for assessing BIM capability for a contracting authority. The model estimates 6 areas, as mention before, assessing the level of maturity on the basis of the target level being aimed for. Unlike the other models, it offers more parameters for assessing employer readiness, and strategy at company level rather than related only to project level. Furthermore, the model also evaluates the infrastructure project, taking into account the present of correct spaces and equipment.

In conclusion, the capability model results provide a guide for future implementation. First of all, BIM methodology has to apply to entire life cycles and not only to the design phase and some part of the construction phase. BIM Vision and Objectives also have to guide further implementation, by providing a picture of what an organization is striving to become, starting from a clear identification of objectives, provided at company level by a BIM planning committee. At the level of information exchange, the interoperability exchange format requires more implementation and standardization. The IFC is the most widely used format in the BIM environment and it allows translation. Notwithstanding, it is necessary to improve automation rules and procedures able to verify the compliance of information contents to normative and technical requirements, in order to avoid errors or lack of data.

Chapter 11

Discussion and Conclusion

11.1 Introduction

This research paper has sought to ascertain, in the first part, the BIM implementation level in public procurement, starting from other national strategic BIM development and standardization initiatives. In the second part, it aimed to investigate the definition of multi-scale models for infrastructure design and the interoperability process. The study carried out shows that at a national level, Italy - with publication of M.D. 560/2017 - gave a great boost to the spread of BIM within public works. Nevertheless, the first sector involved in this change will be the Civil sector, where the maturity of application it is not quite high enough to guarantee a high level of integration between systems, stakeholders and processes. The use of open data format such as IFC, LandXML and BCF (BIM Collaboration Format) is practically obligatory, but especially for civil design even more effort is required to introduce the necessary classes, and to map the component elements.

11.2 General Observation

This research paper has tried to provide a general overview of main BIM research efforts in the international and national panorama. The implementation of BIM for civil design is a new horizon that requires further investigation. The pilot projects tested have demonstrated the possibilities of BIM-GIS integration, with considerable results, that indicate the potential and advantages of a PIM enriched with a large amount of data, derived from different domains. Interoperability, in this context, plays a key role in overcoming resistance and scepticism, by promoting the spread of BIM in the whole supply chain. Notwithstanding, exchange data formats, such as IFC, are already ready to optimise the sharing of civil structures. For these reasons, a property set tailored for ANAS has been defined, in parallel with the standardisation of a BIM library provided to contractors and sub-contractors.

Procurement experiences were essential to test the strength of ANAS EIRs. This path has undergone an evolution from the first procurement *"Curva Carrai e Acquabona"*, up to the latest contracts for engineering and architecture services. This has enabled ANAS to contract `€ 240 million of framework agreements, leading to noteworthy results mapped by CRESME, which identified ANAS as the most important Contract Authority in Italy for BIM procurement, with `€ 39.5 million worth of contracts for services, equal to 16% of whole BIM procurement and 25% of BIM procurement over `€ 1million in 2018.

11.3 Contribution

This work has therefore aimed to show how the Italian public administration is addressing the issue of digitalization of public procurement. The findings of this study provide useful information regarding the positioning of ANAS in the AEC market as the first contracting authority in Italy to have perceived the level of importance of ongoing standardization efforts relating to BIM. This is valued by the CRESME report [53] and by the creation of specific offices within ANAS to manage BIM procurement and to improve the digitalization process. Furthermore, other findings of this study related to improved knowledge of Digital Delivery Specifications, Contractual Support and Concept & Application of LOD. Thanks to the development of case studies, it has also been possible to express a BIM workflow tailored for infrastructure projects, testing the main BIM authoring applications, in order to optimise modelling operations and information exchange, through the open data format.

11.4 Context, Significant and Implication of the Results

The possibility to apply the research theory to a public company such as ANAS, with the possibility to conduct tests on the application of BIM methodology in real case studies was a unique occasion in the national context. As reported, the Italian sector is affected by a delay in the AEC sector and public authorities such as ANAS, which are obliged by M.D. 560/2017, may see a positive boost in the digitalization of the AEC sector, adapting to the EU vision in terms of a reduction of Construction and Demolition Waste (CDW). The findings of the work carried out are confirmed by the CRESME report, which highlights the position of ANAS as the most important Contract Authority in Italy for BIM procurement. This result seemed unthinkable in 2016 when the project started. Now ANAS has approved the creation of a dedicated BIM unit to manage and developed not only BIM projects, but with the aim of creating standards and process tailored for the company, promoting training courses and various other activities around the country.

