Université de Constantine 3

Faculté d'Architecture et d'Urbanisme

Département de Management de Projets

INTEGRATED PROJECT DELIVERY AND BUILDING INFORMATION MODELING ASSESSMENT FOR SUSTAINABLE RENOVATION OF HERITAGE BUILDINGS

THESE

Présentée pour l'Obtention du

Diplôme de Doctorat L.M.D en Architecture et Urbanisme

en Management de Projets

Par

Bani Feriel BRAHMI

Année universitaire

2021-2022

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N° de Série :

N° d'Ordre :

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2021-2022

ACKNOWLDGEMENTS

I begin by thanking Allah for giving me strength, health and inspiration to complete this work.

And of course, this research project would have been impossible without the support of many people:

I would like to thank Pr. *Souad SASSI-BOUDEMAGH* for agreeing to supervise this project. Her valuable guidance and advice helped me in writing this thesis. I am grateful for her respect and support.

I thank Dr. *Ilham KITOUNI* for starting this research with me from the beginning. I appreciate her presence and support during the difficult times. Her insight and capacity to discover and understand what I really wanted to express are remarkable. I am grateful for her confidence and encouragement.

I am deeply indebted to my supervisor abroad, Dr. *Aliakbar KAMARI*, for giving me the opportunity to work as a guest Ph.D. student at Aarhus University (Denmark), and adding so much value to the research. I really appreciate his constant guidance, support, and sharing of his knowledge and expertise.

I would like to thank the members of the jury for accepting to be part of this achievement by reviewing and examining my work.

Finally, I would like to thank all the people who contributed in one way or another to the success of my research.

DEDICATION

I *dedicate this thesis to my precious family*

I am so grateful to you for believing in me. I would not have been in the position I am today if I did not have your love, caring, and support!

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LIST OF ABBREVIATION

AECO : Architecture Engineering Construction and Operation
AIA : American Institute of Architects
ASHRAE : The American Society of Heating, Refrigerating and Air-Conditioning Engineers
BIM : Building Information Modelling
CE : Circular Economy
COBie : Construction Operations Building Information Exchange
HBIM : Heritage Building Information Modelling
IFC : Industry Foundation Classes
IPD : Integrated Project Delivery
IT : Information Technology
LEED : Leadership in Energy and Environmental Design
PLPs : Project Lifecycle Phases
QCA : Qualitative Comparative Analysis
VDC : Virtual Design and Construction
XML : Extensible Markup Language

ABSTRACT

Renovation of heritage buildings has become a revivification pathway to promote sustainability as well as to protect the heritage buildings' significance and values. The complexity of sustainable renovation of heritage buildings requires the adoption of more sophisticated technologies and project management models to deal with the contradiction between sustainable design and heritage values preservation, as well as enhancing process productivity and final performance.

This research aims to assess and evaluate the application of Integrated Project Delivery (IPD) strategies and tools through Building Information Modelling (BIM) to enhance the sustainability aspects and efficiency of renovating heritages via better collaboration and integration. That is a vital key to the successful delivery of building projects.

The research adopts a mixed methodology, Qualitative Comparative Analysis triangulating the collected data. An intensive review of related literature is carried out, besides data collection and analysis of four real-world heritage cases (in different contexts). The research study enables a comprehensive and systematic exploration of the potential use of IPD and BIM, within the development of an analytical framework consisting of a set of defined variables including 50 criteria, classified into 15 categories, and grouped into five thematic strands (*people, process, policy, technology,* and *product*). The focus is to determine the shared collaborative practices across the projects and the level to which the teams are able to implement the IPD and BIM tools and processes effectively.

The findings presented considerable advantages of IPD and BIM collaborative strategies application over different thematic strands and contract types. It was revealed that IPD and BIM application allows reaching sustainability goals together with preserving the heritage buildings' values via holistic decision-making frameworks, ensuring on-time and budget project delivery. The collaborative environment admits the stimulation of integrated intervention design from the earliest stage, within multiple participants. BIM enables design teams to provide faster complex analyses and rapid assessment of energy simulations through BIM coordination with energy models, to produce a full virtual construction model.

The contribution of this thesis is relevant to heritage preservation research and practitioners (especially in the Algerian context), who can use the resultant to better understanding and navigating the IPD through BIM and its potential shift in these projects with multiple stakeholders (e.g. designers, engineers, contractors, etc.). Moreover, it provides decision support for professionals and the government to choose the suitable delivery method (contract and legal terms) and best practices for carrying out similar projects to achieve high-performance buildings as the outcome of renovation of heritage buildings in broader and holistic perspectives.

Keywords: Building Information Modelling (BIM); Integrated Project Delivery (IPD); Heritage Building; Sustainable Renovation; Heritage renovation.

RESUME

La rénovation des bâtiments patrimoniaux est devenue une revitalisation pour promouvoir la durabilité ainsi que pour protéger la signification et les valeurs des bâtiments patrimoniaux. La complexité de la rénovation durable des bâtiments patrimoniaux exige l'adoption de technologies et de modèles de management de projet plus sophistiqués pour gérer la contradiction entre la conception durable et la préservation des valeurs patrimoniales, ainsi que d'améliorer la productivité des processus et la performance finale.

La recherche de cette thèse vise à évaluer l'application des stratégies et des outils de réalisation intégrée de projets (Integrated Project Delivery - IPD) par le biais de la modélisation des données de bâtiments (Building Information Modelling - BIM) afin d'améliorer les aspects de durabilité et l'efficacité de la rénovation des patrimoines par une meilleure collaboration et intégration. Il s'agit d'une clé essentielle à la réussite des projets de construction.

La recherche adopte une méthodologie mixte, l'analyse qualitative comparée triangulant les données collectées. Une analyse approfondie de la littérature connexe est effectué, en plus de la collecte et de l'analyse des données de quatre cas réels de patrimoine (dans des contextes différents). L'étude de recherche permet une exploration complète et systématique de l'utilisation potentielle de l'IPD et BIM, dans le cadre de l'élaboration d'un cadre analytique constitué d'un ensemble de variables définies comprenant 50 critères, classés en 15 catégories et regroupés en cinq volets thématiques (*personnes, processus, politique, technologie,* et *produit*). L'objectif est de déterminer les pratiques collaboratives communes à tous les projets et le niveau de capacité des équipes à mettre en œuvre efficacement les outils et les processus d'IPD et BIM.

Les résultats ont montré les avantages considérables de l'application des stratégies de collaboration IPD et BIM sur différents volets thématiques et types de contrats. Il a été révélé que l'application de l'IPD et du BIM permet d'atteindre les objectifs de durabilité tout en préservant les valeurs des bâtiments patrimoniaux par le biais de cadres décisionnels holistiques, garantissant la livraison du projet dans les délais et le budget prévus. L'environnement collaboratif permet de stimuler la conception d'interventions intégrées dès le stade le plus précoce, au sein de participants multiples. Le BIM permet aux équipes de conception de fournir plus rapidement des analyses complexes et une évaluation rapide des simulations énergétiques grâce à la coordination BIM avec les modèles énergétiques, afin de produire un modèle de construction virtuel complet.

La contribution de cette recherche est pertinente pour les recherches de préservation du patrimoine et les praticiens (notamment dans le contexte Algérien), qui peuvent utiliser les résultats pour mieux comprendre et naviguer dans l'IPD par le biais de la BIM et son changement potentiel dans ces projets avec de multiples parties prenantes (par exemple, les concepteurs, les ingénieurs, les entrepreneurs, etc.) En outre, il fournit une aide à la décision aux professionnels et le gouvernement pour choisir la méthode de livraison appropriée (contrat et termes juridiques) et les meilleures pratiques pour la réalisation de projets similaires afin d'obtenir des bâtiments à haute performance comme résultat de la rénovation des bâtiments patrimoniaux dans une perspective plus large et holistique.

Mots-clés: Modélisation des données de bâtiments (BIM); Réalisation de projet intégrée (IPD); Bâtiment patrimonial ; Rénovation durable ; Rénovation du patrimoine.

ملخص

يندرج تجديد المباني التراثية ضمن المسارات المحبذة والأكثر انتشارا لتعزيز الاستدامة وكذلك لحماية دلالات وقيم المباني التراثية. يتطلب تعقيد التجديد المستدام للمباني التراثية اعتماد تقنيات ونماذج إدارة المشاريع أكثر تطوراً للتعامل مع التناقض بين التصميم المستدام والحفاظ على القيم التراثية، وكذلك تعزيز إنتاجية العملية والأداء النهائي.

يهدف هذا البحث في هذه الرسالة إلى تقييم تطبيق استراتيجيات وأدوات التسليم المتكامل للمشاريع (IPD) من خلال نمذجة معلومات البناء (BIM) لتعزيز جوانب الاستدامة وكفاءة تجديد التراث من خلال تحسين التعاون والتكامل. هذا هو مفتاح حيوي للتسليم الناجح لمشاريع البناء.

يتبنى البحث منهجية مختلطة هي التحليل النوعي المقارن مع تثليث البيانات المجمعة. تم إجراء مراجعة مكثفة للأدبيات ذات الصلة، إلى جانب جمع البيانات وتحليل أربع حالات حقيقية من التراث (في سياقات مختلفة). تتيح الدراسة البحثية استكشافًا شاملاً ومنهجيًا للاستخدام المحتمل ل IPD و BIM، ضمن تطوير إطار تحليلي يتكون من مجموعة من المتغيرات المحددة بما في ذلك 50 معيارًا، مصنفة في 15 فئة، ومجمعة في خمسة سلاسل مواضيعية (*الأشخاص، العملية، السياسة، التكنولوجيا، والمنتج*). ينصب التركيز على تحديد الممارسات التعاونية المشتركة عبر المشاريع و مستوى قدرة الفرق على تنفيذ أدوات وعمليات IPD و BIM بشكل فعال.

قدمت النتائج مزايا كبيرة لتطبيق الاستراتيجيات التعاونية بين IPD و BIM على السلاسل المواضيعية وأنواع العقود المختلفة. تم الكشف عن أن تطبيق IPD و BIM يسمح بالوصول إلى أهداف الاستدامة جنبًا إلى جنب مع الحفاظ على قيم المباني التراثية من خلال أطر صنع القرار الشاملة، مما يضمن تسليم المشروع في الوقت والميزانية المحددة. تسمح البيئة التعاونية بتحفيز تصميم التدخل المتكامل من المرحلة الأولى، بين مشاركين متعددين. يمكن BIM فرق التصميم من تقديم تحليلات معقدة أسرع وتقييم سريع لمحاكاة الطاقة من خلال تنسيق BIM مع نماذج الطاقة، لإنتاج نموذج بناء افتراضي كامل.

المساهمة في هذه الأطروحة ذات صلة ببحوث الحفاظ على التراث والممارسين (خاصة في السياق الجزائري)، الذين يمكنهم استخدام النتيجة لفهم وتصفح IPD بشكل أفضل من خلال BIM والتحول المحتمل في هذه المشاريع مع العديد من أصحاب المصلحة (مثل المصممين والمهندسين والمقاولين، إلخ). علاوة على ذلك، فإنه يوفر دعم القرار للمهنيين والحكومة لاختيار طريقة التسليم المناسبة (العقد والشروط القانونية) وأفضل الممارسات لتنفيذ مشاريع مماثلة لتحقيق مباني عالية الأداء كنتيجة لتجديد المباني التراثية في منظور أوسع وشامل.

الكلمات المفتاحية: نمذجة معلومات البناء (BIM)؛ التسليم المتكامل للمشاريع (IPD)؛ مبنى تراثي؛ التجديد المستدام؛ تجديد التراث.

CHAPTER I: INTRODUCTION, METHODOLOGY, AND RESEARCH DESIGN

This chapter presents an introduction to the thesis, explains the background and rationale for research. It addresses the literature review identifying the knowledge gaps that leads to the development of the research topic. The chapter highlights the research questions, objectives, and hypothesis, as well as it includes the research's methodology and scope.

1.1 Introduction/Overview

Heritage buildings are an important social capital for any country. They are defined as existing buildings with significant architectural, aesthetic, historical or cultural values that require protection (Arrêté du 13 avril 2005. page 13). These assets are a testimony of the history and culture of people and countries. The renovation of heritage buildings offers enormous potential for preserving a sense of identity and continuity in a rapidly changing world for future generations. Today, the renovation of heritage buildings has become a revivification pathway of regeneration, promoting sustainability and protecting the significance and values of heritage buildings (Fouseki & Cassar, 2014). It brings economic, cultural, social and environmental benefits to urban communities (Tweed and Sutherland, 2007. page 03). Renovations save a lot of capital, as it is often cheaper to renovate a building than to demolish it and build a new one. It promotes a circular economy by recycling and reusing as many resources as possible. Preserving existing heritage buildings helps create a sense of place and belonging for people.

Sustainable renovation is influenced by international economies, interest and community involvement. Currently, renovation and reuse of existing buildings directly address some global sustainability challenges, such as combating climate change and improving energy and resource efficiency. Research on energy retrofitting is expected to reduce CO2 emissions and achieve additional benefits, such as reduced life cycle costs and lower maintenance costs. From an environmental perspective, heritage buildings are categorized as having a very high-energy demand, as well as a very low indoor climate standard, especially when it comes to a desirable indoor climate (Rasmussen et al., 2015; Tomšič et al., 2017). For example, 35% of buildings in European unions are more than 50 years old and nearly 75% of the building stock (including heritages) is energy inefficient (European Commission, 2019). The same statistics show that renovating existing buildings can lead to significant energy savings, as it could reduce total EU energy consumption by 5-6% and cut CO2 emissions by about 5%. Conversely, only around 1% of the building stock is renovated each year (European Commission, 2019).

In addition, many researchers and practitioners debate the contradiction between the principle of "minimal intervention" and current energy performance goals, as it has a high impact on architectural values, which should be preserved by the renovation intervention (Fouseki & Cassar, 2014, p. 03). The WBDG Historic Preservation Subcommittee (2019) outlines four basic principles to keep in mind when upgrading systems in historic buildings:

a) *Sympathetic Upgrades:* Building system upgrades should consider the architect's specific design intent, such as utility spaces versus highly finished spaces.
b) *Reversibility:* Improvements to building systems shall be installed in a manner that prevents damage or can be removed without further damage to features and/or finishes.
c) *Retention of Historic Fabric:* "Work around" the historic fabric as much as possible. The basic mindset prescribes foresight and respect for historic materials. For example, systems must be designed efficiently enough to fit into existing openings or be accessible off-site.
d) *Life-Cycle Benefit:* Long-term preservation emphasizes the life cycle benefits of reusing historic assets and planning for changing prerequisites.

The sustainability of a heritage renovation project is affected by a long list of aspects. In their research, Kamari et al. (2017a) studied sustainability more holistically, and the result was a sustainability value map for building renovation, comprising three categories - *functionality, responsibility,* and *feasibility* - with a total of 18 sustainable value-oriented criteria and 118 sub-criteria. In the case of a building, renovation concerns deciding how to change or improve its components and parts, for example by replacing windows, insulating the building envelope or even changing its use. On the one hand, this often leaves clients (or owners) with a relatively large number of choices in deciding what levels of intervention and renovation alternatives to pursue. On the other hand, the design team must deal with increasing energy demand and indoor environmental requirements while considering architectural aspects and qualities in developing appropriate renovation scenarios (design options). This requires managing enormous complexity regarding both the multiple stakeholders involved (Buser & Carlsson, 2016; Kamari et al., 2019b) (i.e., related to their demands and priorities), and the renovation objectives and criteria (Marija et al., 2015; Kamari et al., 2017) (i.e., energy consumption) that need to be met. It also needs exploring and selecting among a large number of renovation alternatives and approaches available on the market (Kamari et al 2019c, Lidelöwa et al 2019). On the other hand, complexity increases in the early design phases, and significant changes may be made due to unavailability of original structural information or pre-existing/unanticipated construction conditions identified late, resulting in increased documentation time and reduced cost control and budget management.

To deal with the above challenges, sustainable renovation of heritage buildings requires cross-disciplinary sophisticated processes and methodologies (Kamari et al., 2019b). This is to develop holistic decision-making frameworks (Kamari et al., 2018a,b) that will help professionals decide on the most appropriate renovation solution (Kamari et al., 2019c), in order to strike a balance by providing additional improvement (i.e.) to user living conditions, building safety, safeguarding heritage values and reducing energy consumption (Fouseki & Cassar, 2014; Tomšič et al., 2017). Likewise, finding an optimal number of interrelated policies, processes, and technologies that will contribute to this success with many stakeholders involved are yet other challenges to be addressed.

1.2 The Research challenge/problem

BIM and collaborative environment

Information Technology (IT) is widely discussed within the emergence of large, ambitious, and complex projects in the Architecture, Engineering, Construction, Operations (AECO) industry, due to the new requirements of sustainability that need efficient information exchange between the project's participants and stakeholders on a regular basis through the whole project lifecycle (Oesterreich & Teuteberg, 2016). Nowadays, all industries are becoming increasingly reliant on IT to uncover previously unexplored value potential. Like a wide range of industrial sectors, the Fourth Industrial Revolution, "Industry 4.0" (Lasi et al., 2014) is transforming the AECO sector. The digitalization and automation of the construction, also referred as Construction 4.0, has changed the supply chains management and products (Dallasega et al. 2018, p. 01), through the adoption of innovative and disruptive technologies including Building Information Modeling (BIM); cloud computing; big data analytics; Internet of Things; virtual/augmented/mixed reality; as well as autonomous robots. Industry 4.0 allows the holistic adoption and implementation of green and/or sustainable business models and promotes a circular economy (CE) performance (Ramakrishna et al., 2020).

In the context of 'Industry 4.0' in the AECO sector, BIM is a cutting edge technology and topic of great interest. BIM is a digital delivery method for generating a systematic approach to managing critical information within a single, shared platform, providing a reliable basis for decisions throughout the building life cycle (Succar, 2009; Bradley et al., 2016). BIM adoption acts as a catalyst of paradigm shift in the AECO sector. How the supply chain itself is shaped (people) and projects are executed (processes) within new roles and competencies to propose an integrated design and construction process for achieving project goals (Eastman et al., 2008; Succar, 2009). BIM allows complex analyses at an early stage through interoperable BIM platforms and software (Kamari et al., 2019). The different created data formats, like the Industry Foundation Classe "IFC" and the Construction Operations Building Information Exchange "CoBie", increase the virtual workflows and enable exchanging data from all entities, stages, and phases of the project life cycle realizing interdisciplinary n Dimensions (nD) models (Barbosa et al., 2016).

BIM adoption has become widespread in developed countries such as United States, United Kingdom, Scandinavian countries (Norway, Finland, Sweden, and Denmark), Singapore, and Hong Kong (Khemlani, 2012). Different market values are placed into BIM according to each industry and country and how it relates to their productivity, as the BIM market is driven by various aspects, such as increasing urbanization and infrastructure projects, the rising benefits offered by BIM to the AEC industry, and the growing government mandates for BIM adoption (Reportlinker, 2020). However, the low level of digitization of the construction sector in some countries (such as Algeria) limits the implementation of BIM.

Furthermore, BIM is clearly a process of change not only in execution processes and functional capabilities, but also in contractual arrangements, as the fragmentation of traditional approaches and struggles for individual benefits work against the collaborative atmosphere for BIM implementation (Migilinskasa et al., 2013). As such, BIM requires new contractual agreements to address issues of digital documentation and facilitation of new collaborative work practices rather than simply incorporating additional contractual terms (Hamdi & Leite 2014).

The synergy between BIM and IPD

Numerous studies have proposed Integrated Project Delivery (IPD) as the best project management method to leverage the functionality of BIM (Rowlinson, 2017). Like BIM, IPD has emerged to improve the quality of construction projects, increase their performance, and eliminate the weaknesses of current project delivery systems (Rowlinson, 2017). IPD is an alternative delivery method that considers six "markers" representing the unique characteristics of the full IPD model (pure IPD), including: relational contracts, protection from litigation, joint goal and target validation, collaborative decision making, open communication, and early identified and accepted risks (AIA, 2012). Today, many projects use IPD as a philosophy (IPDish) via incomplete integration models. Many variations of IPD approaches could occur through the application of different IPD strategies, principles, and tools (commercial, social, environmental, or technological) (Sive & Hays, 2009).

Numerous studies have found that IPD and BIM should play together in a complementary and synergistic way to provide more pragmatic and effective solutions to complex project problems (Fakhimia et al., 2016). The synergy between BIM and IPD can remove barriers to collaboration, and allows the project team to deliver a more efficient design and improve sustainability performance (Fischer et al., 2017). Figure 1.1 illustrates the ability of the IPD design process through BIM to make changes and provide optimal solutions, early in the design process, to address project complexity at a much lower cost than would otherwise be possible (see Figure 1.1).

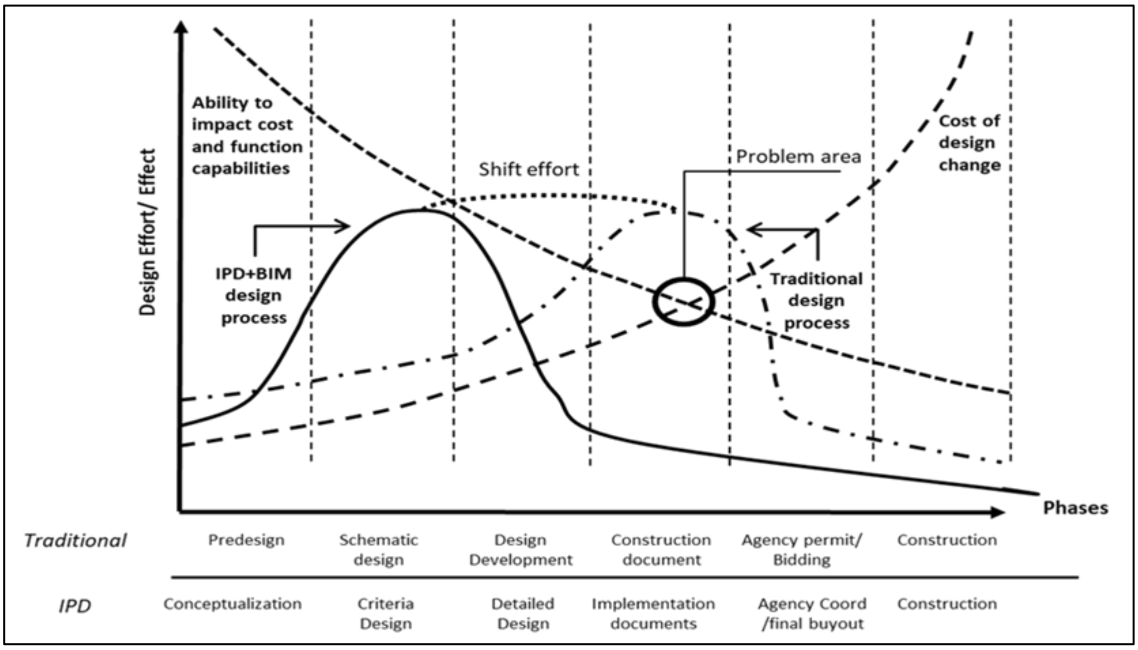

Figure 1.1. MacLeamy curve of current shift into IPD and BIM on construction project (Source: Brahmi et al., 2020)

Many researchers are investigating the potential of using IPD and/or BIM to solve specific industrial problems. Some research provides theoretical frameworks, while others investigate the current use of IPD and BIM and their implementation. The existing studies used a variety of methods: case studies, interviews, surveys, and literature reviews. Based on the current experience of implementing IPD and BIM in new construction and existing buildings, lessons can be learned from examples best practice (AIA, 2012; Cheng, 2015). Ilozor and Kelly (2012) and Nawi et al. (2014) conducted a literature review on the topic. The authors highlight the need for more evidence of the success of IPD+BIM to achieve sustainable projects in high-performing, collaborative teams, especially in quantitative terms. Integrated and collaborative supply chain management through a shared platform can provide optimal solutions, at an early stage, to current construction project challenges and address their complexity (Fakhimia et al., 2016). It could significantly improve communication for effective environmental performance analyses and sustainability improvement (Wong & Fan, 2013), reduce confusion among project participants to support the decision-making process (Nawi et al., 2014), and consequently reduce errors and ensure cost and time optimization (Becerik-Gerber et al., 2012; Ilozor & Kelly, 2012).

Despite these insights, little research explores IPD+BIM in different project types and contexts. There is a need to verify this synergy by examining the requirements of different projects.

BIM and IPD for heritage buildings renovation

There is a growing interest in BIM within renovation projects due to the developing technology and digital methods, including 3D laser scanning and photogrammetry. Almost all research has been written about the potential benefits of using BIM for digital building documentation (Pocobelli et al., 2018, page 06). BIM generate a digital model for the preservation process because of its ability to store interrelated semantic information on promoting the dissemination of a building's intangible values during its life cycle (Angelini et al., 2017). However, BIM effectiveness is subject to greater conversations. It is depending on the challenges of the high effort of modeling/converting captured building data into semantic BIM objects, and the variety/complexity of heritage building components that are not representative in current typical BIM software libraries, but also depending on the level of detail required to perform engineering/design analyses (López et al., 2018; Pocobelli et al., 2018). In addition, few studies have addressed the use of BIM to manage the overall intervention design and renovation processes, such as the generation and assessment of various design alternatives.

On the other hand, Lucarelli et al. (2019) recommend the IPD methodology to enable the improvement of the construction process due to the sharing of data and communication between stakeholders before the start of the work to eliminate any possible delay. Cambeiro et al. (2012) discuss the role of applying IPD elements, through a case study, as a solution to minimize budget variances and risks assumed by each participant, reducing rework and errors through an iterative design alternative. Additionally, Jensen et al. (2018) highlight the benefits of relational contracting and IPD for sustainable renovation projects on building trust and using a wide range of strategic, tactical, and operational tools by collaborative teams.

Unlike for new construction, our review of the existing literature indicates a lack of research that explores the simultaneous use of IPD and BIM for heritage renovation from a broader perspective. The impact of using IPD and BIM is not really exploited by the heritage renovation life cycle. Very little research has addressed the simultaneous use of

BIM and IPD in a sporadic and limited way. Megahed (2015) recommends BIM as a support to IPD in heritages to enable model-based collaboration between people, systems, and business structures and practices. Conversely, Counsell and Taylor (2017) consider IPD as a benchmarking for analyzing the purpose of BIM in heritages as an integrated delivery of a building to maintain the cultural sustainability of the built heritage over their lifetimes, using a management mechanism incorporating all stakeholders. Very few real case studies of renovation (including heritages) have been carried out in the current literature.

We summarize below the literature review and knowledge gaps analysis results (see Table 1.1).

Table 1.1. Synthesis of the problematic (Source: Author)

	BIM	**IPD**	**BIM+IPD**
Advantageous	• Digital delivery method based on a unique and shared platform. • Different collaboration levels.	• Alternative delivery method based on a relational multiparty agreement. • Various integration models.	• Consistency of Information is the real value that BIM can offer to an IPD process. • IPD has appeared as the most effective delivery method that could leverage BIM functionalities in collaborative environment. • More pragmatic effective and solutions to complex project problems.
Challenges of adoption	• Cultural and organizational change. • Wide adoption, but differ from country to country. • The benefits are currently not truly realized and should continue to strive to achieve BIM lifecycle uses.	• Cultural and organizational change. • Limited adoption, in formative stage. • Unexploited potential of the absolutely embrace IPD as a project delivery system.	• Cultural and organizational change. • Unexploited potential of IPD+BIM to achieve sustainable projects in high-performing, and collaborative teams
Knowledge gaps	• Few studies have addressed the use of BIM to manage the overall intervention design and renovation processes, such as the generation and assessment of various design alternatives.	• Very few studies have addressed the use of IPD in heritage projects.	• Limited research has addressed BIM and IPD simultaneous use for heritages in a sporadic and limited way. • Very few real case studies of renovation (including heritages) have been carried out in the current literature.

Therefore, it is fundamental to fill these knowledge gaps by conducting a holistic and multifaceted analysis.

Challenges in the Algerian context

Algeria has a rich built heritage with diverse regional specificities: Mozabite in the South, Kabyle in the center, Chaoui in the Northeast, Arab-Muslim in the North and mainly in the big cities: Algiers, Oran, and Constantine. As worldwide, renovation context of heritage buildings encounters many issues and challenges. Renovation and rehabilitation projects have reported frequent performance failures related to Cost, Time, and Quality. During my Master's curriculum in Rehabilitation Project Management, crowned by a master's thesis entitled: "*Delay problematic in the Heritage rehabilitation projects: Case of Study and Rehabilitation of the Tourists' pathway in Constantine",* we elucidated the real causes that undermine the performance in the lifecycle of heritage projects. We observed the various constraints and problems encountered by heritage projects and their failure. The findings revealed that the non-performance of heritage projects go back essentially to the fragmentation of the delivery process (Brahmi, 2016). Coordination and communication lack was the first factor that affected the projects in terms of time and great dissatisfaction of all the stakeholders (Brahmi, 2016; Fantazi et al., 2019).

From an environmental perspective, the building and residential sector represents more than 40% of the total energy consumption in the country (CEREFE, 2020). However, renovation projects focus only on consolidating old buildings and underestimate energy efficiency and indoor environmental quality (Khledj & Bencheikh, 2019). In 2016, the government launched a program of thermal renovation of existing buildings to reduce energy consumption. This program is run by the National Agency for the Promotion and Rationalization of Energy Use (APRUE). While the existing building stock in Algeria reached 6.5 M dwellings in 2016, including 1.050.000 masonry dwelling built before 1945, the thermal renovation program aims to insulate only 100.000 dwellings per year (Seddiki et al, 2016; Khledj & Bencheikh, 2019).

On the other hand, the digitalization of the construction/renovation sector is very slow in Algeria, in contrary to developed countries. The use of BIM is still in its infancy and formative stage (Bouguerra et al., 2020). In this regard, Bouguerra (2017) cites five main influencing challenges of BIM implementation for energy efficiency in design building, including the high cost of BIM technology, the high cost of training for energy minimization, lack of knowledge, low government support, and absence of clear consensus of BIM implementation. The adoption of BIM is not simply a question of tools and equipment, but also of the need for a cultural change and a profound shift in the skills expected of people. This implies reconsidering the challenges of new technologies in the light of local specificities. Recently, many workshops on BIM applications were dedicated to Algerian building professionals to highlight BIM benefits for projects delivery. However, very little research has been done on the BIM topic in the Algerian construction industry. At the same time, the Algerian construction industry is still based on traditional delivery methods, especially design-bid-build process. IPD approach is an unknown and unexplored area in research and practice.

Thus, in order to deliver successful heritage renovation in terms of time, budget, and sustainability, it is indispensable to identify the benefits, challenges and propose best practices, as a preliminary step, for implementing BIM and innovative methods (i.e. IPD) based on existing experiences.

1.3 Research questions

Based on the above statement, a detailed analysis of such a combination is, however, critical to evaluate outcomes. To this end, we address the following research questions:

1) *How can BIM and IPD adoption for heritage renovation achieve the target balance between sustainable design and heritage values preservation as well as enhance process productivity and final performance?*
2) *How can we assess the level at which project teams are able to effectively implement IPD and BIM collaborative strategies and practices?*
3) *In the light of this assessment, what lessons can be learned and how can we use the existing results for future renovation projects, and especially in the Algerian context*?

1.4 Hypothesis

We build our research on the following hypothesis:
Shifting towards the application of IPD and BIM collaboration strategies in heritage renovation could be an effective and efficient avenue to integrate heritage values into holistic decision-making frameworks that revolve around energy performance improvement, thereby achieving the target balance between sustainable design and heritage values preservation, as well as enhancing process productivity and final performance.

1.5 The Aims of the Research

This research aim is primarily to assess the potential shift into IPD combined with BIM to achieve the target balance of the sustainable renovation of heritage buildings as well as to enhance project productivity and final performance via preparing better collaborative and integrating processes, assumed as the key of successful delivery of building renovation projects. The focus is to determine the shared collaborative practices across projects, and the level at which teams are able to effectively implement IPD and BIM tools and processes. In order to achieve the above goals, the following objectives, summarized as follows, need to be achieved:

1. Develop a thorough understanding of the BIM and IPD concepts and principles by conducting a detailed literature review.
2. Determine the impact of adopting IPD and BIM on the performance outcomes (time, cost, sustainability) of heritage renovation projects.
3. Identify the opportunities and challenges of integrating IPD and BIM for sustainable renovation of heritage buildings.
4. Develop an analytical framework that assesses the relationships between the maturity of teams' projects and the level of benefits they could achieve from BIM/IPD collaborative strategies in different heritage environments.
5. Extract lessons and set recommendations for successful implementation of IPD and BIM in future renovation projects in the general and Algerian context.

1.6 Research Design

The overall plan of the research is presented in Figure 1.2 where the research actions are assembled into three stages:

1 A literature review is piloted in order to critically evaluate the current literature and justify why further study and research is required. In addition, the research methodology is established. An analytical framework for comparative case study research is developed to allow for a comprehensive, structured, and systematic exploration of IPD and BIM application in different heritage environments.

2 Validation of the study through Qualitative Comparative Analysis (QCA): The study uses an exploratory case study design through the use of the analytical framework

developed to investigate the changes undertaken when using IPD and BIM to renovate heritage buildings and within different types of contracts. Hereafter, the in-depth analysis (Case 1) and multiple-case analysis (Case 2, 3, and 4) display how each case leveraged the BIM and IPD framework.

3 Cross-discussion and analysis. Finally, conclusions are drawn, implications for practice are summarized and recommendations for future research are outlined (see Figure 1.2).

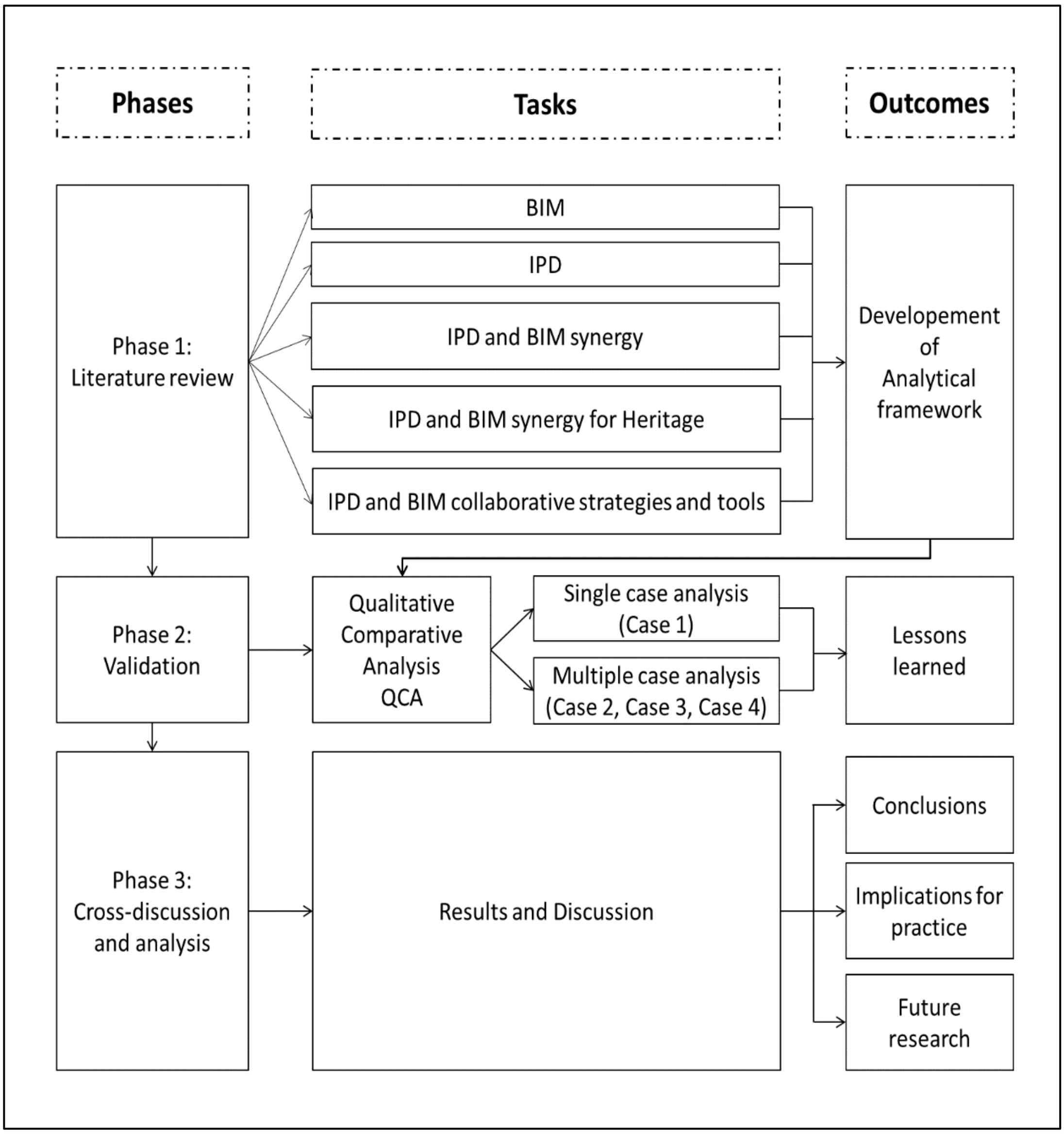

Figure 1.2. The three phases of the research design (Source: Author)

1.7 Research methodology

1.7.1 Epistemological position

An abductive research approach seemed most appropriate for this project given the nature of the research objectives. Saunders et al. (2012) define the abductive approach as a combination of deductive and inductive logic process of going from theory to data (deductive) and from data to theory (inductive) or vice versa. Abductive reasoning consists of a pragmatic approach through a process of "systematic combination" in academic research, as an opportunity to capture and take benefit of both the systemic character of the empirical world and the systemic character of theoretical models (Dubois & Gadde, 2002) (see Figure 1.3).

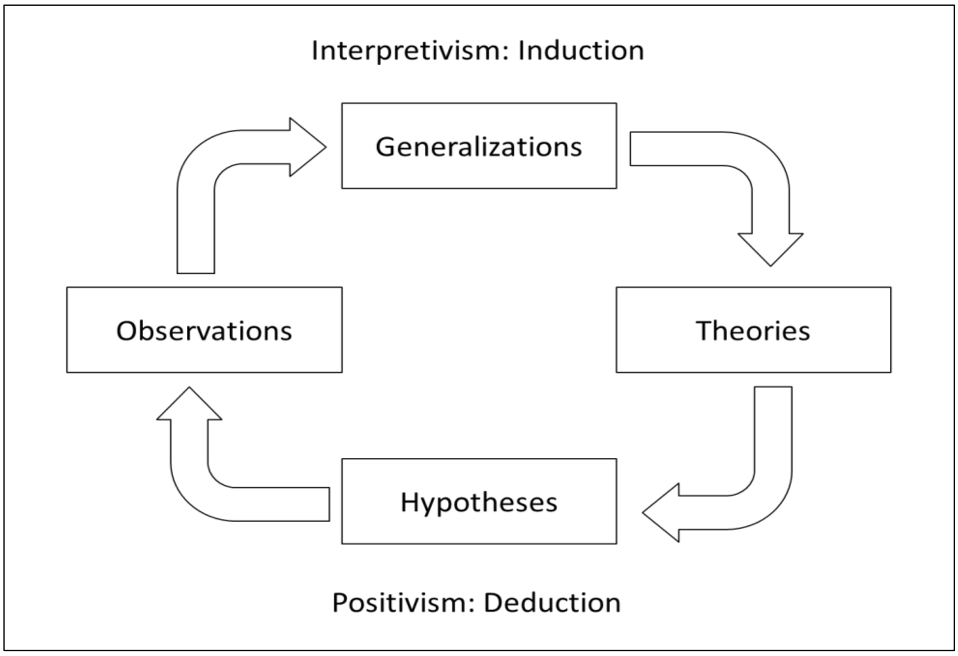

Figure 1.3. Induction and deduction in abductive research approach
(Source: Love et al., 2002)

1.7.2 Methodological Triangulation

For an in-depth understanding of the extent to which IPD and BIM collaborative practices are being used in the sustainable renovation of heritage buildings, and also to increase the validity of the study and generalize knowledge, we adopt a frequently used qualitative research strategy called "methodological triangulation" (Denzin, 1978; Love et al., 2002), which involves the use of multiple methods of data collection and analysis to develop a comprehensive understanding of a phenomenon. First, a brief review of the related literature is conducted. Next, the application of the triangulation approach in this research activates the Qualitative Comparative Analysis - QCA (Ragin, 1987, 2000) of the topic matter.

1.7.3 Qualitative Comparative Analysis (QCA)

The application of the triangulation approach in this thesis activates the Qualitative Comparative Analysis - QCA (Ragin, 1987, 2000) of the subject. QCA can be usefully applied to research designs involving small and medium-sized (N), it is undertaken when there is not enough data to statistically consider a case study, but when the richness of information about each case allows for powerful and compelling stories about the likely causes of the desired outcomes (Ragin, 2000).

QCA has been applied in a wide range of disciplines (Lee, 2020). Ragin identifies four phases for conducting a QCA:

- Phase 1: Identify pertinent cases and causal conditions
- Phase 2: Construct the truth table and resolve contradictions
- Phase 3: Analyze the truth table
- Phase 4: Evaluate the Results

Lee (2020) cites the several advantages of this method. QCA can be used to summarize and explore the data in a synthetic way, as it generates the truth table showing how certain cases are grouped (see section below). In addition, QCA allows investigators to check the consistency of the data (i.e., whether there are conflicting cases and how to deal with them). QCA is also a useful technique for testing existing hypotheses or theories by proving or disproving them. Given its configurational specialty, QCA can both test a theory holistically and any segment involving it. As a result, QCA contributes to the development of new theoretical arguments and opens the door to new theories. The method permits researchers to conduct analyses in a real-world setting, but its configurational nature allows them to control for certain conditions for comparison purposes (Lee, 2020).

1.7.4 Truth table

Subsequently, the descriptive analysis and in-depth cross-case analysis are supplemented with a "truth table" (Cheng & Johnson, 2016) that displays how each of the cases leveraged IPD and BIM processes and strategies. Truth table classifies the cases according to the combinations of causal conditions they present. All logically possible combinations of conditions are considered, even those that have no empirical examples.

The "truth table" analysis enables us to illustrate the variables in a way that allows the audience to grasp the complexity of the cases rapidly. In addition, by making a graphic visualization of data on building projects, hereby, the diversity amongst the cases as they implemented BIM and IPD tools and processes are shown. The truth tables, based on "low detail discovery assessment" (Succar, 2010), display graphically how each of the cases leveraged the BIM and IPD framework into four levels of maturity (see Table 1.2).

Table 1.2. The four levels of projects teams' maturity to implement BIM and IPD collaborative processes and tools (Source: Author)

Symbol	Description
●	**Done well, used often, helpful to the team**: at this level, the almost collaborative strategies were applied and continuously improved over incremental and innovative process and technology enhancements, based on a quantitative understanding of performance objectives and needs and linked to overall project performance.
⊘	**Done, but only somewhat helpful or mixed comments on its effectiveness**: at this level, the collaborative strategies were planned and executed accordingly; produced monitored, controlled, and reviewed outputs; and were evaluated for adherence to their processes description.
○	**Did it, but most of the team didn't find it particularly effective**: at this level, the collaborative strategies produced outcomes in which the specific goals were satisfied, however, they were usually ad hoc and chaotic.
\	**Did not have it**: at this level, the collaborative strategies did not incorporated into business processes and did not established goals and objectives.

1.7.5 Literature review for the development of an analytical framework:

By employing a QCA methodology, an analytical framework for comparative case study research is developed based on the literature review, using a coding scheme (see section 6.3), to enable a comprehensive, structured and systematic exploration of the application of IPD and BIM in different heritage environments across their life cycle. A coding scheme is a set of codes, defined by the words and phrases that identify the topics or issues to which parts of the data refer (Bailey, 2007). The coding scheme is a structured method for conducting a case study, where a detailed "game plan" is developed by the researcher in the research design, identifying all the variables on which data will be collected (Harrison, 2012). It organizes the data in a way that is useful for future analysis (Bailey, 2007).

The framework (including the coding scheme) strives to encompass the multiple perspectives of IPD and BIM synergy and facilitates the complex understanding of the design process of sustainable renovation, given its highly complex value profile and numerous heterogeneous stakeholders. Its development depends on analytical inference rather than statistical inference, where generalization lies not in the replication of results but rather in the strategies and practices applied.

To develop the analytical framework, a narrative literature review is conducted in different steps. In the first step, the search for scientific contribution sources is performed through the reliable database Scopus. The keywords used (using "Title/Abstract/Keyword") are "Heritage BIM", "IPD and heritage", "BIM for renovation", "IPD and BIM", "IPD and BIM for renovation", and "IPD and BIM for heritage". We collected a total of 748 peer-reviewed papers (including journal articles, books, and conference papers) that were published between 2008 and mid-2020 (from the first publication on "BIM for Heritage" in Scopus to the time of conducting the research). It is worth noting here the unavailability of documents related to the keywords "IPD and heritage", "IPD and BIM for renovation" and "IPD and BIM for heritage". Then, we selected only 180 documents with the most citations (60 documents per keyword) for analysis. This filter allowed us to recognize the most effective publications, the evolution of interest in these topics over time, and the relationship between them. In addition, we used unconventional databases from universities and recognized international associations (e.g., The University Digital Conservancy, the American Institute of Architects -AIA-) to collect practical publications. In the end, we selected 20 of the most relevant and comprehensive documents, ranging from research reports to guidelines to white papers.

Many researchers are investigating the potential of using IPD and/or BIM to address specific industry problems. Some research provides theoretical frameworks, while others investigate the current use of IPD and BIM and their implementation. The studies reviewed use a variety of methods: case studies, interviews, surveys, and literature reviews.

1.7.6 Case study design

The study uses an exploratory case study design (Yin 2003) through the use of the analytical framework to investigate the changes undertaken when using IPD and BIM to renovate heritage buildings and within different types of contracts. Case study is a strategy that involves empirical investigation of specific current events (phenomenon) in a real-life context via multiple sources of evidence (e.g. interviews, observations, documents…) to better understand the dynamics that exist in a specific setting (Collis & Hussey, 2003;Yin, 2003). This in-depth study of a phenomenon would not have been investigated by a research strategy that takes into account large samples. Therefore, the case study is primarily adopted in exploratory research, although it can be applied to illustrative, descriptive, experimental, and explanatory research to response research questions about "how", "what", and "why".

Regarding data availability, four projects (from the USA and Canada) were selected because of their use of IPD and BIM collaborative practices, and projects' goals for achieving sustainability targets, and their relatively new insights on the topic, which allow for effective comparative analysis. The case study in this thesis is divided in three steps: started by a single case analysis, multiple case analysis, and cross case analysis. Case 1 (Wayne Aspinall Federal Building) was the most suitable project for conducting a single case analysis due to the richness of information gathered about this case compared to the other three ones. In addition, four project participants responded to the semi-structured interview allowing an in-depth assessment. However, we selected Case 2 (The Renwick Gallery of the Smithsonian Art Museum), Case 3 (The Oakville Arena Redevelopment project), and Case 4 (the Centre Block of the Parliament Hill National Historic Site) for the multiple case analyses to generalize the findings, as we collected less data for these project (see more details in the next sections).

The assessment has been done through the accurate review of the project's reports, documents, and technical articles that are published in the contracting firms' websites and other online sources, alongside with conducting four semi-structured interviews (in case 1).

1.7.6.1 Single case analysis

The project begins by a holistic single case analysis to explore in-depth the phenomenon. Criticism of single-case studies relates to the lack of scientific rigor and reliability in the method and particularly on its inability to provide generalization of results; however it allows gaining new insights. As such, the benefit of the IPD and BIM strategies, business models, and tools applied by the team project (owner, Architects, engineering, and general contractor to achieve collaboration success through specific example is addressed in details (Case 1). That leads to facilitate exploring different outcomes and producing new insight.

1.7.6.2 Multiple case analysis

The multiple case studies allows for cross-case comparisons in different contexts, to understand the similarities/differences between the cases and reveal the best practices. The multiple case study triangulates and establishes the convergent or concurrent validity of the findings. The author states that it is imperative that cases be carefully selected to facilitate the prediction of similar results across cases, or the prediction of contrasting results based on a theory.

Adopting the multiple case study method encourages and supports greater replication across cases (Harrison, 2002). Yin (2009) corroborates this view by asserting that multiple case studies are more likely to provide a stronger basis for theory building than a single case study. The use of multiple sources of evidence as a means of ensuring construct validity has also been advocated (Yin, 2009).

1.7.7 Validity and reliability

For validity testing, the use of multiple sources of evidence can increase the level of validity. The study uses a QCA, developing an analytical framework based on literature and analysis of four cases. Triangulation is applied in all studies during data collection, as well as by comparing the collected data with existing literature. Application of QCA principles besides triangulation approaches for data collection increases the validity of this study. In addition, learning from examples is a valued output of case studies and the new knowledge transferability from single or multiple case studies to similar contexts is more important than formal generalization (Flyvbjerg, 2006).

In the test of construct validity, Different types of data are collected using different qualitative data collection methods to ensure consistency. The assessment has been done through the accurate review of the project's reports, documents, and technical articles that are published in the contracting firms' websites and other online sources, alongside with conducting four semi-structured interviews (in case 1) as a source of evidence.

The coding of the framework (see section 2.5 and 6.3) is a compilation of categories and criteria for analysis that was validated with holistic and structured assessment of the applied BIM and IPD collaborative strategies in the four projects. It enables conducting future research on various heritage projects to further test these research findings and provide a higher degree of confidence in generalizing the results, as well as it could be useful and applied in other contexts, rather than renovation and heritage.

Furthermore, the research in general, representing different stages of this thesis, has been presented in a paper and was peer-reviewed by a journal as it can be seen in the appendices (Appendix A).

1.8 Thesis layout

The thesis includes six chapters as follow:

- *Chapter I: Introduction to the Research, Methodology, and Research Design*

This chapter presents an introduction to the thesis, explains the backgrounds and rationale for research. It addresses the knowledge gaps and literature review which leads to the development of the research topic. The chapter highlights the research questions, objectives, and hypothesis. Then, the chapter discusses the research methodology used to conduct the research and achieve the objectives. It describes the research approach, including the data collection and analysis at each stage of the literature review, case studies and conclusion.

- *Chapter II: Sustainable Renovation of Heritage buildings*

This chapter introduces some core concepts and definitions related to heritage buildings and its sustainable renovation on highlighting the related works.

- *Chapter III: BIM and IPD in construction projects*

This chapter presents and reviews related works to BIM, IPD, and depicts the benefits/barriers of their use.

- *Chapter IV: IPD and BIM synergies for the sustainable renovation of heritage buildings, and development of an analytical framework for Qualitative Comparative Analysis (QCA)*

This chapter investigates the application of IPD and BIM for heritage renovation projects. It starts with the isolated use of BIM and IPD, followed by their simultaneous use.

This chapter presents the development of the analytical framework, based on literature survey, for conducting a comparative case study research using a coding scheme.