The contract projects containing BIM requirements defined in this thesis are attached to a framework agreement contract for `€ 240 million. This means that in the Future, most ANAS projects will be managed according to the design process examined in this research.

Despite the process attaining a high level of commitment and maturity, it is still far from complete and the success of BIM adoption will depend on the first project pilots, which could demonstrate the advantages of this change. This will contribute to changing the perception of BIM as not only a problem to solve but an opportunity to save money, improve quality and facilitate the management phase.

11.5 Further Research

While certain results have been obtained in the definition of processes, standards and workflow, this is only a preliminary part of a more complex research project, one that also aims to involve other ANAS management departments. The process has been re-designed for the CP area without integration in the other direction. This means that it has been possible to test BIM methodology only for the design phase, without the possibility of investigate either the construction phase or the facility management. Those phases will require, in turn, appropriate processes, standards and requirements.

The lack of a platform for the data aggregation for projects from which a correct extrapolation of technical drawings and other information can be obtained, remains a weakness, and will continue to be for as long as the project continues to use traditional communication means involving poor digital supports or even paper.

In this sense, the IFC format has to implement classes in order to succeed with communication of civil projects. Moreover, the near future will see the definition of an API capable of verifying regulatory compliance with respect to IFC information with contract requirements, thereby avoiding handling work.

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Appendix A

BIM Framework Adoption

As-is Process Mapping

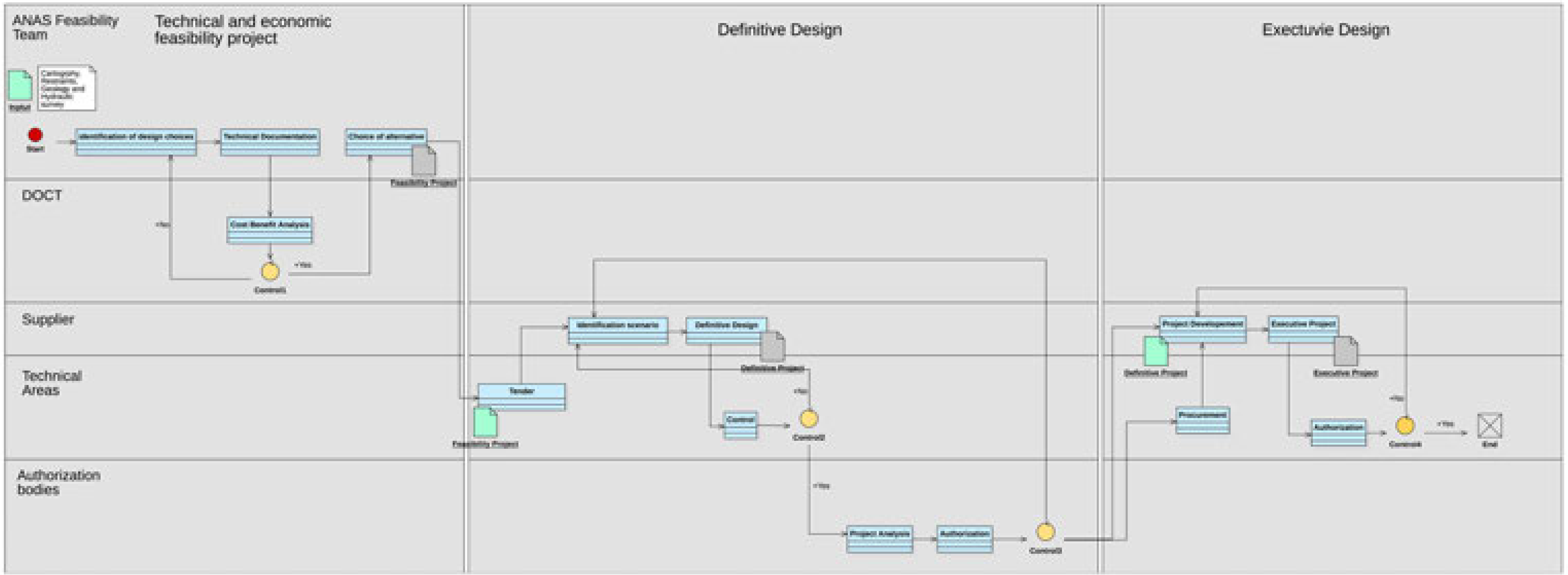