- *Chapter V: Case studies*

This chapter analyses four real-world heritage cases. The chapter includes a Single detailed case-study analysis (case 1), Multiple case-study analysis (Case2, Case 3, and Case 4), and Cross case analysis.

- *Chapter VI: Conclusions and further research*

This chapter provides a discussion of the main results, brief overview to the integrated result of previous chapters, and resumes the lessons learned. The chapter outlines the contribution to the knowledge, the limitations of the work, and provides recommendations for future improvement in International and Algerian context. Finally, the chapter sets out suggestions for future research.

1.9 Summary

This chapter describes the research plan that was undertaken to address the identified research problem. The objective of this study is assessing the potential shift into IPD combined with BIM to achieve the target balance of the sustainable renovation of heritage buildings as well as to enhance project productivity and final performance. Through an abductive approach, the research study uses a Qualitative Comparative Analysis, developing an analytical framework based on literature and analysis of four cases. Figure 1.4 summarizes the research methodology applied in this study (see Figure 1.4).

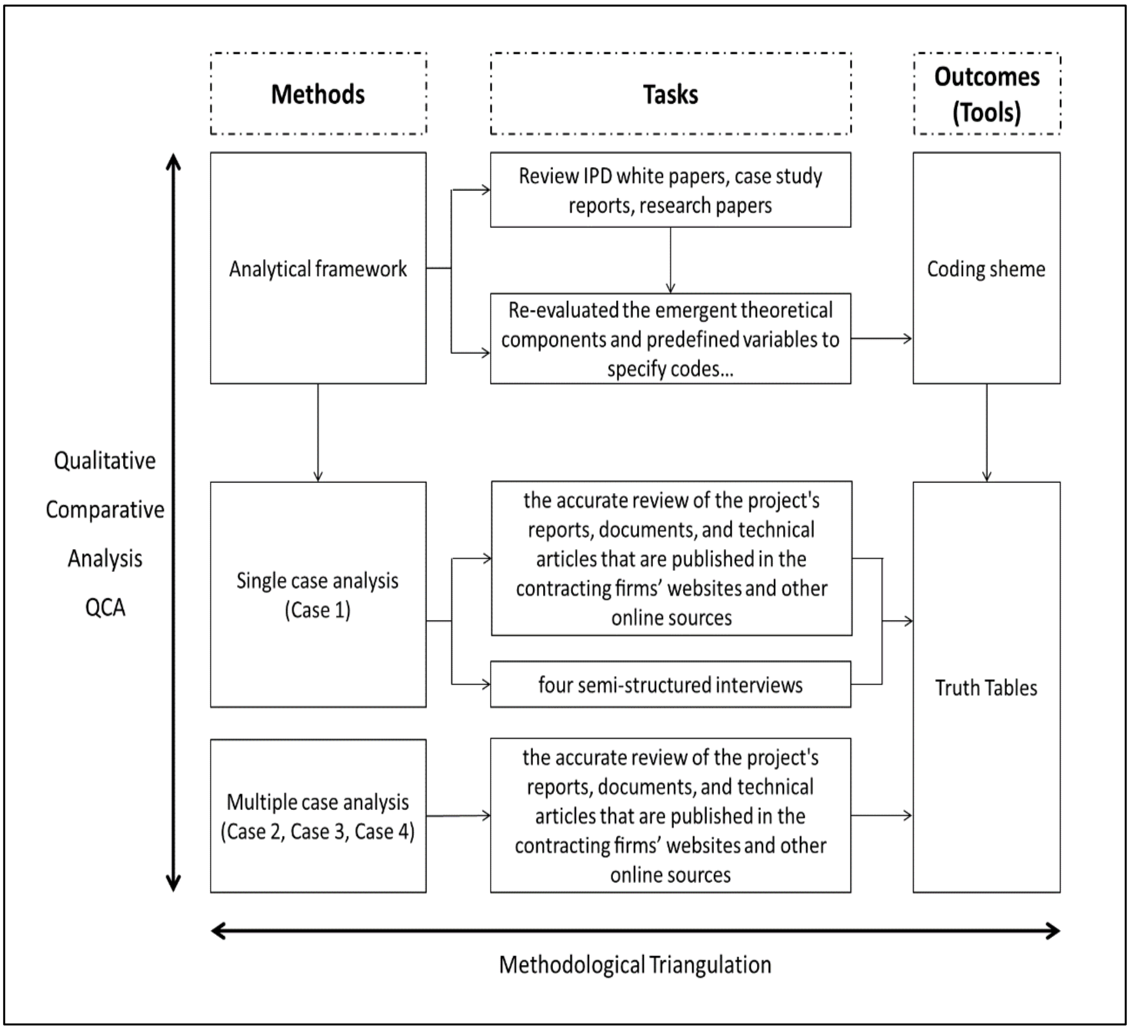

Figure 1.4. Summary of the research methodology (Source: Author)

In the next chapter a theoretical background is provided for heritage renovation projects.

CHAPTER II: SUSTAINABLE RENOVATION OF HERITAGE BUILDINGS

This chapter envisages elucidating the real causes that undermine performance in heritage renovation project during the whole the life cycle. Through literature review, the chapter indicates the challenges facing the projects on reviewing the role of standards and new regulation guidelines on the evolution of renovation industry.

2.1 Heritage buildings

2.1.1 Heritage building: definition and classifications

Heritage buildings are classified as "tangible cultural heritage: immovable items" (NSAI, 2011). Al-Sakkafa et al. (2020) identified and reviewed three main aspects concerning heritage buildings: definitions, types and conservation treatments, in order to develop a standard unified assessment to be used in heritage building rehabilitation projects. The authors show the variability of heritage building definitions, types, and treatments, where each country (or organizations) has its own norms in each of the three aspects. Heritage buildings are defined based on the local geographic or policy context leaving no exact or explicit definition that can be applied worldwide (Al-Sakkafa et al., 2020). For instance, in India Heritage building means: *"a building possessing architectural, aesthetic, historic or cultural values which is declared as heritage building by the Planning Authority/Heritage conservation committee or any other Competent Authority in whose jurisdiction such building is situated"* (BUILDTECH India, 2018*).*

Sometimes, the term "heritage buildings" is preferred over the term "historic" or "traditional" to include more "modernist buildings". Akande (2015) determined three factors to consider if a property is worthy to be listed as heritage including: historic significance, integrity, and context. In many countries (e.g. Denmark), heritage buildings classified either in listed buildings with a high significance (national level) or worthy of preservation that can tell us about architecture, architectural styles, and cultural history on a regional or local level. Whenever an intervention is carried out on a classified building or nevertheless on a building of cultural value, the execution should falls under the renovation scope and the primary objectives are to preserve and adapt these properties to the future in the best possible conditions.

Regarding this variety, Al-Sakkafa et al. (2020) highlight the need for collaboration between academic institutions and other organization, e.g. UNESCO and ICOMOS in order to lead the intellectual discussions on common terms, scope, and terminology and for each country to adopt them on a country-wide level.

In this thesis, although the study contribution deal specifically with listed buildings that have official protection, it can also encompass more recent structures that may potentially be perceived as a heritage of cultural value by specific groups of people.

2.1.2 Heritage building significance and values

The significance of heritage buildings is a key factor in the renovation projects (i.e. in recognition, diagnosis, and preservation objectives of this building). Cultural heritage as a whole and each building have their own significance where many factors can contribute to it. Therefore, several authors have classified the values of built heritage in different ways to define its significance. Among them, Khodeir et al. (2016) classify built heritage values on three main categories: cultural values (historical, evidential, identity, and architectural and urban values), use values (Social and economic values), and age values (see Figure 2.1).

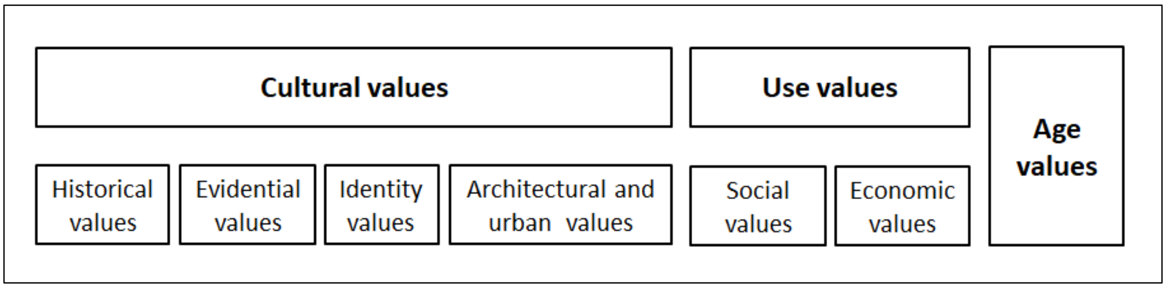

Figure 2.1. Classification of built heritage values (Source: Khodeir et al., 2016)

Architectural heritage is a complex system that encompasses interrelated tangible and intangible values (Attenni et al., 2017). Recently, the instrumental value of heritage, manifested in its social and economic implications, has been promoted by various heritage advocates and recognized by many policymakers. In other words, investment in heritage can generate a social benefits and economic growth. At the same time, culture (and heritage as its indispensable part) is now considered by many authors as one of the four pillars of sustainable development, along with the others (Tweed & Sutherland, 2007). Table 3.1 illustrates the two main categories of heritage building values: cultural-historical values and socio-economic values adjusted to current needs (see Table 2.1).

Table 2.1. The two main categories of valuation of Heritage buildings
(Source: adapted by author from Szmelter, 2013)

Cultural-Historical Values	**Contemporary Socio-Economic Values**
Relative artistic value	Educational value
Aesthetic (visual appeal) and age value	Economic value (heritage as source of social well)
Historical value, including memorial value	Functional value, use value
Identity value (role of cultural heritage in the society identity, both global and regional)	Social value (cognizance, knowingness)
Scientific value (construction technics and methods)	Social access value (i.e. platform for reflective society)
Rarity value, uniqueness	Political value, regional value
Authenticity value (identity and veracity of the building)	Operational value (living conditions, building uses)
Emotional value (provocation of empathy)	Newness value (sustainability)
Integrating value (fostering society's capacity for reflection, innovative participatory approaches)	Situational value (influences on tourism evaluations)
Associative/symbolic value (spiritual,cultural, and political value)	Financial value "value of value"
Creative value (the work of human creative genius – artistic or technical)	Potential value for future exploitation and generation of value

Governments, heritage institutions, and researchers have developed standards for assessment criteria, whereby the heritage values of buildings can be clearly and unequivocally identified. For instance, the conservation value buildings in Denmark have been registered widely according to the so-called SAVE method. SAVE is a compilation of "Survey of Architectural Values in the Environment". The method is based on an assessment of five different conditions of a building: Architectural value, Cultural-historical value, Environmental value, Originality, Condition.

2.1.3 Typology of heritage buildings Interventions

The intervention at historical building is defined as an: *«action that has a physical or spatial impact on a historic building or its setting»* (The British Standards Institution, 2013, p. 5). Decision-making in heritage preservation is a major issue, where choosing appropriate interventions is not an easy process. The challenge is to respect all the building values, and the situation is more complex when the resource is still used by communities. The question of which values to respect, or which methods to use, is not simple. Literature review reveals a great variability regarding interventions applied for heritage buildings. Table 3.2 provides a list of the different preservation strategies that can be used for conservation treatments along with their detailed definitions (see Table 2.2).

Table 2.2. Definitions of different interventions in heritage buildings projects
(Source: adapted by author from Institution of Historic Buildings Conservation, 2021)

Action	Definition
Restoration	The process of returning a building to its original condition and previous state
Maintenance	The process of keeping the building in good condition.
Renovation	The process of improving or modernizing a damaged, old or defective building, and returning it to a good state of repair.
Refurbishment	The process of improvement by cleaning, decorating, and re-equipping. It may incorporate elements of retrofitting.
Retrofitting	The process related to the new building systems installation, such as heating systems, but it might also refer to the building fabric, like retrofitting insulation or double glazing.
Rehabilitation	The process of reusing, repairing, or maintaining existing features

The terms renovation, refurbishment and retrofit are often used interchangeable. However, they have different specific meanings. A single project may include elements of renovation, refurbishment, and retrofitting simultaneously. During renovation, it is common to upgrade construction standards to bring them closer to current standards rather than to the standards in effect when the building was originally constructed (Jensen, 2018).

2.1.4 Heritage project lifecycle phases (Heritage PLPs)

During planning and conceptualization phase, the *Pre-diagnostic* visit marks the beginning of any renovation operation. The architect must gather as much information as possible on the legal nature of the property to know what to look for and with whom to deal during the intervention (nature of the owner, classification and degrees of protection, regulations of the area of the situation...), on the system of values of the building, whether architectural, technical or other and gather any graphic or historical document that could help him to complete the ocular evaluation that he will make of the building to understand the constructive system, its different pathologies, its constructive and functional potentialities or deficiencies. Thus, the diagnostician will be able to rule on the state of conservation of the building, to classify it by degree of alteration and finally to evaluate the means to be put in place for its rehabilitation. *Multidisciplinary studies* should carry out as a prospective research which will allow a better apprehension of the building through its multiple facets: aesthetic, historical, architectural, physical, environmental and constructive.

The diagnosis is primordial step that occurs in the study and analysis of a building for its renovation. It consists in interpreting and synthesizing the results obtained during the pre-diagnosis and multidisciplinary studies. The aim is to compile information about the building, to assess its state of conservation and to evaluate its condition. The diagnosis will touch the three fundamental aspects that define a building, namely, its history, its constructive system and its functional mode, with the aim of recovering the constructive function of all these elements (repair), recovering its functionality (rehabilitation) and safeguarding its historical and authentic value. Figure 2.2 represents the eight common phases in traditional project delivery of heritage renovation (see Figure 2.2).

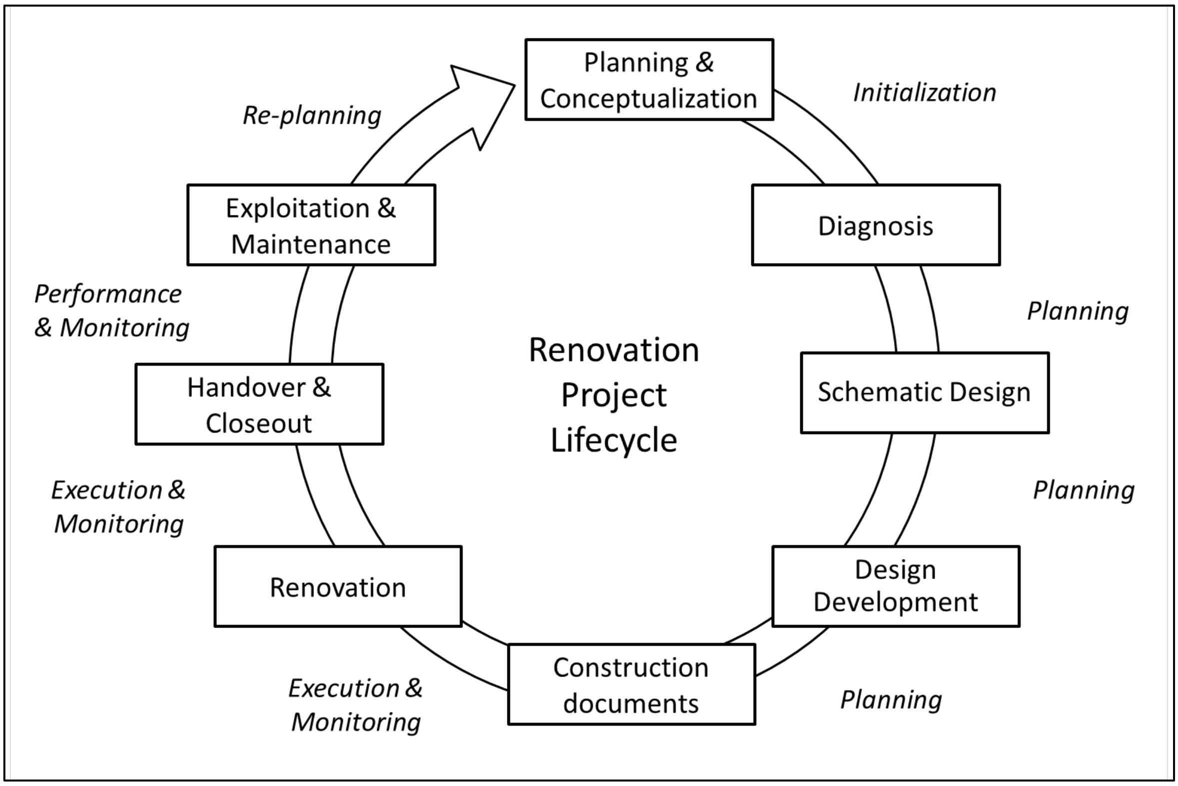

Figure 2.2. Project lifecycle phases of heritage renovation (Source: Author)

2.1.5 Actors and stakeholders

The renovation project takes place in complex contexts involving that entail interactions of multi-disciplinary fields (see figure 2.3). Therefore, it requires a high degree of communication, experience and knowledge of building materials and construction enhance decision-making (Harun, 2011).

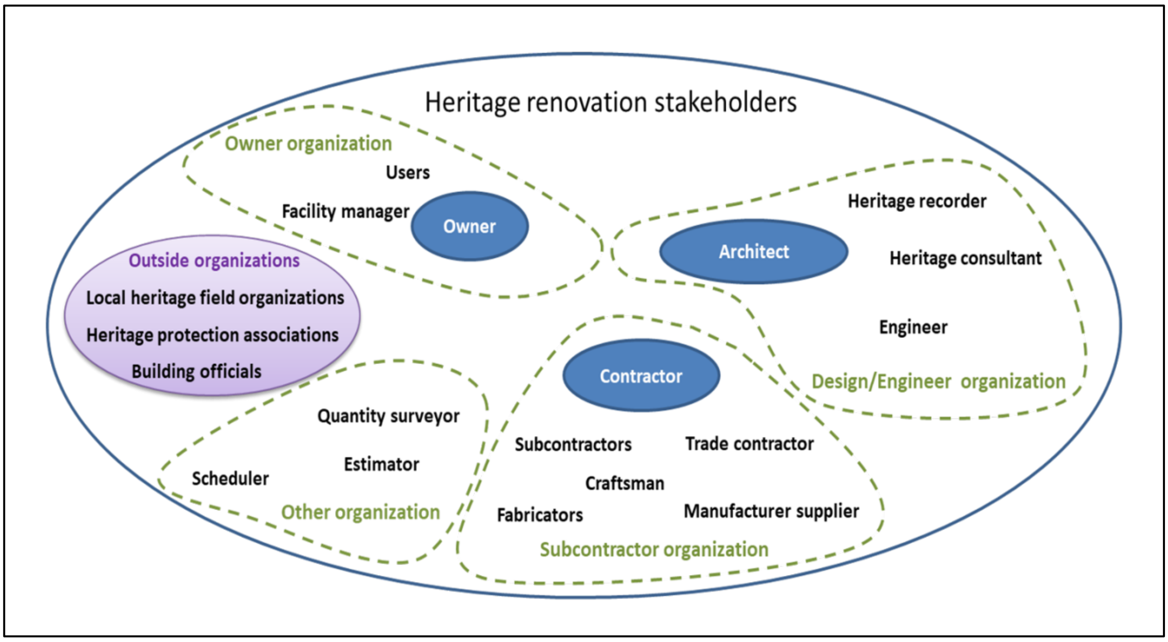

Figure 2.3. Conceptual diagram representing the different actors and stakeholders in the heritage renovation project (Source: Author)

2.2 The frame of legal and ethical aspects of heritage renovation

2.2.1 Sustainable renovation of heritage buildings and energy efficiency

The buildings renovating contribute to a more sustainable built environment, on considering environmental, economic and social aspects, what we call the triple bottom line (Tweed & Sutherland, 2007). Jensen (2018) identifies the main factors that initiate the need for Sustainable Building Renovation (SBR): durability/building physics, economy, environment and comfort. Building renovation saves a lot of capital, as it is often cheaper to renovate a building than to demolish and build new. It contributes to a circular economy, when we recycle and re-use as much resources as possible (Tomšič et al., 2017). social aspects related to building adaptation should not be underestimated. Preserving existing heritage buildings helps enhancing the indoor climate and creating a sense of place and belonging for people (Rasmussen et al., 2015).

From environmental perspective, the existing buildings renovation deal directly with some global sustainability challenges like combatting climate change and becoming more energy and resource efficient. By adapting buildings, less CO2 emissions occur, less energy and water is used, and fewer materials are extracted from our earth. Renovating buildings with environmental-friendly features makes them more future proof (Martínez-Molina et al., 2016). For instance installing solar panels and water recycling systems reduce the building energy and water usage.

Buildings and construction together account for 36% of global final energy consumption and 39% of energy-related carbon dioxide (CO2) emissions when upstream power generation is also included (Globle report, 2016). According to the last report by the European commission, buildings are the single largest energy consumer in Europe union, with approximately 40% of energy consumption and 36% of CO2 emissions (European commission, 2019).

Annually, we add just 1 to 2% of new buildings to the total building stock in the world. This is because buildings have a long life span. Much of the built environment that will exist in 2050 has been built already! So, it makes more sense to focus on adapting our existing buildings, as quickly and sustainably as we can.

As part of the energy provisions for new buildings, there is a strong pressure to make heritage buildings in developed countries (USA, UK, Australia, Italy, Denmark...) ecologically sustainable to reduce energy consumption, to reduce CO2 emissions and to ensure that these structures can continue to be an attractive part of the private building stock while maintaining their heritage values. Currently, 35% of buildings in European unions are more than 50 years old and nearly 75% of the building stock (including heritages) is energy inefficient (European Commission, 2019). The same statistics show that renovating existing buildings can lead to significant energy savings, as it could reduce total EU energy consumption by 5-6% and cut CO2 emissions by about 5%. Conversely, only around 1% of the building stock is renovated each year (European Commission, 2019). While in the southern and eastern Mediterranean countries, this activity does not even represent 10% of the sector's activity, despite its importance for the economic development and social cohesion of the population.

While many heritage building - particularly older homes - are energy inefficient, many historic buildings are remarkably energy efficient (Carroon and Moe, 2010). Today, a sustainable renovation design must rely on passive means and efficient facilities to achieve its goal of producing well-functional buildings with positive energy (that produces more energy than it consumes). In this regard, we can learn from our ancestors, who used different techniques depending on the climate: humidification, ventilation, insulation, etc

(Casanovas, 2007). However, they failed to understand how sophisticated traditional building techniques were. Having failed to understand buildings as a whole, designers using modern technologies now have many lessons to relearn. It is beneficial for any architectural firm to have at least one member of the design team who is knowledgeable about historic building preservation.

Kamari et al. (2017a) developed a new simplified holistic sustainability decision-making support framework for existing building renovation. The holistic sustainability framework allows auditing, developing, and evaluating building retrofit performance, and supporting decision making during the project life cycle. The outcome was a sustainability value map with a total of 18 sustainable value-oriented criteria and 118 sub-criteria for building renovation classified on three categories: *Functionality*, *Accountability*, and *Feasibility* (see figure 2.4).

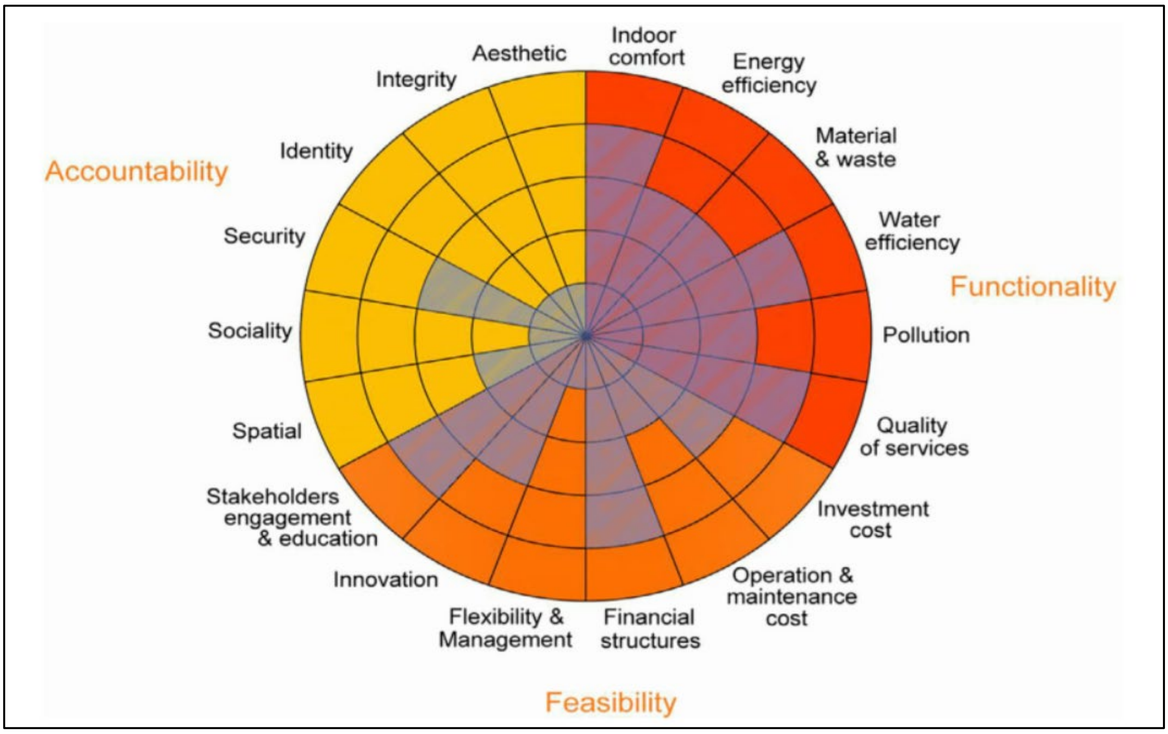

Figure 2.4. Value Map of holistic sustainability decision-making support framework for building renovation (Source: Kamari et al., 2017a)

On the other hand, Khodeir et al. (2016) divided the Sustainable performance assessment of the building on five categories including: *process performance* (e.g. energy modeling, integrated design, contracts, etc.), *building performance* (e.g. public benefits, flexibility and adaptability, sustainability compliance, etc.), *feature or system performance* (e.g. energy/water, quality, indoor environment, materials and resources, etc.), *financial* *performance* (e.g. risk and value, return on investment), and *market performance* (e.g. investor demand, operating costs, space user demand, etc.)

2.2.2 History and development of renovation scenarios in an international context

The pressure on heritage/traditional buildings began with the processes of industrialization, although it was accentuated in a definitive way with the modern movement and urbanism of the early twentieth century, in search of new models of living and making the city, models capable of overcoming the deficiencies of traditional settlements, even managing to deny them any functional, social and even aesthetic value, and radically opposing "the new" to "the old". Institutions such as UNESCO and ICOMOS have repeatedly warned about the loss of this heritage.

Currently, renovation is influenced by international economies, interest and community involvement in order to reduce CO2 emissions and achieve additional benefits, such as reduced life cycle costs and lower maintenance costs. Researches discussing energy efficiency and thermal comfort in historic buildings augmented over the previous decade. Martínez-Molina et al. (2016) found that more than twice as many were published between 2011 and 2014 than between 1978 and 2010. The authors note also the studies focus on 19th- and 20th-century historic buildings, as buildings from this period are less heritage protected, and energy renovation strategies can be more easily applied to them than to older buildings.

2.2.3 Requirements and standards for sustainable renovation of heritages in an international context

The International Council on Monuments and Sites (ICOMOS) developed a framework of the flagship Initiative of the European Year of Cultural Heritage 2018: "*Cherishing heritage: developing quality standards for EU-funded projects that have the potential to impact on cultural heritage*", it has provided a quality principles guidance for all stakeholders directly or indirectly involved in EU-funded heritage conservation and management (i.e, European institutions, managing authorities, private sector, civil society and local communities, and experts). Under the mandate of the European Commission, a group of expert was gathered by ICOMOS. They established a document that focuses on the core issue of quality in cultural heritage interventions (including renovation) (ICOMOS, 2018). The document inspects the critical determinants of quality at the entry and during implementation of cultural heritage interventions.

In addition, 11 ethical and technical principles for heritage interventions have been identified (see Figure 2.5)

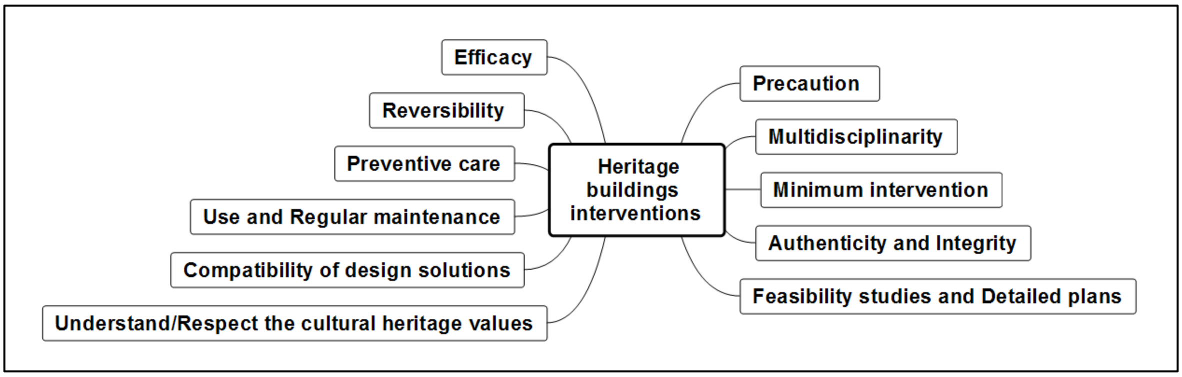

Figure 2.5. Ethical and Technical guidance on the quality of cultural heritage interventions (Source: adapted by author from ICOMOS, 2018)

Jensen (2018) highlights the importance of incentive systems, building codes, certification systems, etc. as well as a number of inhibiting factors, including the treatment of cultural heritage buildings, to open sustainable renovation markets. The European Union has issued several directives that directly and indirectly address the energy performance of buildings in order to reduce their energy consumption (European Commission, 2019). These directives deal with existing buildings but do not take into account the architectural heritage in a specific and uniform way by applying the exemption: Exemptions are possible at the national level to exclude buildings classified as architectural heritage from their application. Therefore, each country can adopt its own rules to include or exclude buildings from meeting the energy performance requirements for existing buildings. Therefore, to date, there are no general rules, codes, and standards for energy retrofits of historic and architecturally significant buildings. On the other hand, there is no international law in the field of historic preservation that deals with energy and energy rehabilitation. Moreover, the European Union Treaty does not provide for cultural heritage to be the focus of European legislation. Therefore, in order to close this gap between historic/historical buildings and energy refurbishment, lobbying is needed, led by national heritage authorities, which can more effectively direct EU policy towards energy refurbishment of historic/historical buildings.

2.3 Energy renovation of heritage buildings

Heritage buildings are generally categorized to have a very high-energy demand, as well as a poor indoor climate standard, particularly when it comes to a desirable indoor climate (Rasmussen et al., 2015; Tomšič et al., 2017). Many researchers and practitioners in heritage renovation focus on the contradiction between the principle of "minimum intervention" and the current objectives of energy performance, as it has a high impact on the architectural values, which should be preserved through the renovation intervention (Kamari at al., 2017b). Different approaches to preservation are applied. Kamal (2008) argue the opposing philosophies of “the developer”, who sees a property as an opportunity to be exploited, and “the preserver”, who sees the building as a heritage to be preserved. This results in a balance of subjective judgment, philosophical stance, and professional expertise, but rarely professional unanimity. Fouseki and Cassar (2014) discuss the issue of the balance achievement between “heritage values” and energy efficiency needs; they mentioned that heritage values should have an equal focus with energy priorities at any project beginning (Fouseki & Cassar, 2014). Where intervention operations involve a change in the fabric or usage of a heritage edifice or its setting, the potential effects of the proposed change on the building significance must be identified, quantified and justified. The effects of the change may be direct (i.e., affect the building fabric, attributes, or character) or indirect (i.e., alter spatial qualities or relationships within the setting). Changes that protect or reveal the significance of the heritage building should be encouraged. Changes that would detract from the building significance should be avoided to the extent possible (The British Standards Institution, 2013).

Rasmussen et al. (2015) present case study of the renovation of Fæstningens Materialgård Complex in Copenhagen, Denmark. The project includes energy upgrading, restoration, and renovation of individual buildings that create the listed complex. On identifying feasible energy-upgrading measures and quantifying the reduced CO2 emissions, the authors confirmed the practicability of the energy performance improvement of heritage buildings as well as the indoor climate though not compromising recognized heritage values. Therefore, they remain part of the attractive building stock. The design team supports the involvement of the Heritage Agency, the Danish Working Environment Authority and the owner to cooperate in the process and identifying feasible energy-upgrading measures.

TOMŠIČ et al. (2017) present “the Slovenian national technical guidelines for energy efficient renovation of cultural heritage building”. The authors reveal the effect of the payback period of the investment as a parameter in the decision-making process, and highlight that energy renovation must comply with local characteristics to ensure sustainability of investment. They emphasize on the importance of the building lifetime as a parameter within the renovation. TOMŠIČ et al. (2017) turn also to the importance of the owner involvement in the planning process of the renovation and their education about how living and working regimes and practices affect actual energy consumption. They identified three factors that are the most important from the perspective of the owner or tenant: lower operating and maintenance costs, improved living and working comfort and, of course, increase of the property value.

Baggio et al. (2017) present a case study of an energy improvement of the “A. Canova” high school located in Treviso in Italy. The paper applied the GBC Historic Building™ protocol as a design tool (and not for assessment) in order to develop a sustainable design strategy for the project. The authors used a multi-criteria approach in order to reach the best solutions mainly in terms of energy saving and performance (reduction of 39% of the energy consumption), historic preservation, and indoor thermal comfort. The importance of energy retrofitting was the driver to operative conservation of historic value and subsequent indoor quality; this required a new evaluation of more relevant aim in case of equal score to maintain a higher level of conservation rather than to prefer comfort or energy saving in the construction phase. The study confirmed the feasibility of the proposed strategy on reaching 56 points (27 verified points and 29 simulated points) that leads a silver level LEED certification.

Lidelöwa et al. (2019) conducted a literature review about the energy efficiency in heritage building, they analyzed the relevant peer-reviewed journal articles published (or in press) between 2005 and 2016. The study gave an overview of how heritage conservation and energy efficiency have been approached in the existing literature. The authors directed the state of the art from different perspectives: energy analysis, life-cycle perspective on energy use, Analysis of cultural heritage value. From the defined gaps in this review, the authors conclude their work with some areas and suggestions for further research:

- Highlight energy efficiency measures that have been or could be implemented in listed buildings of different ages, designs, construction methods, and climate regions.
- Expand the scope of operational energy analysis to include district, city and regional stocks rather than single buildings and their components.
- Explore (on details) the relative amount of embodied energy and operational energy for heritage buildings, both in the context of retrofit/reuse versus demolition/new construction and to evaluate the relative effectiveness of possible energy retrofitting options.
- Determine the theoretical foundations (the conservation principles or the methodology) for the assessment of cultural heritage values and their impacts on the evaluation of potential energy-efficiency measures.
- Develop best practice guides or decision support systems to guide practitioners on, among other things, how different interventions paradigms can be applied in practice and how they can influence the potential for integrating energy efficiency practices in heritage buildings.
- Develop complementary quantitative assessments of cultural heritage values (in addition to the qualitative analysis) to facilitate energy-efficiency strategies design for historic districts, cities and regions.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers "ASHRAE" (2019) has developed an Energy Guideline for Historic Buildings (Guideline 34) that comprehensively details the processes, procedures, and workflows for retrofitting historic buildings to achieve higher measured energy efficiency (see Figure X). "Guideline 34" affords a step-by-step approach to a sensitive energy retrofit, beginning with the formation of the project team and the collection of building and energy use data and ending with the implementation of energy efficiency measures (EEM). The guide addresses heating, ventilation and air conditioning (HVAC) system selection, building envelope improvements, environmental control strategies, energy systems analysis, and lighting design considerations. All recommendations are made with consideration for preserving the integrity of the building's historically significant character, materials, and associated artifacts (see Figure 2.6).

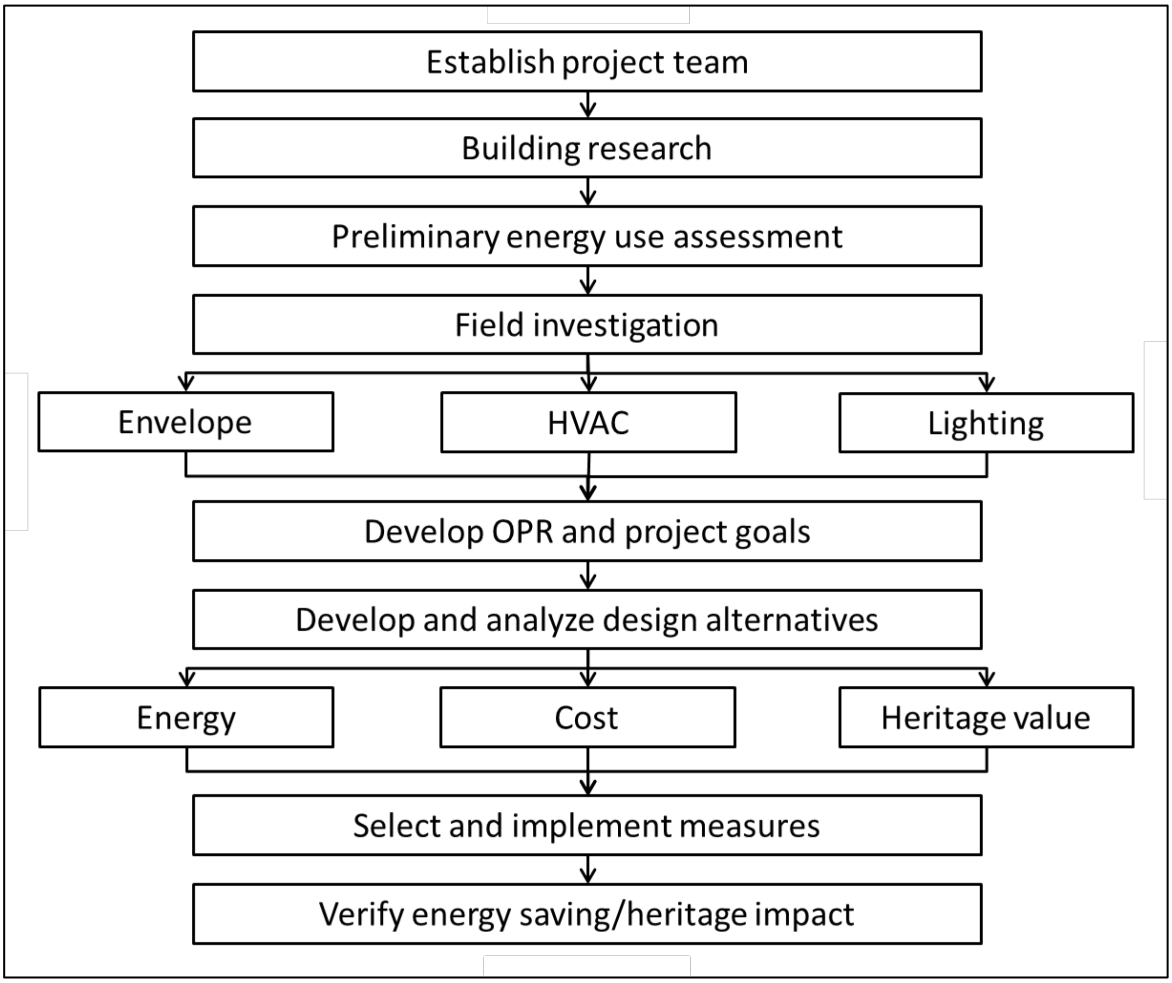

Figure 2.6. Energetic renovation process of historic buildings
(Source: adopted by author from ASHRAE, 2019)

2.4 Issues and challenges of heritage renovation projects

Several authors mentioned that heritage renovation projects are among the most risky, complex, and uncertain projects in the construction industry (Roy & Kalidindi, 2017). Many problems faced make the management of these projects a great challenge (Azizi et al., 2015). Heritage renovation issues are discussing on different strategic, tactical, and operational levels through the literature. Roy and Kalidindi (2017) conducted an exploratory study in India in which conservation professionals were interviewed to identify factors that influence the performance of historic preservation projects in terms of the project management parameters of time, cost, and quality. Based on coding of the unstructured interviews, 26 factors were identified, which were qualitatively grouped into eight categories: Agency competence, estimating problems, insufficient and unprofitable documents, resource constraints, client capacity, lack of expertise, stakeholder problems, and functional building problems.

However, Azizia et al. (2016) identified 46 problems in the renovation of heritage buildings from the literature and classified them into five themes*: technical, environmental, organizational, financial,* and *human*. The results showed that technical problems such as limited availability of professionals, availability of original building components, lack of manpower and expertise, and lack of staff training are the main challenges in renovation projects.

Each renovation project is considered unique and cannot be duplicated (Zolkafli, 2012). Building renovation involves an indefinite scope where a large number of variations in the amount of work and change orders can be made conditions is not available and is not recognized until late in the process when work begins. Consequently, cost overruns, delays, and levels of contingency allocation are significantly higher on renovation projects (Guccio & Rizzo, 2010; Reyers & Mansfield, 2001). On the other hand, renovation works suffer due to untrained staff and limited technical knowledge due to the lack of documents and guidelines that define the purpose of these projects and reflect the processes or a methodical recipe for management (Azizi, 2015; Azizia et al., 2016). In addition, legislation for heritage buildings is not specific and inflexible.

Regarding sustainability, decision-making in heritage renovation is a major issue, as mentioned in the previous section. Choosing appropriate renovation interventions is not an easy process. The challenge is to respect all the values of the building, and the situation is more complex when the building is still used by communities. The question of which values to respect, or which methods to use, is not simple. Fouseki and Cassar (2014) address the problem of collaboration lack among professionals involved in such projects, who have practical and theoretical expertise in heritage conservation methods and tools for understanding heritage values. They see collaboration as the key factor in achieving a balance between heritage preservation, human comfort, and cost-effective energy technologies.

In this regard, the occupants' attitudes and behavior are very important to be investigated during the design stage. Fouseki and Cassar (2014) discuss the values relevant to non-expert users of heritage buildings (such as residents) during the introduction and implementation of energy-efficiency interventions on contrary with the previous researches which addressed only the historic or the aesthetic values. The authors stated the importance of studies regarding the occupants' attitudes and behavior, which are very lack in the heritage areas. They gave examples from other studies that conducted on the European area (i.e. UK, Italy, and Sweden) for residential buildings. These studies reveal that the European Energy Performance of Buildings Directive is not adopted by the majority of homeowners because it does not take into account the complexity that an owner-occupied home brings (Fouseki & Cassar, 2014). The driving question for energy-efficiency projects should take in account "How people view and value their buildings" and "Which interventions (if any) can be implemented that could harmoniously coexist with these meanings?"

Table 2.3 summarizes 19 main challenges and issues in the management of heritage renovation projects, divided on six categories (see Table 2.3).

Table 2.2. Summary of project management challenges in sustainable renovation of heritage buildings (Source: adapted by author)

Categories	**Challenges and issues**	**References**
Complexity	Dynamic intervention	Zolkafli, 2012; Khodeir et al., 2016; Roy and. Kalidindi, 2017
	Multi-disciplinary field	
	Tangible & Intangible values	
	A unique and non-duplicate project	
	Contradiction between value preservation and energy efficiency	
Hierarchical Fragmentation	Transactional contract	Avrami et al., 2000; Smith, 2005; Kamal, 2008; Ismail & Azlan, 2010; Azizi et al., 2015 ; Perovic et al., 2016
	Vertical / Horizontal / longitudinal fragmentation	
	Different organizational cultures and philosophies	
Risks and Uncertainties	Pre-existing & unforeseen conditions	Mckim et al., 2000; Rayers and Mansfield, 2001; Mitropoulos & Howell, 2002; Naaranoja & Uden, 2007; Ali et al., 2008, Guccio & Rizzo, 2010 ; Zolkafli, 2012; Perovic et al., 2016; Roy and. Kalidindi, 2017
	Unavailability of information	
	Undefined scope / ambiguity	
	Change in scope/ design/ quantity of job	
	Cost overruns/delays	
	High level of contingency allocation	
Material	Durability of material, structures, and landscape	Sanna et al., 2008; Erdem and Peraza, 2014
	Uncommon material or systems	
Legislation	Not specific and inflexible	Azizi et al., 2016
Skills & knowledge	Unskilled personnel /limited technical knowledge	Azizi, 2015; Azizia et al., 2016; Barbosa et al., 2016
	Lack of documents and guidelines	
	Nonstandard method of renovation	
Exploitation	The negligence of the building maintenance	Syahrul, Emma & Aiman, 2011; Aksah et.al 2016
	The high cost of building operation	

2.5 The need for innovative methodologies to renovating heritage buildings

Kamari et al. (2017a) highlight that the shift from technical assessment and environmental technology to sustainability paradigm and holistic design of building renovation, require the development of integrated design processes and evaluation methodologies, as well as a holistic decision support framework. Fouseki and Cassar (2014) and Kamari et al. (2019b) suggest the use of cross-disciplinary, sophisticated processes and methodologies to develop holistic decisions-making frameworks. Fouseki and Cassar (2014) advocate their use for understanding and integrate heritage values into decision-making frameworks that revolve around improving the energy efficiency of the heritage building stock.

Jensen (2018) argue the use of strategic collaboration employing framework contracts allows to implement innovative solutions and learn how new technologies, processes and methods can be implemented across projects to further enhance sustainability.

2.6 Summary

Sustainable renovation of heritage buildings is a dynamic intervention, which takes place in complex contexts involving interactions of multidisciplinary fields. A key, fundamental challenge in this field is dealing with the enormous complexity, both at the level of an individual heritage project (consisting of various existing conditions that are remarkably different from one project to another) and at the level of the AECO community of knowledge about what intervention options are available and how each of these intervention options affects criteria (e.g., energy efficiency). Likewise, finding an optimal number of interrelating policies, processes, and technologies that will contribute to this success with many involved stakeholders, are yet another remaining challenges. In the next chapter, a theoretical background is provided for BIM and IPD use and their advantageous in construction projects.

CHAPTER III: BIM AND IPD IN CONSTRUCTION PROJECTS

This chapter reviews the concept of IPD and BIM and their application in construction projects, their benefits, and barriers via exploring the relevant literature in these areas.

3.1 Quality management and project performance

Construction is one of the most dynamic and complicated industrial sectors in the world, which comprises 13 percent of the global economy. According to the last estimation of the "Global Construction 2030" report, the construction output volume will raise by 85% to $15.5 trillion worldwide by 2030 (Dixon, 2020). However, The McKinsey Global Institute estimates the need to spend $57 trillion on infrastructure worldwide at that time to save global GDP growth (Agarwal et al., 2016). The numbers within these reports are huge and that interprets as creating vast numbers of new jobs and prosperous societies across the globe in the next fifteen years. The construction sector engages in different kind of industries and processes to complete the building project. Nowadays, The evolution of the construction industry aspects: socio-economic, environmental, technological, knowledge and know-how, resulted in a change of the construction organization and management as the labor division, the emergence of new businesses and diversification of stakeholders (suppliers, subcontractors, partners …) (see Figure 3.1).

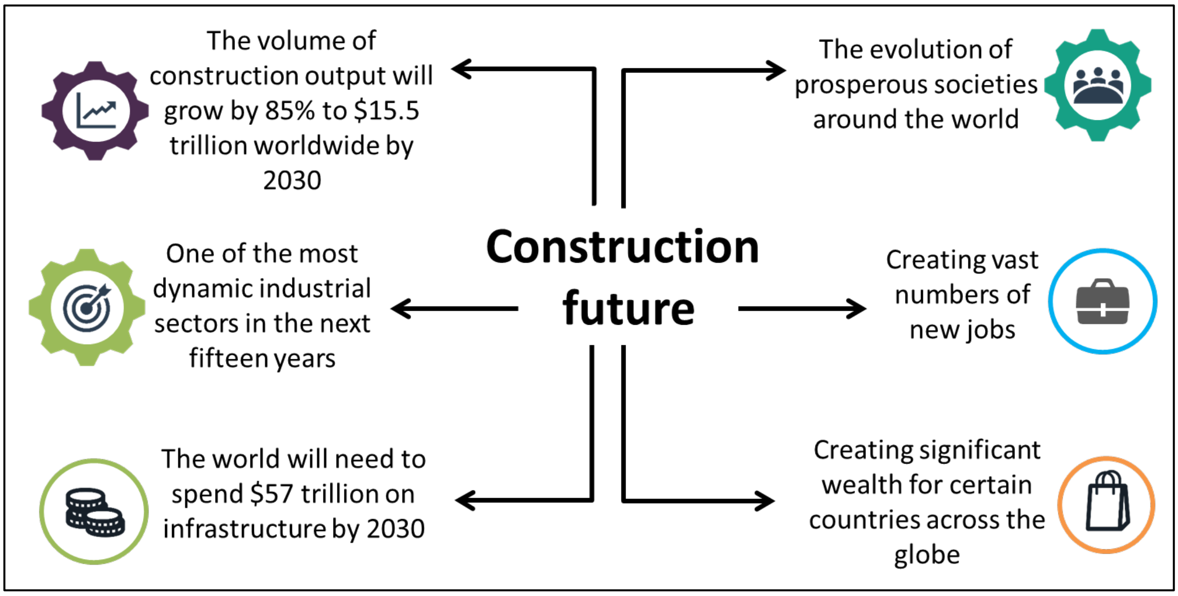

Figure 3.1. The evolution of the construction industry
(Source: adapted by author from Agarwal et al., 2016)

Unfortunately, numerous studies and research demonstrate that the construction industry suffers from problems of productivity, predictability (costs and schedule) and quality of the final product. These problems are mainly related to the strong fragmentation of this industry as well as the temporary nature of the projects, whose objective is the delivery of a unique product that satisfices the new needs of sustainability.

According to a study by KPMG in 2015, in a period of three years, less than a third of projects carried out by construction companies were on a budget, and a quarter of them were completed on time. In addition, only 32% of building owners have high confidence in the contractors they work with. Even more than the issues of quality, productivity, complexity and cost management, safety remains a thorny subject for the construction industry today. According to the US Department of Labor, there is an average of 19 deaths each week in the construction industry in the United States. A brief analysis of historical industry data on a global scale for major capital programs discloses the performance indicator statistics presented in (see Table 3.1).