Fig. A.1 As-is process with design in outsourcing

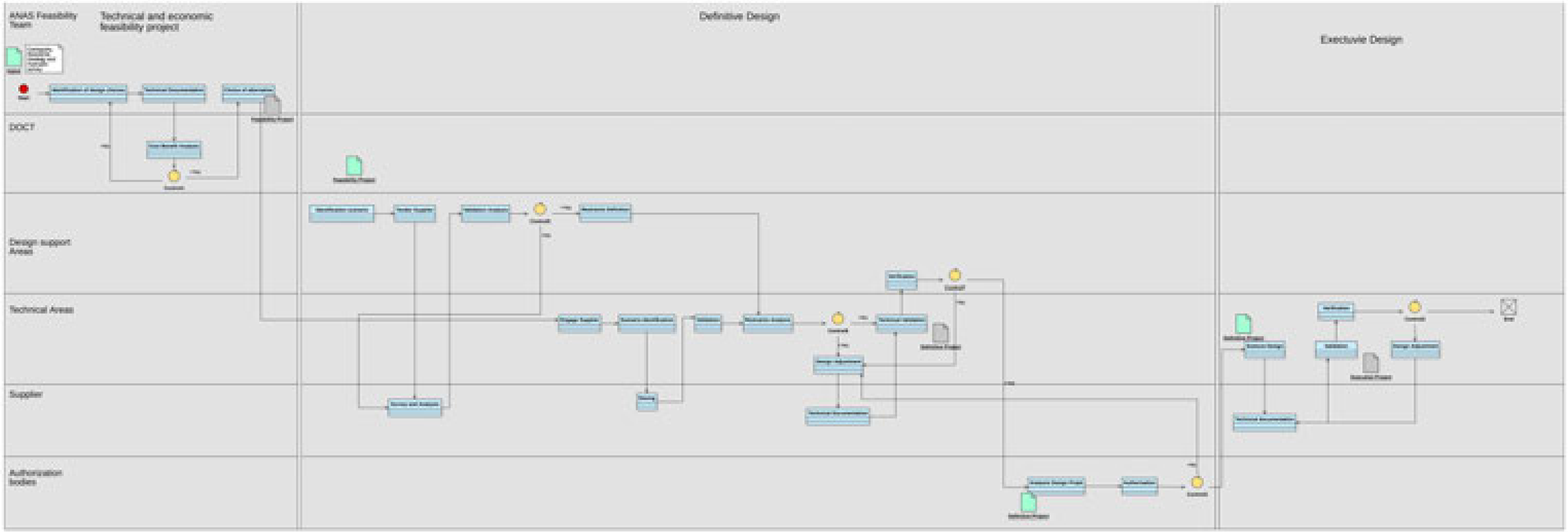

Fig. A.2 As-is process with internal design and support srvices