Table 3.1. Failure rate of major capital programs globally (Source: Autodesk, 2015)

Infrastructure projects	**Construction projects**
• Cost overrun of / variant: 10-50%	• Cost overrun of / variant: 15% on average, majority of projects with an overrun between 5 and 20%
• Timeout of / variant: 30-120%	• Deadline of / variant: 50% on average, majority of projects with an overrun between 30 and 120%
• About 2/3 of projects generate budget and deadline overruns	• Around 2/3 of projects generate overruns budget and deadlines

In addition to the cost and delivery time, Ebrahimi (2018) identifies (through literature review) variety performance-related problems in the AEC industry. These include labor productivity, safety, quality, material waste, post-occupancy performance (like energy use and GHG emissions, water use, indoor environment quality measures). The authors highlight that disintegration of processes, the uncoordinated behavior of different stakeholder groups, and the focus on local rather than global optimization throughout the project, are the root causes of performance gaps.

3.2 Disruptive innovation or Incremental innovation

Construction sector is becoming increasingly complex. Collaboration, coordination, and sharing of information and documents are the key issues face of the growing volume of data must be managed in projects. Therefore, we need to facilitate the access of the different actors and to manage more and more important projects by involving new innovative solutions and improved practices. Innovation in construction sector can take many forms, including changes in project delivery, collaboration, and product improvement.. The innovations involve either a "product" or a "process" (W. Nofera et al., 2011). The McKinsey study (2016) attributes the construction industry's productivity problem to the slow adoption of process and technology innovations. The industry also faces a constant challenge when it comes to getting the basics right. Project planning, for example, is still not coordinated between the office and the field and is often done on paper. Contracts lack incentives for risk sharing and innovation, performance management is poor, and supply chain practices are still not mature. The sector has not yet adapted to new digital technologies that require upfront investment, although the long-term benefits are significant. Research and development (R&D) spending in the construction sector is well below that of other industries: less than 1% of revenues, compared to 3.5 to 4.5% in the automotive and aerospace sectors. The same is true for information technology spending, which accounts for less than 1% of sales in construction, despite the development of a number of new software solutions for the industry (McKinsey, 2016).

Aricò (2010), creative and design manager at the Hot Spots movement, looked at how design-based innovation will drive business. He identifies seven key elements of innovation at the company level to consider more or better innovation practices, including leadership, processes, strategy, resources, performance metrics, measurement and incentive rewards. These elements - and the way they are arranged - shape organizational structure and culture, and have a significant effect on the quantity and quality of innovation an organization manages to achieve.

Verganti (2008) identifies three approaches to innovation: market pull, technology-push and design-driven approach. Stakeholders are increasingly concerned about building maintainability, durability, accessibility (lee, 2002). Each of these parameters must satisfy a range of social, economic, and legislative conditions, which may even conflict with each other. Moreover, as each of these factors varies - in the amount and type of requirements they pose - they have a direct impact on the course and nature of the construction project. (see Figure 3.2).

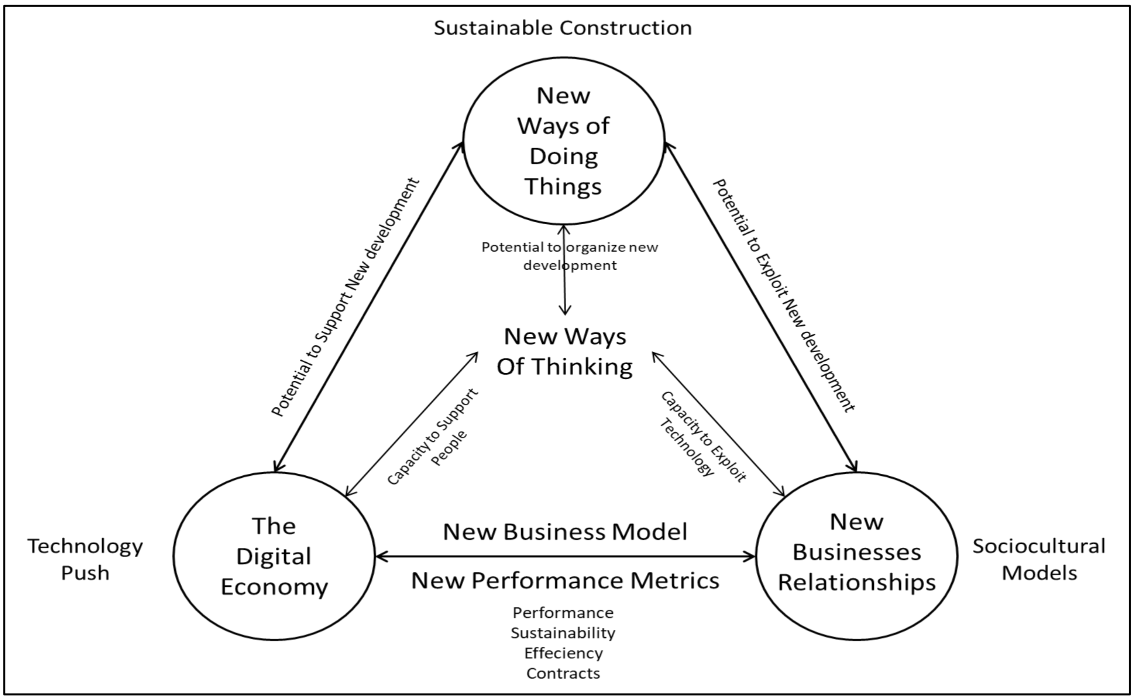

Figure 3.2. Construction Business Change Model
(Source: adapted by author from Lee et al., 2002)

3.3 Digitalization of the construction industry: Construction 4.0

Nowadays, all industries are becoming increasingly reliant on IT to uncover previously unexplored value potential. Like a wide range of industrial sectors, the Fourth Industrial Revolution, “Industry 4.0” (Lasi et al. 2014) is transforming the AECO sector. The digitalization and automation of the construction, also referred as Construction 4.0, has changed the supply chains management and products (Dallasega et al. 2018), through the adoption of innovative and disruptive technologies including building information modeling (BIM); cloud computing; big data analytics; internet of things; virtual/augmented/mixed reality; as well as autonomous robots (see Figure 3.3). However, the digitalization of construction is still slow in comparision with other industries. For instance, and according to the Harvard Business Review the construction industry itself has fallen behind in its advancement of digital technology, 2nd last compared to other sectors in USA.

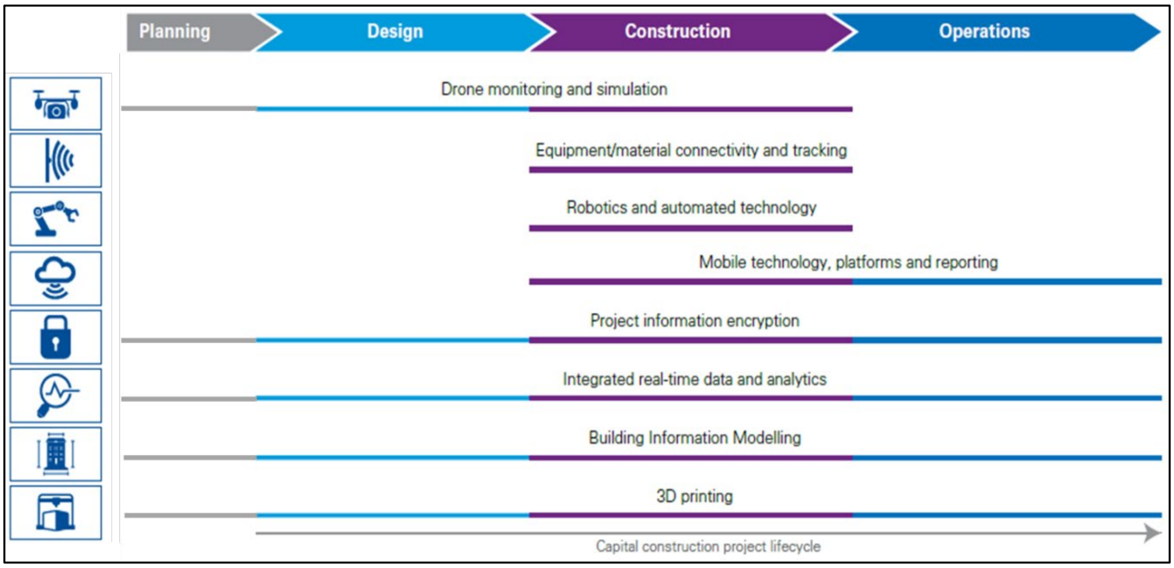

Figure 3.3. Types of digital technologies employed in engineering and construction, across the lifecycle project (Source: adapted by author from KPMG, 2016)

3.4 Building Information Modeling (BIM)

3.4.1 BIM background

The first theoretical approach of BIM was appeared with the 3D modeling using a computer tool. In 1960s, the earliest spatial 3D-design with computers had to be simulated with box-like parallel-pipeds due to limited computing capability. In1970s CAD offered the possibility to model also mathematically defined 3D-curved forms. Eastman used the term "Building Information Model" for the first time in 1975. Elementary research on product modelling was conducted, and originally developed the object-based parametric modeling in late 1980s. However BIM was adopted in pilot project even mid-2000.

As a concept, BIM continues to evolve, so the literature on BIM varies and offers a variety of definitions. In general, the definition of BIM can be very narrow and relate exclusively to the technology aspect, but it can be quite broad and consider organizational and operational aspects such as governance, processes, standards and people. What these definitions have in common is the model-centric aspect of BIM. Just as the benefits of BIM are derived from this model-centric approach, the implementation of BIM must consider this. As a holistic definition, BIM is a Digital delivery method made up of four key elements: collaboration, representation, process, and lifecycle (Bradley et al., 2016). As shown in Figure 3.4, all the elements interact to generate a systematic approach for managing the critical information within a unique and shared platform, founding a reliable basis for decisions throughout the building life cycle (Bradley et al., 2016; Succar, 2009) (see Figure 3.4). However, Figure 3.5 illustrates the emergent concept (technologies and approaches) related to BIM adoption.

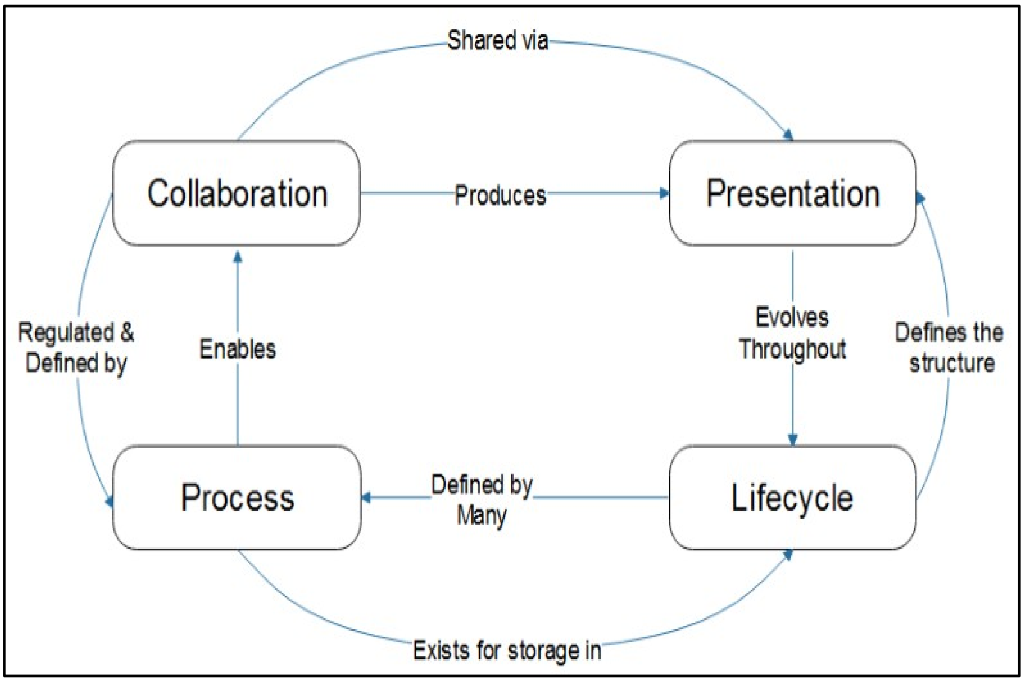

Figure 3.4. The four Key Elements of the BIM Concept
(Source: adopted from Bradley et al. 2016)

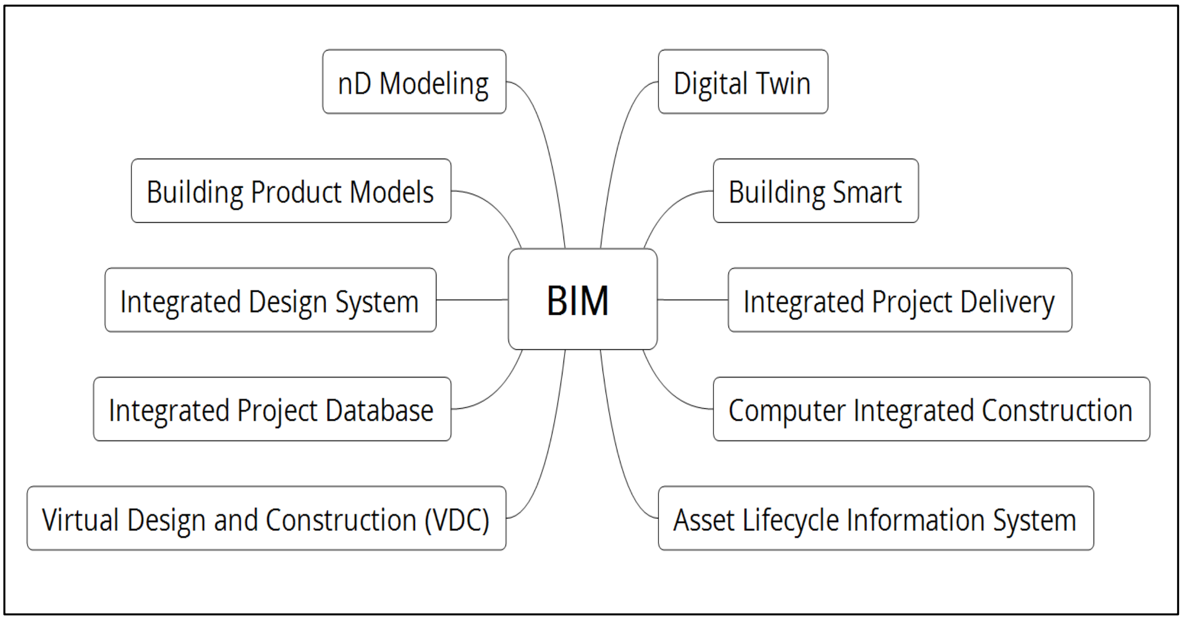

Figure 3.5. Showing the relationship of BIM with other concepts
(Source: adapted by author from Coates, 2013)

3.4.2 BIM as a pathway to change

BIM drivers and enablers

The BIM acts as a catalyst for change in Architecture, engineering and construction. BIM is changing the traditional methods of working; roles and relationship divided between specialties and organized as a series of sequential activities, to propose an integrated design and construction process around a unique and shared platform through the entire lifecycle of the building.

The shift into BIM in construction is obviously a process of change in contractual agreements because the fragmentation of traditional approaches and struggles for individual benefits work against the collaborative atmosphere for BIM implementation (Migilinskasa et al., 2013). Figure 3.6 summarizes the different drivers and enablers of BIM adoption in the construction industry.

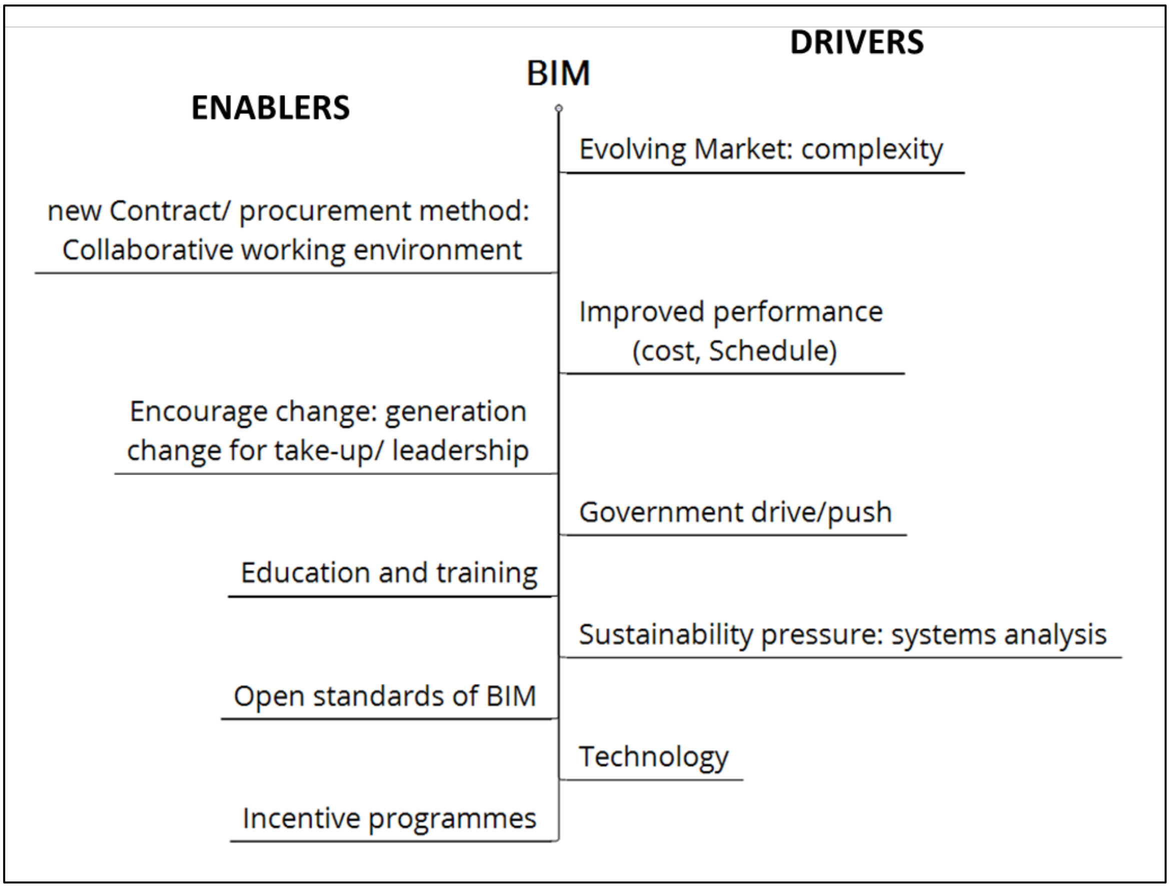

Figure 3.6. Drivers and Enablers of BIM adoption in AECO projects (Source: Author)

Roles and responsibilities

BIM adoption requires a cultural and organizational change, on how the supply chain itself is shaped (people) and projects are executed (processes) within new roles and competencies (i.e. BIM manager, BIM coordinator, BIM modeler…) to propose an integrated design and construction process for achieving project goals (Eastman et al., 2008; Succar, 2009). Therefore, it requires an understanding of certain BIM concepts that are sometimes new or misunderstood. BIM professionals will need training to help them adopt BIM and integrate it into their projects on a daily basis. BIM training programs are also a source of motivation for professionals and strengthen the intellectual capital of the companies (Autodesk 2008).

BIM contract, standards, manuals and guidelines

Many studies address the evolution of BIM processes and requirements that are projects-dependents. Work procedures and methods put in place through different manuals, contracts, and standards (i.e. data structure, exchange requirement standards, identifier standards, and process model standards) to ensure the team integration that is measured by the number of BIM uses and capabilities (Computer Integrated Construction Research Program, 2013; Barbosa et al 2016).

In order to produce a model that meets the needs of end users and facilities manager, the client should put with them an Employer's Information Requirement (EIR) document; it should be referenced in the contract. A BIM consultant or member of the design team can assist clients who are new to the process.

The core group shall establish the BIM Execution Plan (BEP) and other management protocols and tools. The BEP is produced as a direct response to the EIR and reflects the requirements documented in the BIM Contract. This document referred to in the contract as an unfixed document due to its evolving nature. The BEP is submitted first prior to the contract to address issues outlined in the EIR, and then in more detail post-contract award to clarify the supplier's methodology for BIM project delivering. It will contain project specific BIM processes, requirements, and information workflows. Each project BEP may be unique, although they may all have a common framework. Therefore, it is required to develop new protocols and standards to cover the nature of each project and the high level of collaboration needed (Computer Integrated Construction Research Program, 2013)

In order to solve the problem of exchange data from different BIM platforms and software, the IAI (International Alliance for Interoperability) (currently known as buildingSMART) created the format "IFC" in 1996, which documented later in 2013 as an international standard "ISO16739:2013"

There are many examples of BIM procurement language that an owner can reference to create their own procurement language. Two examples are: "Digital Data Exhibit and the ConsensusDOCS 301 BIM Addendum" and "American Institute of Architects (AIA) E203 Building Information Modeling". Many owners wish to further specify their BIM requirements, created documents which are available for reference.

BIM maturity level and Capability assessment

BIM are not 'one-size-fits-all' approaches, according to the collaboration achievement, different BIM maturity levels are demonstrated (Becerik-Gerber et al., 2010). BIM maturity assesses the BIM readiness of the organization as a whole and at the project level. There are different types of maturity measures, but at a high level, they tend to focus on a company's technological and organizational transformation, providing a useful indication of its progress in the BIM transformation of its business.

Various authors discussed BIM maturity and developments to occur and envisage future of practical implementations of BIM and related techniques. Two maturity models, have been widely used in discussing and ascertaining BIM maturity, the UK maturity model of BIM /the iBIM model or the BIM Wedge developed by Bew and Richards (2008) and the Building Information Modelling Maturity Matrix developed by Succar (2009).

In the BIM paradigm, the Framework of Succar (2009) is commonly regarded as one of the most valuable contributions to the BIM field. He describes the domains of BIM knowledge and their interrelationships. These domains are 'BIM fields', 'BIM maturity stages' and 'BIM lenses'. Succar defines three BIM Fields: *Technology, Process* and *Policy* (TPP) within two sub-fields each: *players* and *deliverables*. They refer to all topics, activities, and actors across the BIM domain to position BIM as an integration of product and process modelling, not just as a disparate set of technologies and processes. These subdivisions help distinguishing between three stages leading to or transitioning from Pre-BIM (a fixed starting point), through three well-defined Maturity Stages (object-based modelling, model-based collaboration, network-based integration) towards IPD as the overall goal of BIM implementation.

The CICRP (2013) presented another BIM framework for a structured approach to plan the BIM integration within an organization effectively. Three planning procedures are defined: Strategic, Implementation, and Procurement procedures. The BIM implementation requires the consideration of six cores “BIM Planning Elements” through all stages (*Strategy, BIM uses, Process, Information, Infrastructure, and Personnel*).

3.4.3 BIM advantages in the construction industry

BIM uses and workstreams

BIM is perceived as a major enabler of sophisticated and integrated design and construction to promote sustainability and productivity. Zhoua et al. (2017) divided BIM implementation into operational, managerial, organizational, and strategic factors. The BIM integration in construction industry enables to gain *in automation and data manipulation* at different phases of a project's life cycle (Eastman et al., 2009). In addition to the *knowledge sharing* opportunities (people) through the introduction of technologies that more efficiently support information sharing, the *interoperability* between BIM applications and energy simulation tools (technology) improve the *visualization* and *virtual simulation* of the renovation practices, as well as the operation of the renovated building (process and product). That can lead to more effective decision-making with the *standardization* of design practices (policy) to facilitate these processes on exploring and selecting among a large number of renovation alternatives and approaches available in the mark, and thus leading to cost savings, time-saving, and improving quality and sustainability (Figure 3.7 and 3.8).

The concept of 4D modeling (3D + time factor) emerged in the research study of Rischmoller et al, (2000). Later, Lee et al. (2002) defined the vision of the 3D to nD project to incorporate a prototyping platform for the building and engineering sector.

In addition to the major dimensions of time (4D) and cost (5D), occupational health and safety has become an increasingly important issue. With the further integration of 3D, 4D and 5D data into building information models, it has become possible to quantitatively analyze health and safety aspects of both the static design geometry and the accompanying scheduling and active site layout. The integration of health and safety aspects into BIM is becoming an increasingly important issue, as is the use of BIM for enterprise resource management.

Other emerging areas include the use of 4D BIM models for constructability analysis, e.g., Chen et al. (2015) are analyzing space utilization to improve construction sequencing and perform time-based clash detection in addition to traditional static clash detection.

Because BIM allows multidisciplinary information to be overlaid on one model, this approach provides the ability to perform environmental performance analysis and sustainability improvement measures (6D) accurately and efficiently; "Green BIM" has become an enormously popular term and concept in the construction industry (Wong & Zhou, 2015).

Recently, the research focus has shifted from the earlier life cycle (LC) phases (i.e. Pre-planning, design and construction) to maintenance, refurbishment, deconstruction, and end-of-life considerations, especially for complex structures (Volk et al., 2014).