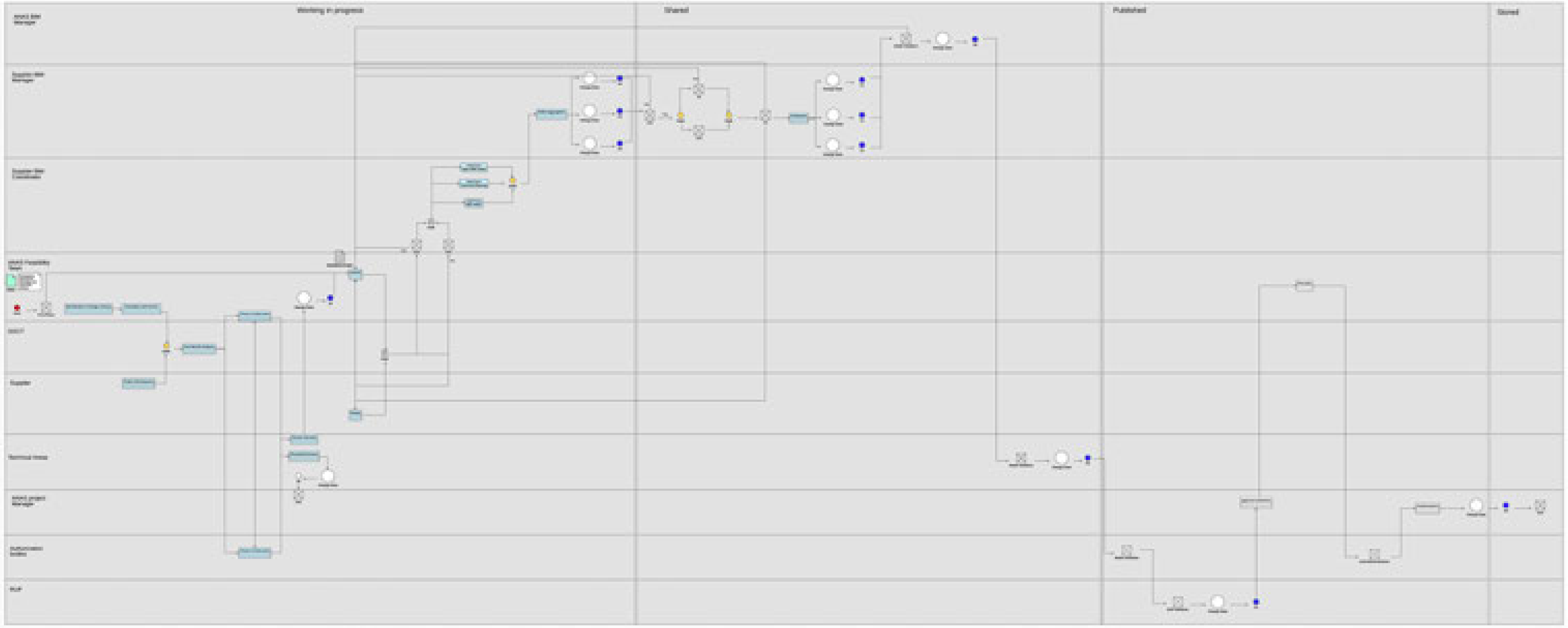

Fig. A.3 To-be process with design in outsourcing

Appendix B

InfraBIM workflow

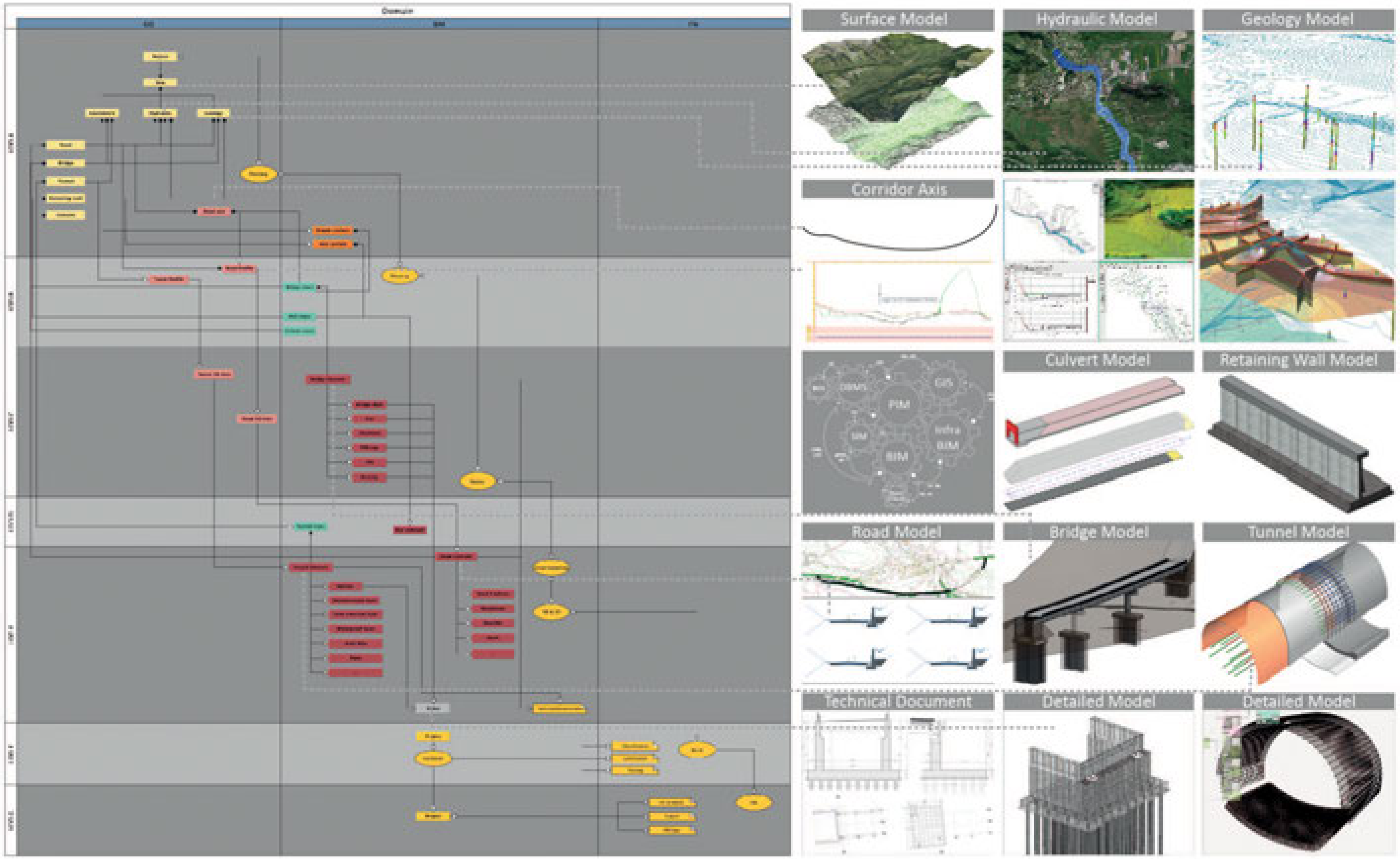