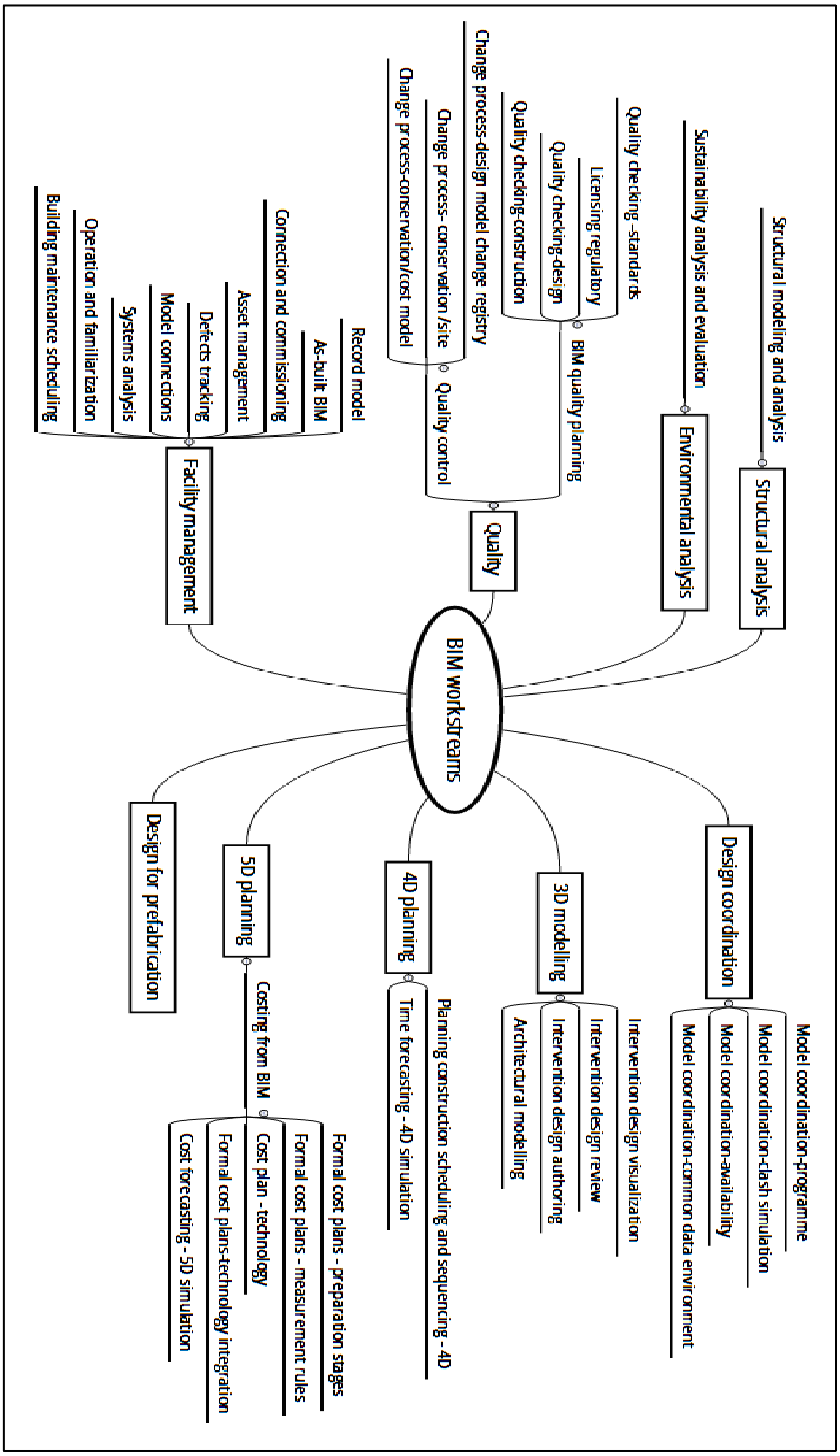

Figure 3.7. BIM workstreams (Source: Author)

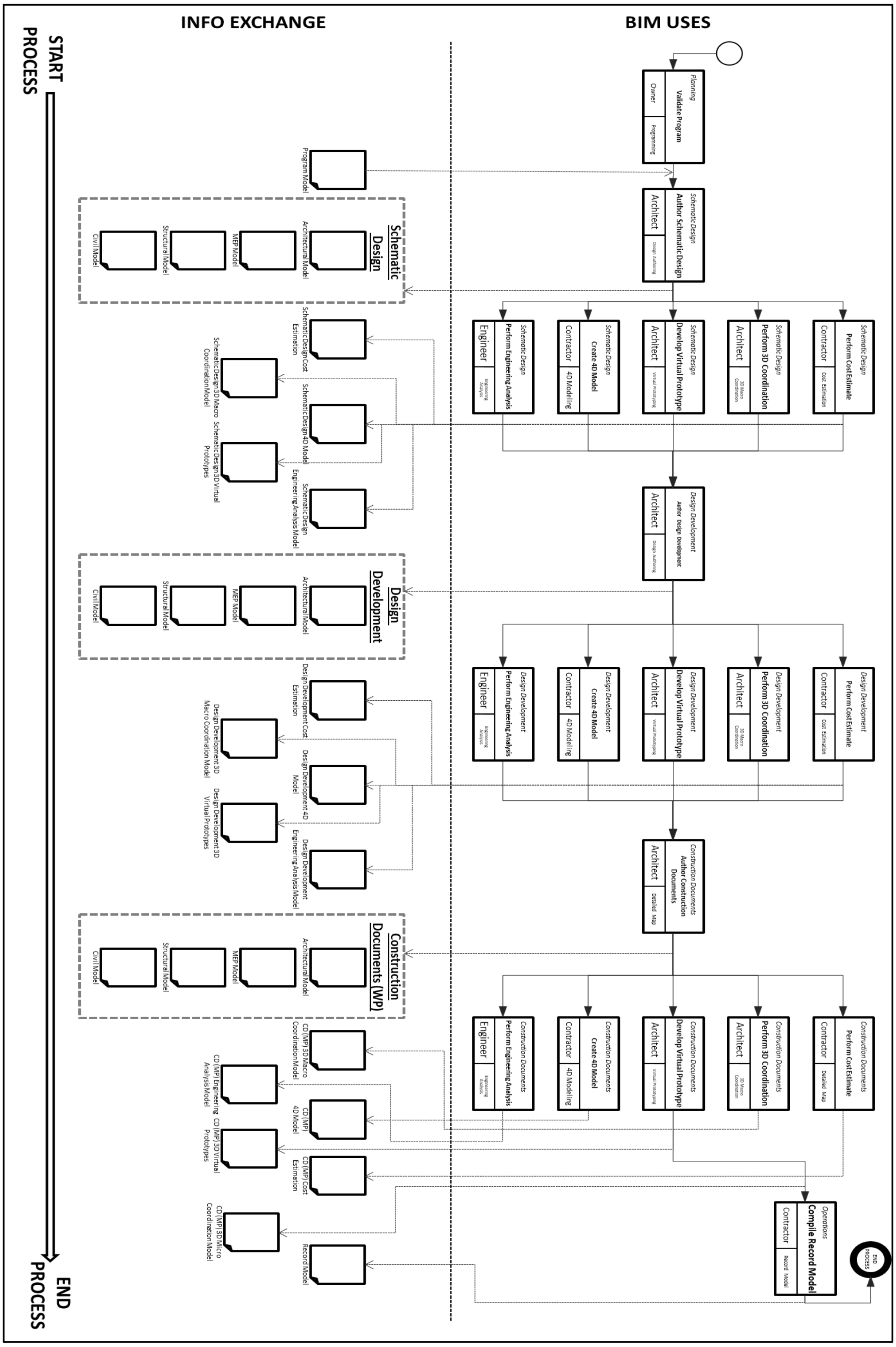

Figure 3.8. BIM Execution Planning Process: BIM uses and information exchange (Source: adapted by author from Penn State CIC Research Team, 2016)

BIM workflows, Level of Development (LOD), and Level of information need

BIM allows complex analyses at an early stage through interoperable BIM platforms and software (Kamari et al., 2019). The different data formats created like the Industry Foundation Classe “IFC” and the Construction Operations Building Information Exchange “CoBie”, increase the virtual workflows and enable the exchange data from all entities, stages, and phases of the project life cycle realizing interdisciplinary nD models (Barbosa et al., 2016). Although there are many predefined specification formats that we can use or guidelines that we can follow, these standards are usually country-specific or very general (such as COBie). Zhao (2017) mentioned that IFC has received the citation pushes in recent years. An open data model schema allows defining the geometry of components and other physical properties to enable data transfer between CAD applications.

To enable this work process, industry and research’s efforts have created Level of Development (LOD) for the modeled elements. It specifies the content requirements and associated authorized users at each phase, focusing primarily on what content needs to be modeled, and to what degree (BIMforum, 2019). Six levels of development were defined from LOD 100 to LOD 500 by the AIA/AGC BIMForum LOD Working Group. Each LOD levels were built on the previous level and included all the characteristics of previous levels (see Figure 3.9). Recently, "LOD" terminology has been changed in the latest ISO 19650 with "Level of Information Need" without any abbreviation/number used.

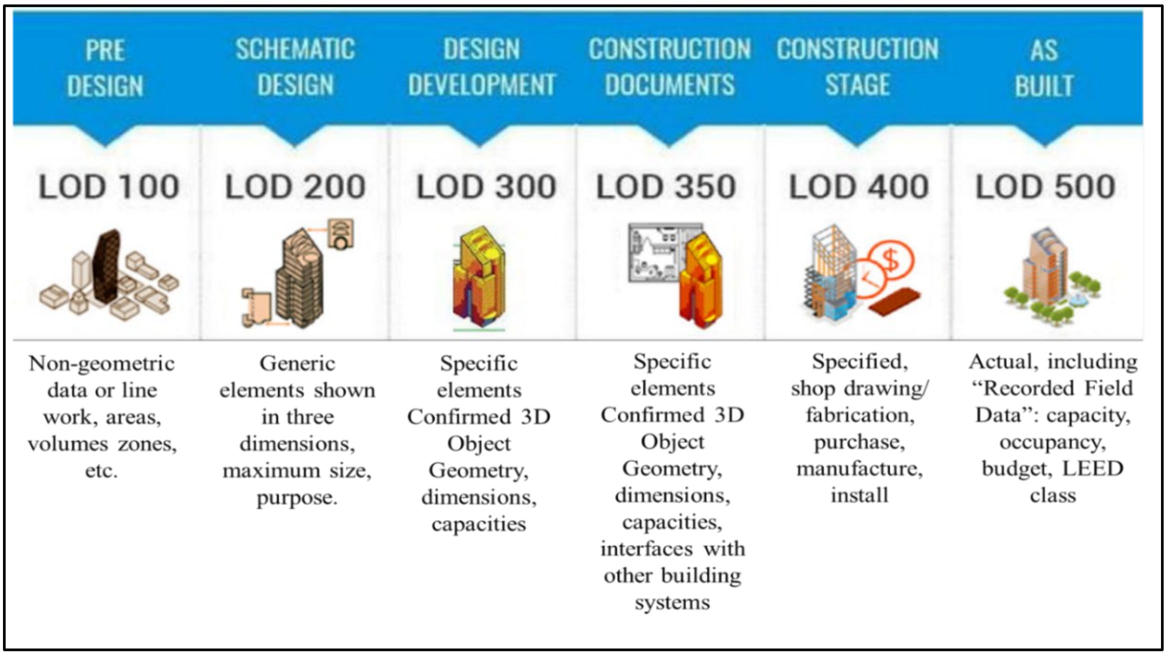

Figure 3.9. BIM Level of Development (LOD) summary
(Source: adapted by author from Bedrick & Builders, 2008; and BIM Forum, 2019)

Some project information is confidential. When sensitive information is involved, digital systems enable access control. The more important question is who is allowed to make changes to the information and how those changes can be documented and potentially reversed. Therefore, model server data security measures should be considered and information management protocols must be established to meet the organization's security requirements for all participants accessing the information. These protocols include intellectual property (IP) and copyright protection concerns, as shown in Figure 3.10, which can be mitigated through greater awareness and legal action.

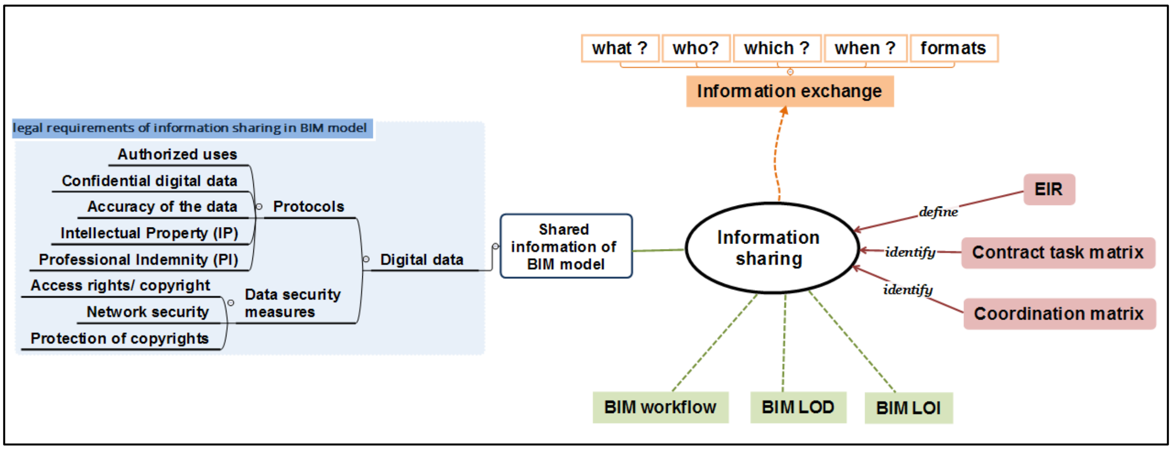

Figure 3.10. Conceptual diagram representing the process of sharing information in BIM models (Source: Author)

BIM and Life Cycle Assessment (LCA)

Life cycle assessment is a suitable tool to evaluate the environmental performance of a building. Nevertheless, there are some problems that need to be solved for integration into the design process and use as a design assessment tool (i.e. data availability, uncertainty, late implementation). By integrating LCA with BIM, a more holistic approach to sustainable building could be achieved. Antón and Díaz (2014) mention that: *"On the one hand, BIM supports integrated design and improves information management and cooperation between the different stakeholders throughout the different project life-cycle phases. On the other hand, LCA is a suitable method for assessing environmental performance. Both LCA and BIM should be integrated in the decision-making process at an early stage with a view to achieving a holistic overview of the project, including environmental criteria, from the beginning*".

Soust-Verdaguer et al. (2017) defines three levels of BIM-LCA integration development: 1) Integrates BIM as a tool, during the LCA phase for quantification of materials and construction elements; 2) Integrates environmental information into the BIM software or into the building energy assessment, in addition to using BIM as a tool to quantify and organize building materials and components; 3) Involves developing an automated process that combines various data and software.

BIM trending in the different type of AEC projects

Several reviews highlight the multiple potential benefits of using BIM environments for different types of projects, some of the most important studies directed by: Volk et al. (2014) and Joblot et al. (2017) on existing buildings; Tang et al. (2010) on heritage buildings preservation; Shou et al. (2015) on infrastructures; Wong and Zhou (2015) on sustainable projects. Therefore, the term BIM has spawned other terms such as City Information Modeling (CYM); Existing Buildings Information Modeling (EBIM); Historic/ Heritage Building Information Modeling (HBIM); Bridge Information Modeling (BrIM); Urban Information Modeling (UIM); and Green BIM.

From reviewing literature related to these projects and current BIM concepts, it appears that some aspects are very similar to their counterparts in the new construction sector, such as the process of design review, the methodology of collaboration and the coordination of works, which can take the same approach as BIM in the new construction sector. However, the main difference lies in considering the benefits. Modeling in new buildings is very component-based and offers advantages in clash detection, clarity of information and visual aids during the design phase.

Open BIM

The interoperability with BIM provides a potential for interfacing with other enterprise systems. Project Lifecycle Management technology (PLM) is a complementary solution to BIM to ensure complete management of the project/building on the whole lifecycle. The Computerized Maintenance Management System (CMMS) and Computer Aided Facilities Management Systems (CAFM) allow the facility staffs to identify, track, coordinate, and access facility maintenance work in the 3D environment and use it for asset management (see Figure 3.11).

Interoperability becomes a very important issue in the BIM domain. Several attempts are still being made to overcome interoperability issues and improve the seamless exchange of data between multiple applications and different file formats. Wong and Zhou (2015) highlight the insufficient consideration given to the current cloud computing technology and 'big data' management within the green BIM tool.

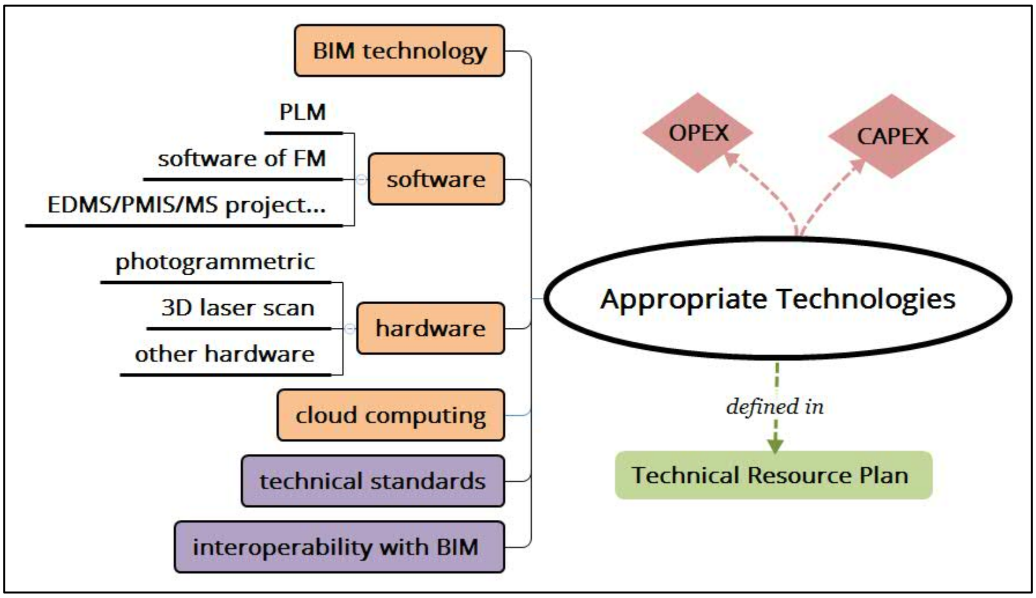

Figure 3.11. Conceptual paradigm representing the appropriate technologies (Source: Author)

3.4.4 Current state of BIM adoption, challenges, and barriers

Different market values are placed into BIM according to each industry and country and how it relates to their productivity (e.g. Government/Industry commendations; comparison in benchmarks, cost-benefit analysis, outputs, and standards). However, despite this development, the benefits of BIM are not really being covered, and there should be a continued struggle to achieve BIM uses throughout the life cycle (Shou et al., 2015).

BIM market size is projected to grow from USD 4.5 billion in 2020 to USD 8.8 billion by 2025, with a CAGR of 14.5%. KPMG (2016) conducted a Global Construction Survey through interviews face-to-face with 218 senior leaders. 61% of the respondents indicated that they use BIM on a majority of their projects.

The most significant development in BIM research took place primarily in the USA, South Korea and China (Zhao, 2017). The U.S already plays a tremendous leadership role in providing innovative technologies and design and engineering services to a global marketplace. The American Institute of Architecture (AIA, 2020) is conducting a study, collecting data from almost 1,000 firms. This essential resource includes the percentage of firms using BIM and energy modeling. The results show that the rising of BIM using from 49% of firms in 2015 to 58% in 2019. In 2019, the American firms that used BIM software, 76% of their revenue coming from projects using BIM (AIA, 2020).

Design visualization continues to be a top use of BIM while sharing models with clients becomes more popular (see Figure 3.12). Half (51%) of firms reported using energy modeling software in 2019.

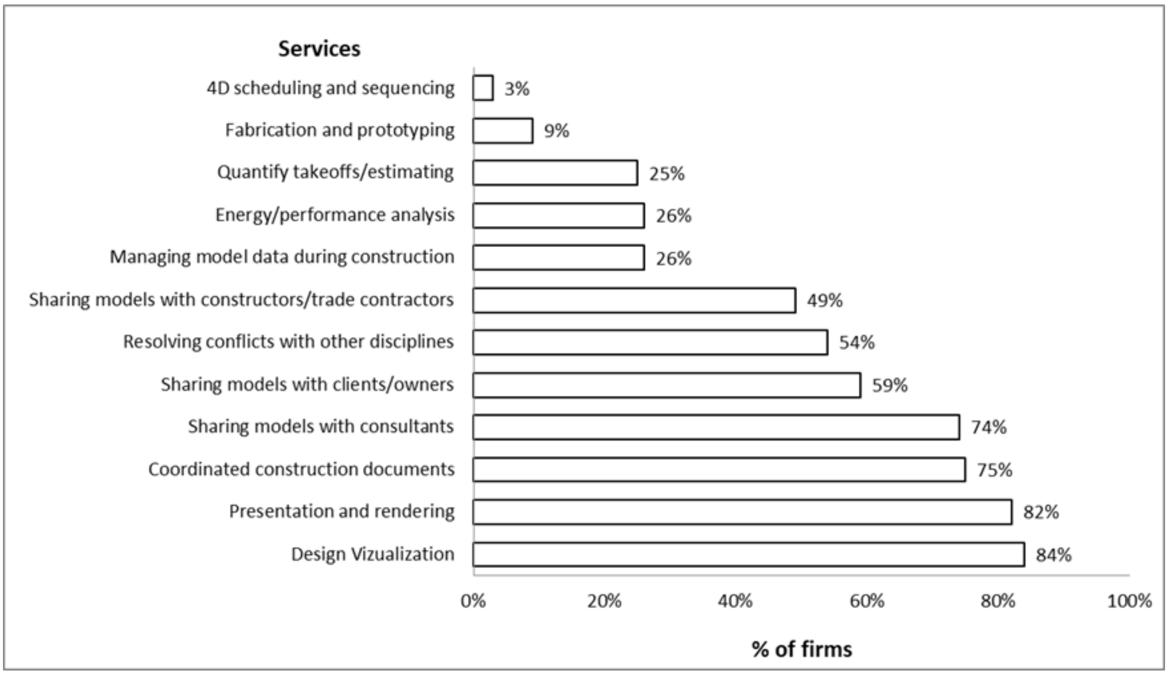

Figure 3.12. Percent of firms using BIM for different services on USA
(Source: AIA, 2020)

BIM is not a panacea for every project and every firm. The BIM adoption might not be suitable for every construction project. These methods were used more often for large and complex projects, such as healthcare projects or projects with high level of uncertainties, than for small and simple projects. The share of firms using BIM software by firm size: 100% of large firms, 88% of midsize firms, and 37% of small firms using BIM for billable work in 2019 (AIA, 2020). Many researches were identified BIM implementation barriers from the viewpoint of different parties of construction projects.

The BIM barriers may not be suitable or be generalized to all countries. Barbosa et al. (2016) highlighted BIM standards development differs from country to country. They are also rapidly becoming mandatory for public projects such in the United Kingdom, who required that all government-procured projects should be what is defined as “Level 2 BIM” by 2016, and COBie became a contractual obligation for deliverables, although there is no date yet set for “Level 3 BIM”. However, in other countries, the BIM use is not even stimulated, let alone guided or required (Barbosa et al., 2016).

Figure 3.13 summarizes the different barriers of BIM adoption in the construction industry, divided in six main categories (see Figure 3.13).

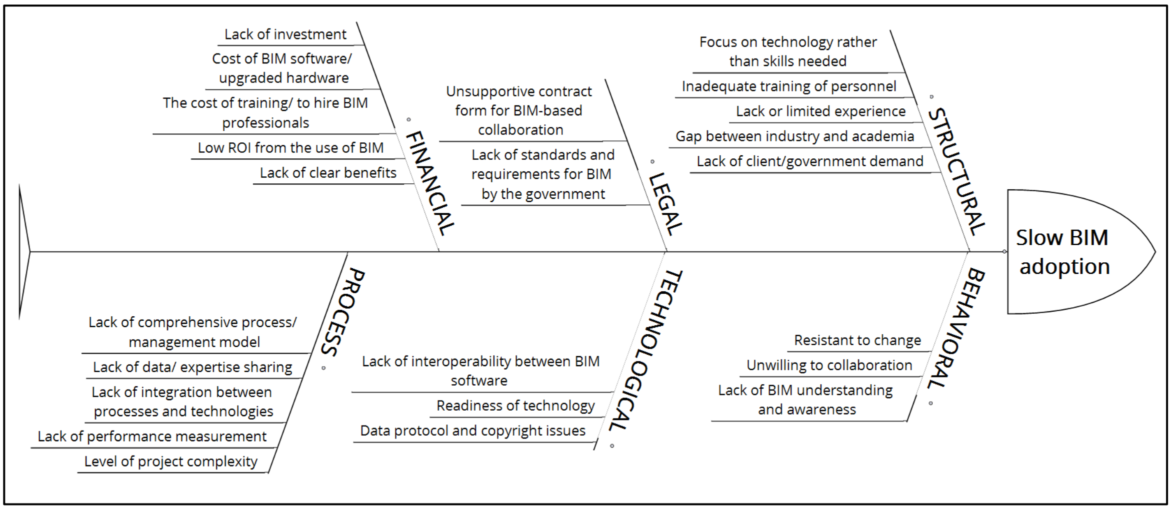

Figure 3.13. Fishbone diagram summarizing barriers related to BIM adoption (Source: author)

3.5 Integrated Project Delivery (IPD)

3.5.1 IPD background

The traditional delivery methods have shown to be inefficient and litigious (Azhar et al., 2014; El adaway et al., 2017). The fragment of traditional approaches and the fights for individual benefits results in delays, increased cost, wastage of materials, and reduction in productivity/quality control (Ashcraft, 2012). Therefore, IPD emerged as an alternative delivery method to reduce the current inefficiencies and wastes of the construction industry and to improve its performance (AIA, 2007). Sustainability and high-performance goals serve as positive drivers of IPD adoption to create interdisciplinary development of appropriate solutions (Sive & Hays, 2009).

AIA and AIA California council (2007) defines IPD as: *"a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction."*

Figure 3.14 represents the current collaborative forms of project delivery. Although these relational modes of project delivery share certain principles with IPD, there are distinct differences in their procedural practices, tools and techniques.

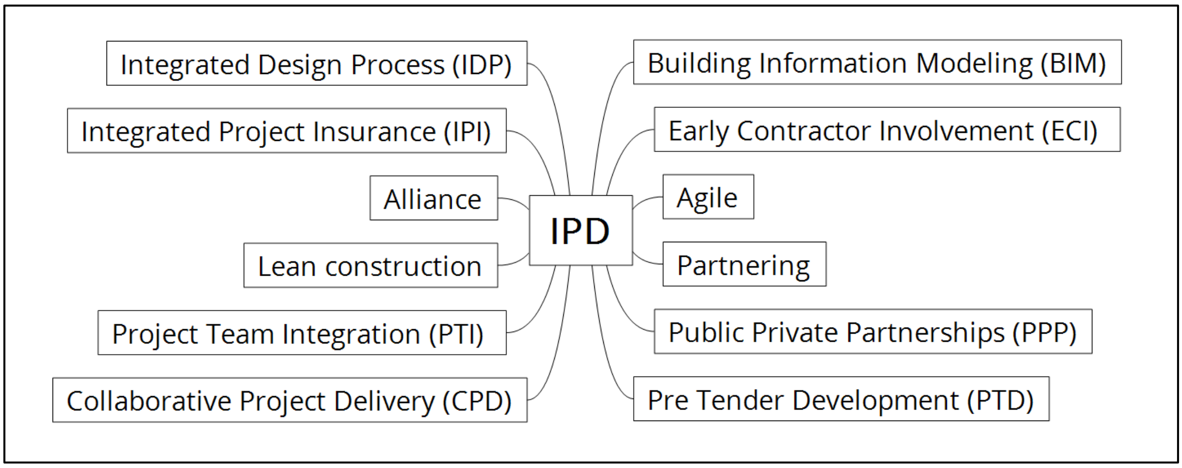

Figure 3.14. Showing the relationship of IPD with other concepts of collaborative arrangements (Source: adapted by author from Coates, 2013)

3.5.2 IPD drivers and enablers

Some authors identify the different drivers and enablers of IPD adoption. Project complexity is one of the key factors in achieving the benefits of deep collaboration and IPD. The project should be significantly complex to justify the increased planning and design costs that come from leading a larger team through these phases of the project (Sive & Hays, 2009). An organization should carefully consider the opportunity for production savings during the construction phase (which is driven by design and construction complexity), and evaluate whether the opportunity provides a reasonable return on investment (cost, schedule, value, etc.) for the increased planning and design costs (KPMG, 2013). Sustainability and high-performance goals serve as positive drivers of IPD adoption to create interdisciplinary development of appropriate solutions (Sive & Hays, 2009). Figure 3.15 summarizes the different drivers and enablers of IPD adoption in the construction industry.

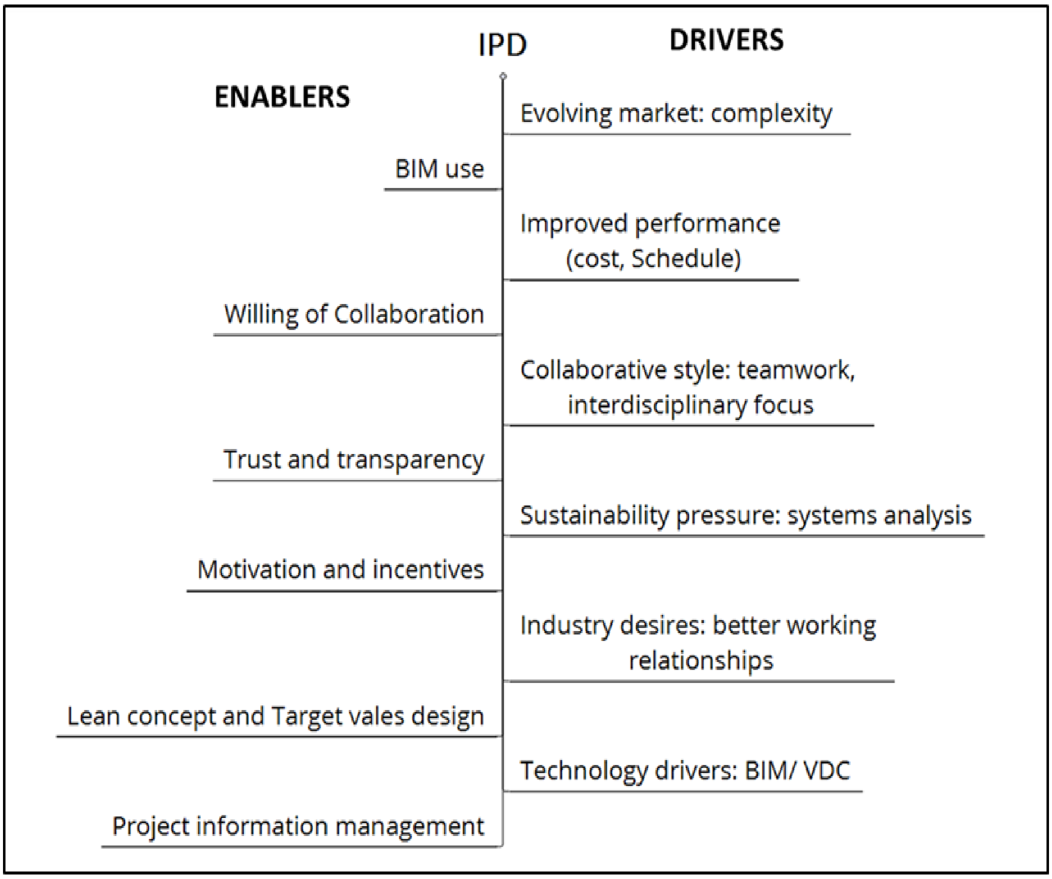

Figure 3.15. Drivers and Enablers of IPD adoption in AECO projects
(Source: adapted by author from Ismail, 2019 and Sive and Hays, 2009)

3.5.3 IPD advantages in the construction industry

IPD principals and elements

Numerous professional organizations and researchers discuss the IPD principles in a range of journals, standards, and white papers. AIA and AIA California council (2007) state that: "*IPD principles can be applied to a variety of contractual arrangements and IPD teams can include members well beyond the basic triad of owner, architect, and contractor. In all cases, integrated projects are uniquely distinguished by highly effective collaboration among the owner, the prime designer, and the prime constructor, commencing at early design and continuing through to project handover*." AIA (2014) proposes drawing a line to distinguish IPD from IPDish and other delivery models that offer some of IPD improvements. 11 IPD essential elements are identified, as well as the 15 key constructs that enable an optimized IPD project include the optimal business model, contractual structures and team behavior.

Figure 3.16 illustrates 21 elements of IPD by Yee et al. (2017), through four categories including contractual/legal principles, behavioral principles, structural principles, technological principles.

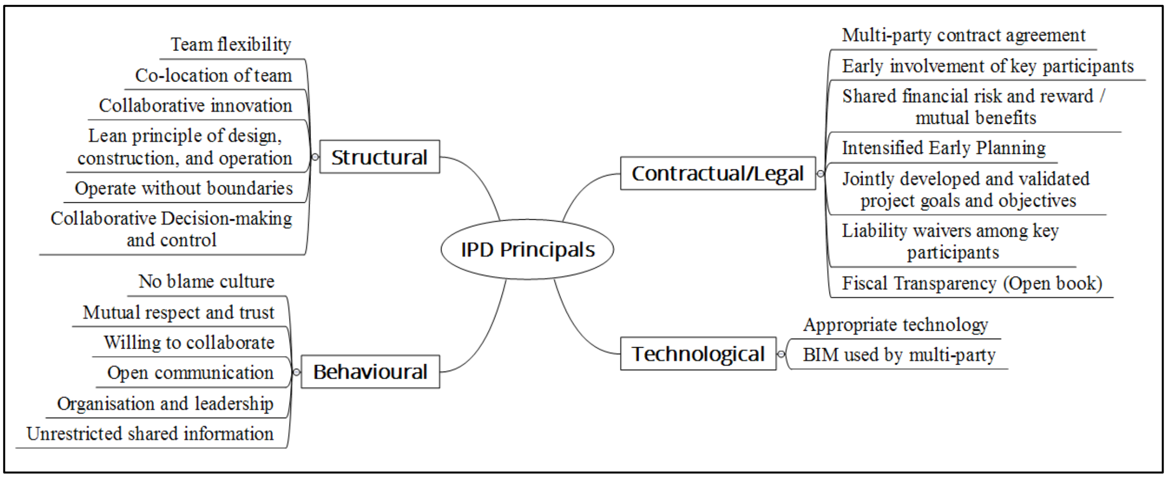

Figure 3.16. IPD principals (Source: adapted by author from Yee et al., 2017)

The IPD arrangement requires each party to have a high level of trust in each member that allows the parties to treat projects as collective enterprises. It allows for the movement of money across traditional commercial boundaries, requires fiscal transparency through open accounting, and reimbursement of project costs to keep contingencies visible and controllable

IPD agreements can provide a commercial framework among key project actors to recognize organizational policies that address both compensation and risk through the implementation of a painsharing/gainsharing compensation model. In the gainsharing approach, the core group collaboratively develops a mutually agreeable estimate of the project's likely maintenance costs and designs a system of financial incentives. Many compensation methods are used to incentivize project collaboration based on the value added by the team. On the other hand, IPD agreement uses many creative ways to promote collective risk management as an alternative to the risk-shifting unitary approach. It helps align commercial interests, supports limiting liability for cost overruns, allows the organization to focus on value-add, and rewards "what's best for the project" behavior. Painsharing typically works through the mechanism of a profit pool, where a portion of the key team member's profit is pooled, supplemented by a share of the cost savings, and they assume the risk for cost overruns. The agreement must include key provisions regarding liability waivers, waivers of consequential damages, and dispute resolution.

Members of the team may agree to limit their liability to each other for losses related to the project, but they are usually jointly liable to third parties for injuries or damages.

Differences between IPD and traditional contracts

Many researchers explore the differences of the IPD and the traditional delivery approach (Kahvandi et al., 2017). Table 3.2 summarizes the main differences between them.

Table 3.2. IPD and Traditional Project Delivery – A Comparison
(Source: adapted by author from AIA and AIA California Council, 2007; Shendkar, 2017)

Categories		Traditional Project Delivery	Integrated Project Delivery
Contractual	Agreement	Standard agreements; Encourage unilateral effort; Goals and objectives are misaligned.	Encourage and support multi-party agreements; Goals and objectives are aligned through parties.
	Compensation / Reward	Individually tracked; Minimum effort for maximum return, First-cost based (mostly).	Team success tied to project success; Value engineering –based.
	Risk	Higher; Individually managed; Transferred as far as possible.	Lower; Collectively managed; Appropriately shared.
	Process	Linear; Distinct; Segregated.	Concurrent and multi-level; Iterative
	Measures	Budget outcomes; Activity; Standards; Productivity.	Related to propose; Capability and variation; Key performance indicators (KPIs).
Structural	Teams	Fragmented; Silo based; Assembled on “just-as-needed” or “minimum-necessary” basis; Strongly hierarchical; Controlled; Minimal owner involvement is required; Predefined role or responsibility.	An integrated team unit composed of key project stakeholders; Assembled early in the process; Collaborative; Providing active input and flexible to form teams.
	Management ethos	Top down: manage the program, manage the contract, manage people, and manage budgets.	Outside-in: act on the system to improve it.
	Performance matrix	Schedule / Cost / Quality.	Cost /Schedule / Quality / Sustainability
	Decision Making	Late; Separated with work.	Early; Integrated with work; Based on data
Behavioral	Culture	Blame; Finger pointing; Exploiting loopholes.	Stakeholder trust and respect; Innovation; Mutual respect between parties
	Data Sharing	Allowed; Information hoarded; Very selective.	Encouraged; Information openly shared.
	Team knowledge	Work overload leads to knowledge waste; Knowledge and competence silos; Knowledge gathered “just-as-needed.	Earlier work efforts lead to earlier knowledge attrition; Earlier contributions of knowledge and expertise
Techno	Communications (technology)	Segmented tools.	Collaborative tools.
	Modeling (technology)	Paper-based; 2 dimensional; Analog	Digitally based; Virtual; BIM (3, 4 and 5 dimensional).

IPD changes the paradigm often seen in construction projects where the consultant and general contractor work for the owner as separate teams with often conflicting priorities. Pishdad-Bozorgi (2012) presents the key differences from the standpoints of behavioral/ contracting / and technological approaches. However, Viana et al. (2020) cited five major areas of IPD that represent the main modifications from the traditional methods: *contract, process, information & modelling, team,* and *communication* categories. The IPD model aligns the interests of the parties; the owner, consultant and general contractor form a single team at the beginning of the project with mutually agreed upon goals and objectives that form the basis for project success and compensation. This coordinates the work among the three parties and the project moves away from the discrete tasks performed by the consultant or contractor to be understood as a large, predictable production system that seeks to eliminate errors, waste and redundancy. With IPD, project success and compensation are linked, so all project participants have a shared financial interest in seeing the project delivered on time, on budget, on scope and without claims.

3.5.4 IPD process and framework

Since IPD adoption is founded on a shift in mindset and practice, many authors have strived to create a roadmap for integration through the development of IPD framework to define the relationship between the project participants and the process that guide their actions (El-adaway, 2017; Fischer, 2014). Ashcraft (2012) suggests a Micro-Framework made up of three key concepts: Team design, Work design, and Information design (see Figure 3.17).

The Micro-Framework consists of the structures, protocols, and evolving processes during the project that should be developed by the team based on their capabilities and needs, to execute it efficiently. This framework is regulated and restricted by a contractual framework (Macro-framework), which sets the business and legal structures of the project.

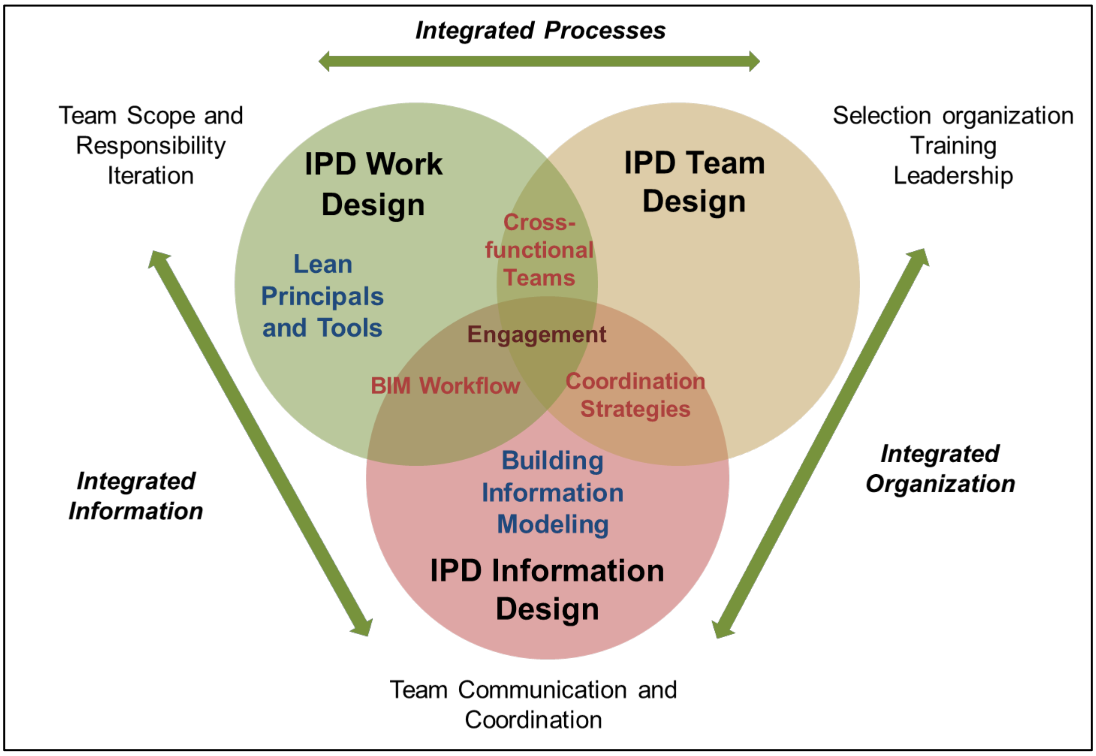

Figure 3.17. The three key components of the IPD process (Source: Machado et al., 2020)

In an IPD approach, the team members are aligned with the project's operating system and culture. All key participants must subscribe to collaborative efforts towards meeting clear goals over the individual interest, with a basic level of trust among them to form a kind of Virtual Enterprise Paradigm (Neve at al., 2017). The IPD projects involve some form of integrated project leadership where decisions are made by consensus (NASFA et al., 2010). As such, the design work in IPD projects is recognized while the relational contracting members get together at the earliest stages, forming a cross-functional and interdisciplinary team with clearly defined and synchronized roles and responsibilities. As such, they can look at alternative outline design solutions and value engineering on a collaborative, multi-level, and iterative basis, where they define the connection point between subsystems and negotiate their interfaces (El-adaway, 2017). That requires an Information system to provide broad access to team members and focus on how the information will be created, exchanged and managed (AIA, 2007; Sive & Hays, 2009).

Nevertheless, the highly cited Simple Framework of Fischer et al. (2014, 2017) combines four key elements: integrated organization, process integration, Integrated Information and finally integrated system to create a high-performing building through virtual design and construction (VDC).

3.5.5 IPD integration levels

IPD employs multiple strategies to achieve collaborative and high-performing teams, and cannot be reduced to a contract structure or management formula (AIA, 2012). IPD is not a 'one-size-fits-all' approach (KPMG, 2013). AIA (2012) rearranges the IPD characteristics into two categories, IPD "markers" and IPD "strategies". IPD markers represent the characteristics unique to IPD projects consisting on: *relational contracts, protection from litigation, joint validation of goals and target, collaborative decision making, open communication,* and *risks identified and accepted early*. However, IPD strategies stand for the tactics or strategies used, commercial, environmental, social, or technological, such as the early involvement of key participants and BIM use to support the IPD process.

Pishdad-Bozorgi (2012) considers four elements as the required features of an IPD contract including: commitments of participant to IPD behavioral principles; early involvement of key actors; a single multi-party contract, or a bonding/bridging IPD agreement between the owner, designer, and constructor; as well as shared financial risks and benefits. However, the other elements are considered to further increase the level of integration of an IPD process.

Therefore, different IPD collaboration levels are required (Sive & Hays, 2009; NASFA et al., 2010). The IPD considered as a philosophy, where using incomplete models of integration to a variety of contractual arrangements (Sive & Hays, 2009; NASFA et al., 2010). We illustrate below some of the key differences between different IPD approaches (see Table 3.3).

Due to that many buildings and infrastructure projects have begun to apply the IPD principles or as a delivery model (Shou et al., 2015), the level of IPD integration should be determined after careful consideration as some characteristics like delivery model like may affect the level of integration that can be achieved, whether it is legislative restrictions, policy limitations, or cultural barriers could affect integration level achievement (AIA, 2007; NASFA et al., 2010).

Kent and Becerik-Gerber (2010) interviewed 15 construction industry professionals, all with knowledge and/or experience with IPD, and conducted a web-based survey designed with a broad range of construction industry professionals to highlight the current state of IPD use and future adoption. The results showed that professionals are more concerned on the application of contractual principle. In addition, they believe that design/build is the most contractual agreements to which IPD can be applied, and CM at risk came in second with both groups.

Table 3.3. Collaboration levels of IPD in construction projects
(Source: adapted by author from NASFA et al., 2010; Sive and Hays, 2009)

	Traditional	**IPD**		
Level of Collaboration	N/A	Level One « Typical » Collaboration	Level Two « Enhanced » Collaboration	Level Three « Required » Collaboration
	Lower ◄			► Higher
Philosophy or delivery method?	Traditional Delivery Method	IPD as a Philosophy	IPD as a Philosophy	IPD as a Delivery Method
Also know…	N/A	N/A	IPDish, IPD lite, Hybrid IPD	Pure IPD, Real IPD
Nature of Agreement	Transactional	Transactional	Transactional	Relational
Team organization	-Hierarchical and Sequential	-Behaviors and attitudes to collaborate	-Contract language requiring collaboration -Earlier hiring/ participation of some areas of expertise	- Single agreement that contracts collaboration -Early involvements of key participant
Decision-making	Hierarchical	Encourage team decision making, with the final decision by the owner	Team decision making, with final decision by the owner	Mandate joint decision making
Risk/Reward	Separate risk/reward pools	Limited team risk sharing	Optional team risk sharing	Risk and rewards sharing
Tools and Process	-Linear information -Segmented tools -Meetings	- Multidisciplinary coordination workshops	-BIM use -Charrettes -Co-location of team -Lean principles and techniques	-Shared models -Set-based design -Co-location of team -Lean principles and techniques

3.5.6 Current state of IPD adoption, challenges, and barriers

Like BIM (see Section 3.4.5), IPD may not be suitable for every construction project (Xie & Liu, 2017). The IPD method has been used more often for large and complex projects, such as healthcare projects or projects with high uncertainty, than for small and simple projects (Xie & Liu, 2017). The high collaboration environment leads to better performance and results. From the interviews, the researchers conclude that projects unsuitable for IPD were those where the driving motivation of the owners was solely the lowest initial cost.

IPD has been successful on hundreds of projects in the U.S., but is relatively new to other countries, such as Canada and UK, with several high-profile projects completed in the healthcare and education fields in recent years. All of these projects have been completed on budget, on schedule, and with value added through increased programming or better building systems.

Although many researchers have highlighted the benefits of the IPD method, there is a large untapped potential of IPD integration, and adoption is still limited and in its infancy (Shou et al., 2015; Azhar, 2014). More evidence is needed to support the full adoption of IPD as a project delivery method (Yee et al., 2017; Kent & Becerik-Gerber, 2010). Ghassemi and Becerik-Gerber (2011) identified four types of barriers: Legal, Cultural, Financial, and Technological limitations due to legal challenges of ownership, liability and interoperability.

Ghassemi & Becerik-Gerber (2011) identified four types of barriers: Legal, Cultural, Financial, and Technological. which represented mainly in: lack of appropriate legal structure, including risks allocation and insurance; the unwillingness of the industry to vary from its traditional methods; compensation and incentive structures commensurate to the unique characteristics of the project and its participants; and technologies limitations due to legal challenges of ownership, liability and interoperability.

Similarly, Yee et al., (2017) also divided IPD implementation barriers in four categories: Contractual, Behavioral, Structural, and Technological. They stressed that the main obstacles in the Iranian context are: the lack of an IPD insurance product, the lack of a new contractual agreement that includes all the criteria necessary for true integration, and the need for a protocol and copyright to secure and protect the rights and liability of the parties.

Azhar et al. (2014) mention that the most of the few project delivered with IPD are done under private sector. The authors highlight the factors of influence and limits which hinder the implementation of IPD in public sector, and reorganized them in legal, organizational and technological issues. The results designate that there are issues require changing procuring laws related to public construction, further others could be achieved through utilizing tools that are already in use, including BIM technology where it has been discussed to improve these barriers.

Ebrahimi and Dowlatabadi (2019) identify challenges to IPD implementation based on 39 semi-structured interviews with key project stakeholders (owners, builders, and designers), experienced in both IPD and non-IPD projects in the U.S. and/or Canada. Over 90% of respondents reported challenges in the following areas: (1) maintaining a collaborative environment, (2) managing the operational environment, (3) selecting the right team, (4) integrating IPD notions, and (5) making informed and well-timed decisions

Figure 3.18 summarizes the different barriers of IPD adoption in the construction industry, divided in six main categories (see Figure 3.18).

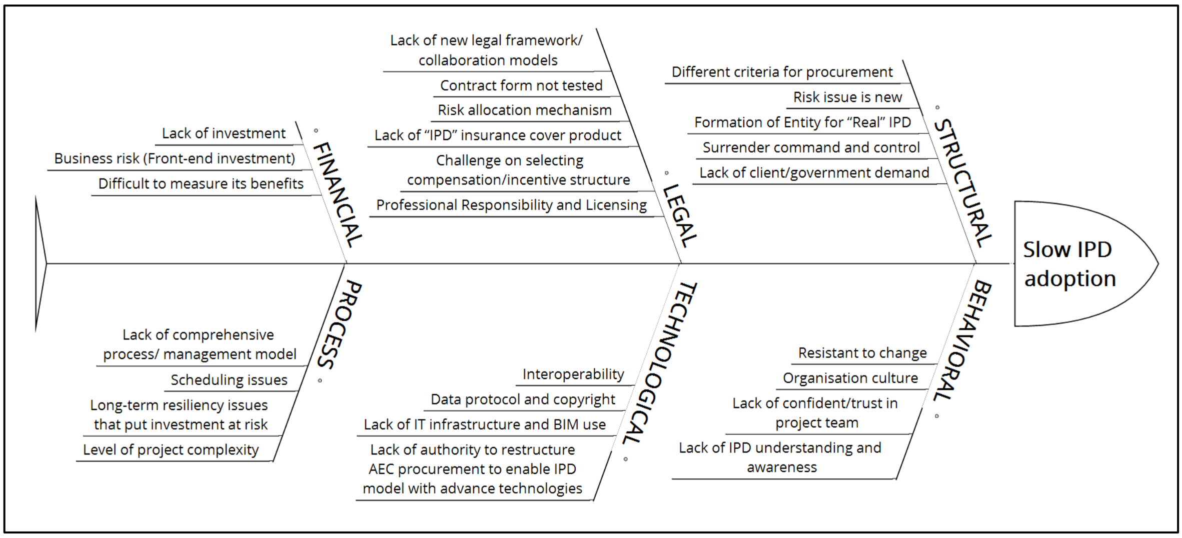

Figure 3.18. Fishbone diagram summarizing barriers related to IPD adoption (Source: Author)

The industry personnel awareness and appreciation are dissatisfying (Yee et al., 2017). There is a high level of uncertainty about the possibility of creating this environment type, more evidence is desired to fully adopt IPD as a project delivery method (Kent& Becerik-Gerber, 2010). To expand the IPD use, the education system should take a more collaborative approach in teaching and researching IPD methods (Xie & Liu, 2017; Kent & Becerik-Gerber, 2010). In addition, collecting best practice of case studies would help professionals who are not familiar with IPD to gain certainty about how gains have played out in both successful and unsuccessful project examples (Kent & Becerik-Gerber, 2010). In addition, Xie and Liu (2017) suggest beginning with simple and familiar project to discover IPD method implementation. In addition, the authors concluded that there is a large untapped potential of IPD adoption and more evidence needs to be sought to prove this.