Fig. B.1 InfraBIM Multi-scale model

Appendix C

BIM Capability Maturity Model

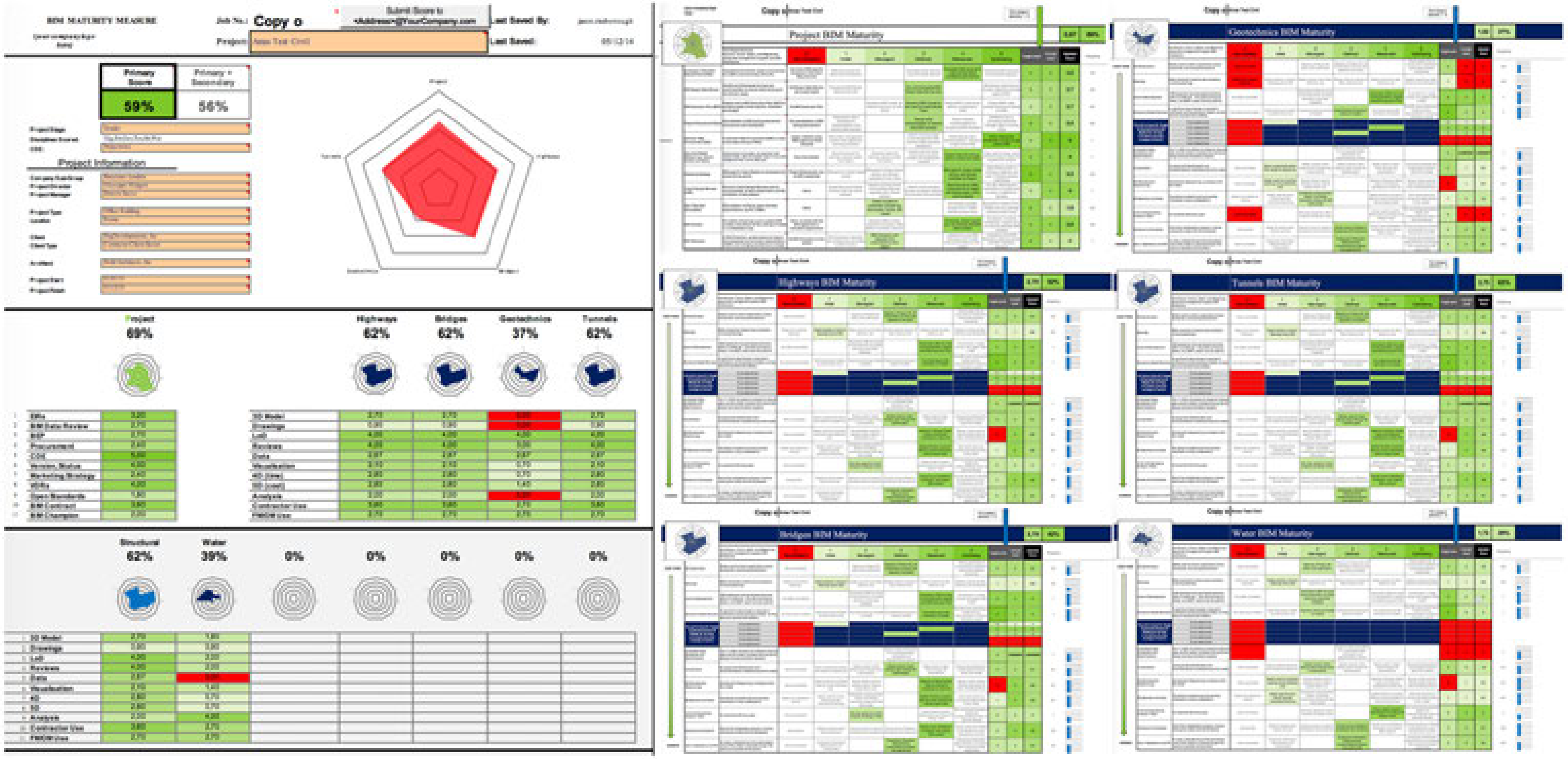

Fig. C.1 BIM Maturity Matrix

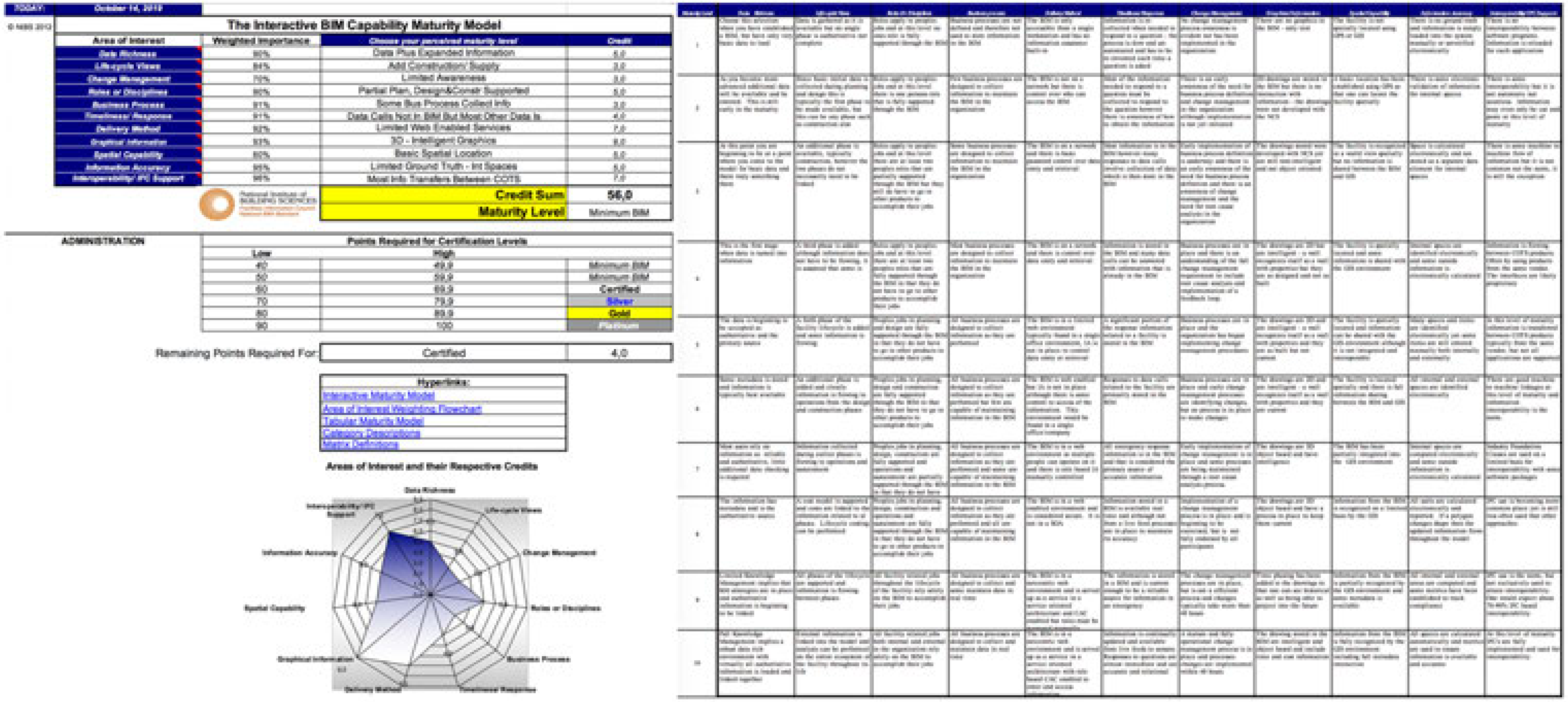

Fig. C.2 NIBS Maturity Assesment

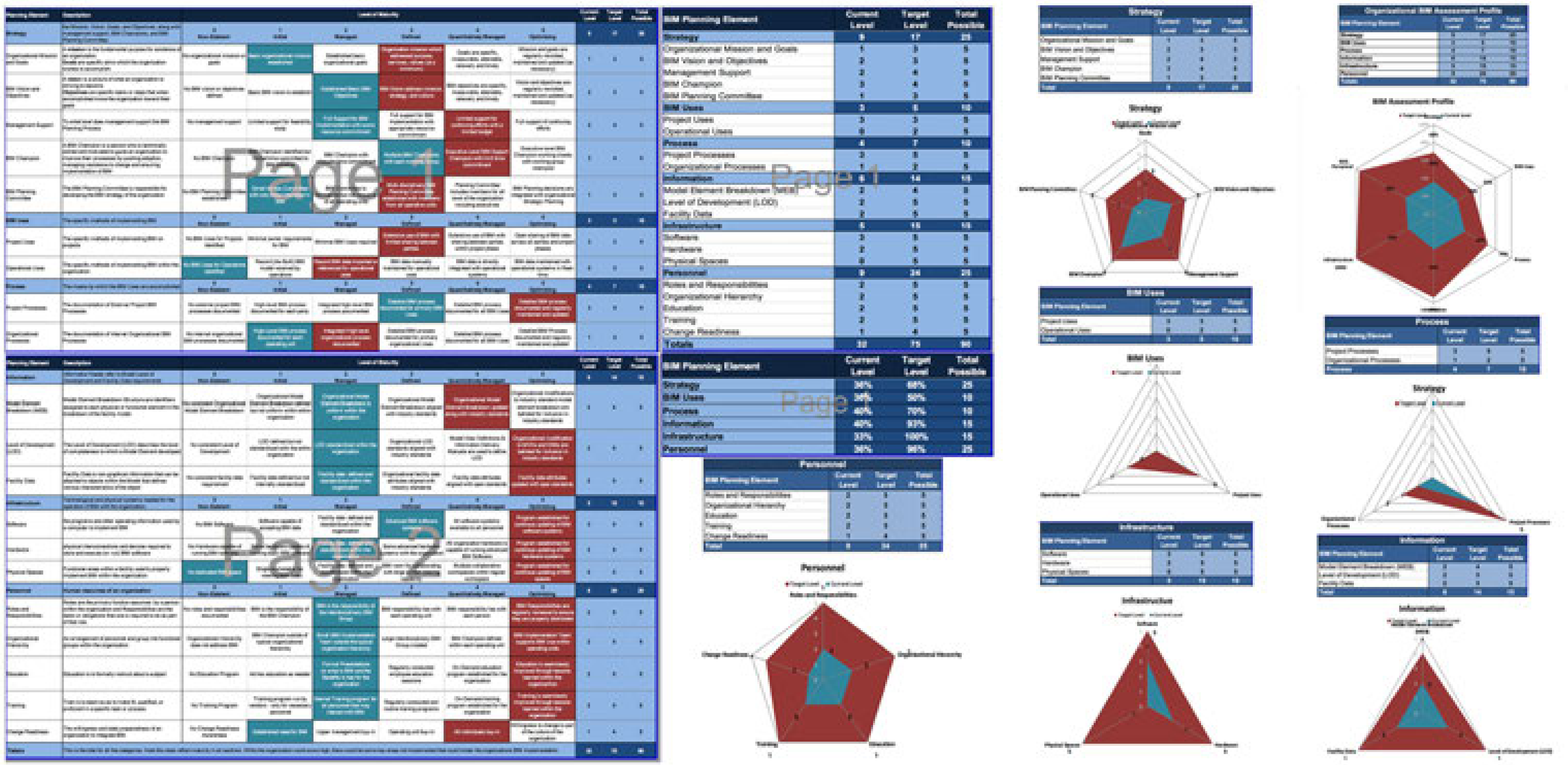

Fig. C.3 Penn BIM Maturity Matrix