Ebrahimi and Dowlatabadi (2019) see the challenge of successful IPD not only in educating industry on the principles and concepts, but also a successful IPD requires a cultural shift in the AEC industry and effective strategies development for project planning, allocation, and management. The authors suggest that universities should consider a capstone project implementation approach in which design and engineering students collaborate to complete projects for real or imagined clients (Ebrahimi & Dowlatabadi, 2019). Ghassemi & Becerik-Gerber (2011) identified the best IPD practices and provided lessons learned to practitioners through nine case studies in order to overcome these barriers including: organizational anticipation, training of individuals, establishing a collaborative framework within IPD teams, Selecting the right team early and based on quality, reconciling project goals and setting procedures for problem solving and resolution (Ghassemi & Becerik-Gerber, 2011). However, Ebrahimi and Dowlatabadi (2019) suggest four key ideas to improve IPD implementation from detailed analysis of stakeholders' experiences. These ideas consisting on: (i) focusing on partnership capacity when selecting IPD teams; (ii) empowering IPD team members and establishing a flatter organizational structure; (iii) bridging IPD elements and implementation knowledge gap; and (iv) balancing efficient resource allocation and collaboration. More generally, this study shows that IPD cannot succeed on its own. It requires a cultural change in the AEC industry and a new approach to project planning and management.

3.6 Summary

More sophisticated and advanced project delivery methods, like BIM and IPD, have emerged to make the construction process more productive and efficient. The adoption of BIM and IPD is a paradigm shift for the construction supply chain. The application of these advanced methodologies improve the construction process and eliminate weaknesses of current project delivery systems, that will surely shape the way of work for years to come, to get into the mindset of trust and respect required in IPD project. The next chapter explores, through literature review, the IPD and BIM simultaneous use for heritage renovation.

CHAPTER IV: IPD AND BIM SYNERGIES FOR THE SUSTAINABLE RENOVATION OF HERITAGE BUILDINGS AND DEVELOPMENT OF AN ANALYTICAL FRAMEWORK FOR QUALITATIVE COMPARATIVE ANALYSIS (QCA)

This chapter investigates the application of IPD and BIM and their synergy for heritage renovation projects. Then, this chapter presents the development of the analytical framework, based on literature survey, for conducting a comparative case study research using a coding scheme.

4.1 Synergies between IPD and BIM

4.1.1 BIM and IPD two innovative approaches: the convergences and divergences

The two innovative project management methods IPD and BIM are driven by advances in technology and the redrawing of social relationships (Rowlinson, 2017) (see Table 4.1).

Table 4.1. IPD and BIM: convergences and divergences (Source: Author)

<table>
<tr><td rowspan="6">Convergences</td><td>Definition</td><td colspan="2">BIM and IPD are a convergence of technologies, business process innovation and interrelating policies</td></tr>
<tr><td>Benefits</td><td colspan="2">Managing the critical information
Collaboration among project participants
A reliable basis for decisions throughout the full lifecycle of a building</td></tr>
<tr><td rowspan="3">Adoption</td><td colspan="2">Cultural and organizational change</td></tr>
<tr><td colspan="2">Their adoption might not be suitable for every construction project and every firm</td></tr>
<tr><td colspan="2">They are not a ‘one-size-fits-all’ approaches</td></tr>
<tr></tr>
<tr><td rowspan="3">Divergences</td><td></td><td>BIM</td><td>IPD</td></tr>
<tr><td>Delivery method</td><td>Digital delivery method around a unique and shared platform</td><td>Alternative delivery method based on a relational multiparty agreement</td></tr>
<tr><td>Adoption</td><td>Wide adoption
Benefits are currently not really realized and should continue to struggle to achieve lifecycle BIM uses</td><td>Limited adoption, in the initial stages
The need for more proofs to justify the absolutely embrace IPD as a project delivery system</td></tr>
</table>

Similar to the classifications defined by Sarhan et al. (2019), the studies related to IPD or/and BIM use four research purposes and approaches:

- *Conceptual investigation:* discusses the theoretical development of BIM or/and IPD, and focus on the development of theory.

- *Theoretical integration:* discusses the feasibility and benefits of integrating BIM or/and IPD and possibly other techniques. The focus is on application (i.e. tools and processes).
- *Practical investigation:* examines the potential of using BIM and IPD to solve specific industry problems.
- *Empirical implementation:* examines implementation and quantifies the outcomes of BIM or/and IPD implementation.

4.1.2 IPD merged within BIM

The organizational changes required to effectively implement BIM are constrained by current contractual arrangements. Therefore, IPD is proposed as the best project management system to force BIM functionalities and facilitate the adoption of BIM in construction projects (AIA, 2007). IPD team achieves a clear understanding regarding BIM and takes advantage of the tool's capabilities. The IPD project team agrees on how the model will be developed, accessed, and used, and how information can be shared between models and participants. Without such a clear understanding, the model may be used incorrectly or for an unintended purpose (Xie & Liu, 2017). In addition, IPD contracts are one of the most effective ways to manage the technical and legal risks of BIM (Kent & Becerik-Gerber, 2010; Azhar, 2011).

Contrariwise, the authors argue the integration requirement in IPD projects that can be effectively accomplished by BIM implantation to achieve better decision-making and remove its implementation barriers to deliver high-performance buildings (Azhar et al., 2014; Fischer et al., 2014). Moreover, it can play an important role to reap the potential benefits of Lean Principals (Sacks et al, 2010; & Eastman et al., 2010) and provides great value to public IPD owners in the exploitation phase (NASFA et al., 2010). Although BIM is widely used in IPD projects, BIM or advanced information technology applications are not a prerequisite for IPD.

Figure 4.1 illustrates the main conceptual paradigm that highlighting in particular the bidirectional relationships between BIM and IPD and their role in the improvement of construction project performance.

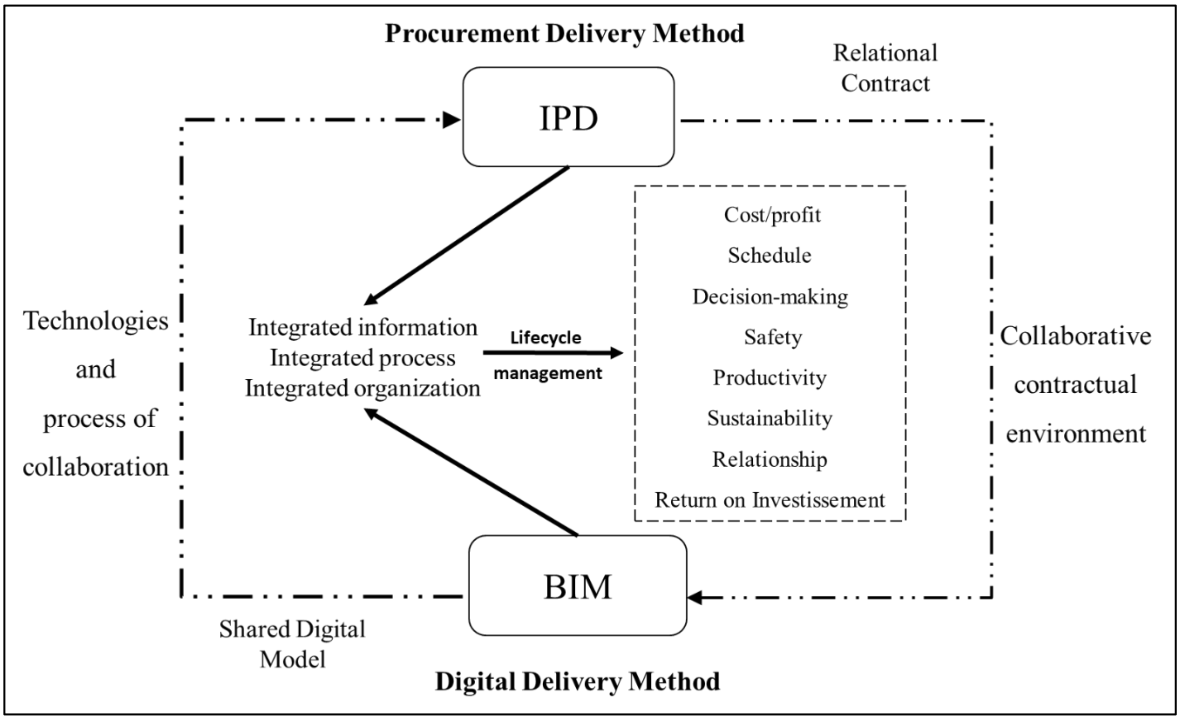

Figure 4.1. Benefits of IPD and BIM synergy in project performance
(Source: Author)

4.1.3 Integration of BIM, IPD, Lean construction, and sustainability

IPD, BIM, and Lean Construction (LC) are three of the trending concepts in the construction industry that have proven to be very value-added and forward-looking approaches (Ashcraft, 2012). LC creates the possibility to achieve improved outcomes of the final product, considering the economic, social, and environmental aspects of the building (Fischer et al., 2014), its operating system seeks to reduce inefficiencies, wastes and maximize the values perceived for the client, from the significant advance of workers' productivity to the final quality of the product (Sacks et al., 2010; Jaaron & Backhouse, 2012). Figure 3.17 in Section 3.5.4 illustrates how BIM and LC are incorporated into the IPD process to achieve its success.

Several studies have already tried to address the synergy between the aforementioned approaches using a bi-dimensional view (BIM and LC, or IPD and LC). Cheng and Johnson (2016) explore the powerful complementary strength of IPD and LC to support success. They conclude that IPD sets the terms and provides the motivation for collaboration, and LC provides for teams the means to improve their performance and achieve project goals (see Figure 4.2).

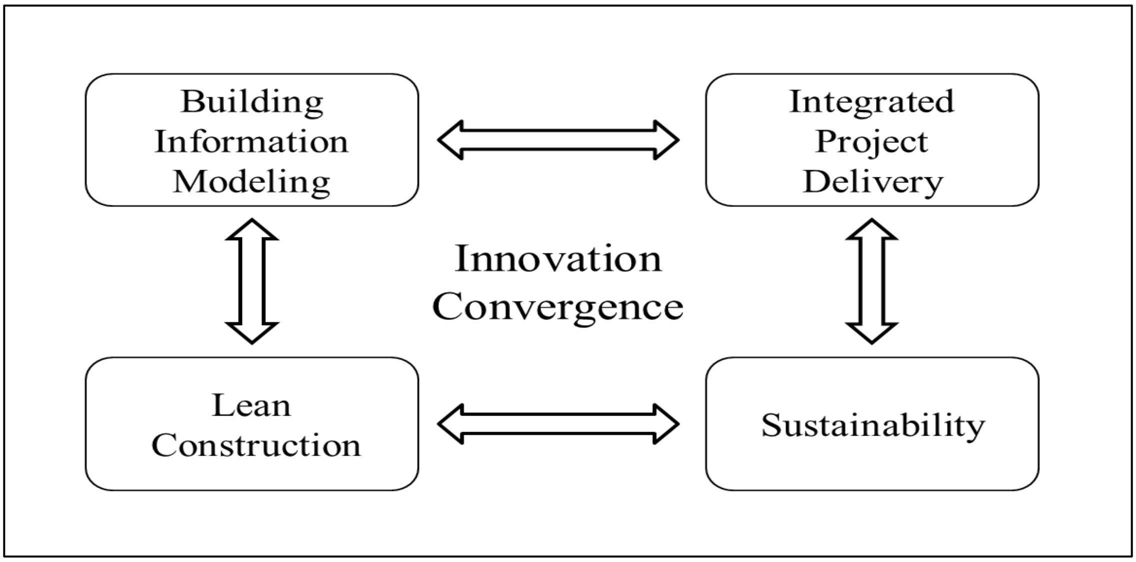

Figure 4.2. Convergence of related construction industry trends
(Source: adapted by author from NASFA et al., 2010)

Nevertheless, limited studies have looked at the intersection between all the three of them. On using qualitative/quantitative methods, Nguyen and Akhavia (2019) evaluate this synergy in terms of cost and schedule performance measures. The results have shown considerable effectiveness in terms of time performance whereas the effect on cost performance was not as significant. In addition, collaborative supply chain management could significantly improve proper communication (Lostuvali et al., 2012) to reduce the number of conflicts, increase the efficiency of the design and construction process, reduce errors. On the other hand, some companies and researchers conduct together studies to measure the final productivity of projects by trying the IPB/BIM/LC framework to make improvements in the future (Hunzeker & Selezan, 2015).

4.1.4 Potential advantages of BIM and IPD

Many studies and documents highlight several connections and the benefits of using BIM and IPD together (Kahvandi et al., 2017). Migilinskasa et al. (2013) and later Fischer et al. (2014) discuss that BIM adoption supported by the integrated agreement, can remove collaboration barriers, and enables the project team to function as a virtual organization within the search for better project delivery solutions and alternatives rather than the fights for individual benefits. IPD and BIM synergies enable the creation of a virtual integrated/collaborative supply chain management as a kind of Virtual Enterprise Paradigm (Neve et al., 2017). The processes and communication procedures required for collaboration were detailed in the IPD contract and key BIM documents for all interdisciplinary team members (see Figure 4.3). IPD design process through BIM allows to make changes and provide optimal solutions, at an early design stage, to deal with the project complexity at a much lower cost than is otherwise possible (see Figure 1.1 in chapter 1).

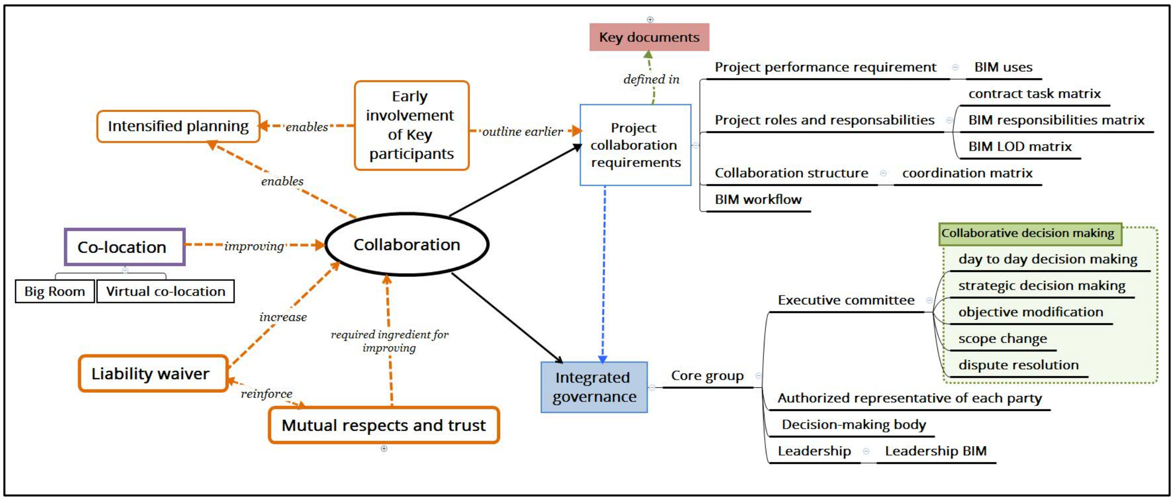

Figure 4.3. Conceptual paradigm representing the collaboration mechanism and decision-making in project using IPD+BIM framework (Source: Author)

As seen in Figure 4.4 below, the IPD team jointly develops a commitment to the overall project based on the owner's requirements and focusing on the "best for the project" basis. The broad experience of the diverse team benefits the target value design. The project team clearly defines achievable goals and benchmarks to measure them. These goals can take into account the interests of selected third parties and comply with specific regulations.

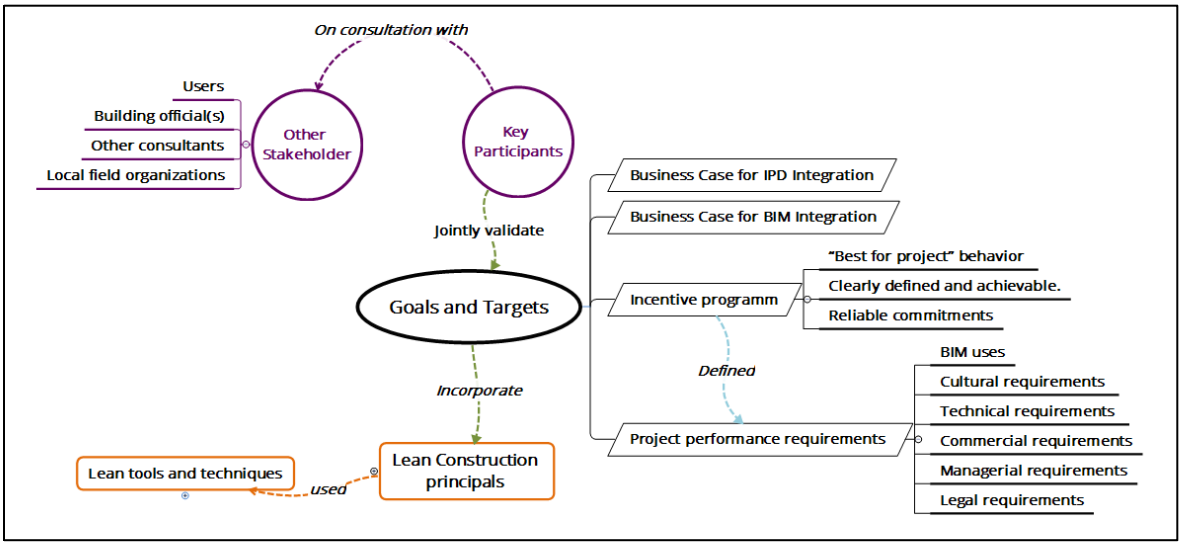

Figure 4.4. The development of project goals and targets in IPD projects (Source: Author)

Based on the current IPD+BIM implementation experience in new construction and existing buildings, lessons learned from best practice examples can be extracted (AIA, 2012; Cheng, 2015). Besides, evidence of success to achieve sustainable projects within a high performing and collaborative teams is important, but that does not currently exist to a great extent within the literature (Ilozor & Kelly, 2012; Nawi et al., 2014). The integrated and collaborative supply chain management through a shared platform can provide optimal solutions, at an early stage, for the current construction projects issues and deal with their complexity (Fakhimia et al., 2016). It could significantly enhance the proper communication for efficient environmental performance analyses and sustainability-enhancement (Wong & Fan, 2013), reduce the confusion between the project participants on supporting the decision-making process (Nawi et al., 2014), and therefore, reducing errors and assuring cost and time optimization (Becerik-Gerber et al., 2012; Ilozor & Kelly, 2012).

The project team should be willing to share information throughout the project duration. Information systems should provide broad access for team members by default. All parties should have access to the BIM models, reports, asset data, and any other required information at appropriate intervals as defined in the BIM standards. This often requires the establishment of a file exchange website or other collaboration software specifically designed for file sharing. The free exchange of data required in IPD and the limited liability among team members where collaboration is confidential allows them to feel secure in sharing information.

4.2. BIM adoption in heritages

4.2.1 3D scanning and photogrammetry

Recently, the BIM field has become an area of significant attention in the cultural heritage projects within the developed 3D laser scanning and photogrammetry. BIM technology generates a new development of integrated and efficient information management for renovation processes due to its ability to store semantically related information to promote the distribution of building intangible values during its lifecycle (Angelini et al., 2017). In recent years, numerous researches have proposed a methodology to link heritage BIM and various digital technologies and simulations, especially laser scanning and photogrammetry, for the visualization, analysis and documentation of the complicated edifices remotely, efficiently and accurately in contrast to the previous surveying techniques (Logothetis et al., 2015). Zhao (2017) considers laser scanning as a hot topic in BIM research. Laser scanning capture dense 3D measurements of the as-built condition of a facility, and can manually process the resulted point cloud to create an as-built BIM (existing spatial condition model) (see Figure 4.5).

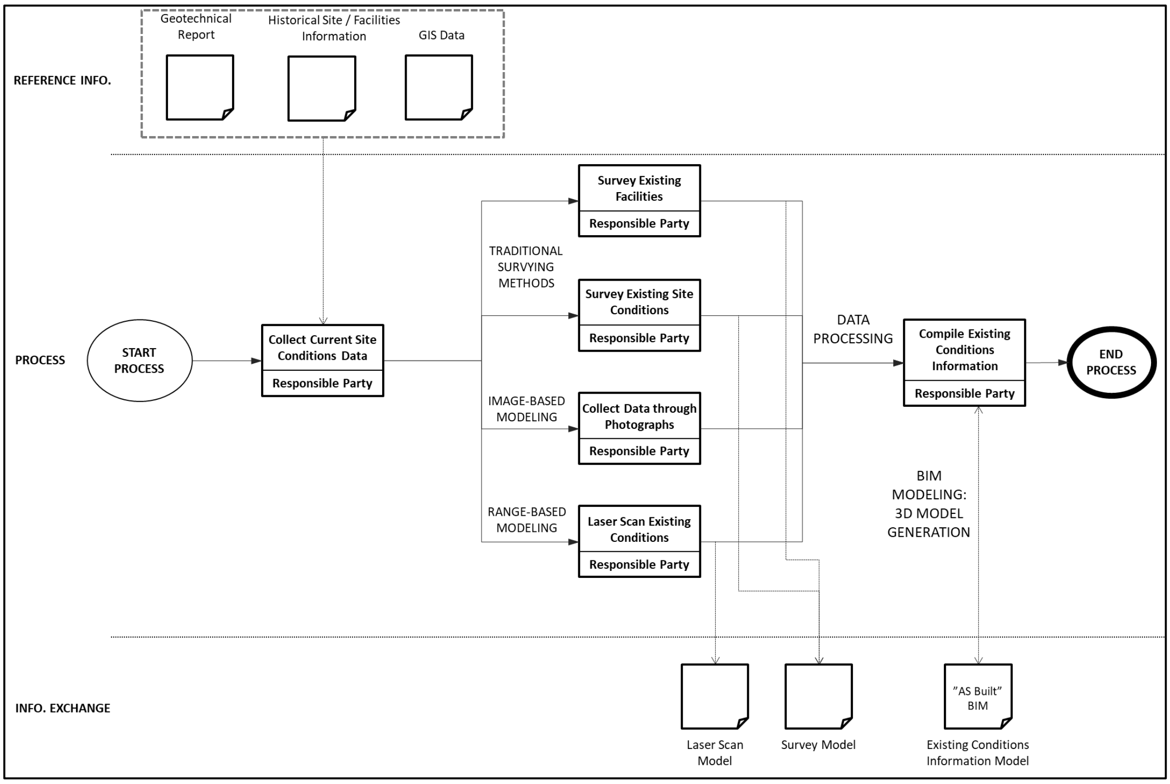

Figure 4.5. Systematic overview of surveying methodologies and the construction process of as-built BIM model (Source: Author)

4.2.2 BIM adoption in existing building projects

While BIM processes are established for new buildings, the majority of existing buildings are not yet maintained, renovated, or deconstructed using BIM. The promising benefits of efficient resource management motivate research to overcome the uncertainties of building condition and poor documentation that are prevalent in existing buildings (Volk et al, 2014).

BIM implementation in existing buildings faces other opportunities and challenges. Matějka et al. (2016) discuss the potential benefits of BIM integration in later project life cycle phases through three simple case studies. BIM allows easier data transfer from the BIM model to the CAFM system, a possible way to obtain live as-built documentation for future use from the beginning of any construction-related project, and a possible way of future use (i.e., moral age extension). Potential benefits of using BIM in Facilities Management (FM) appear to be significant, e.g., as valuable as-built documentation, maintenance of warranties and service information, quality control, assessment and monitoring, energy and space management, emergency management, or retrofit planning (Barbosa et al., 2016; Pärn et al., 2017). Renovation or deconstruction processes could also benefit from structured, up-to-date building information to reduce errors and financial risks, e.g., through deconstruction planning and sequencing, cost estimation, debris management, optimization of deconstruction progress tracking, or data management (Barbosa et al., 2016).

BIM creation process can be distinguished between new and existing buildings due to the different quality of building information, availability of information, and functionality requirements. Volk et al. (2014) argue the hard BIM implementation in existing buildings due to the challenges of the high modeling/conversion effort of captured building data into semantic BIM objects, updating information in BIM, and dealing with uncertain data, objects, and relationships in BIM that occur in existing buildings. Despite rapid developments and spreading standards, challenging research opportunities arise from process automation and BIM adaptation to the requirements of existing buildings (Volk et al., 2014).

Existing buildings without pre-existing BIM face significant challenges in automated data capture and BIM creation. Captured and processed building data is used to recognize building components and their properties relevant to the required functionalities. Object recognition includes object identification, extraction of relational and semantic information, and treatment of occlusions and remaining blurs (Barbosa et al., 2016). Object recognition methods and tools differ based on the geometric complexity of the building, the level of detail required (LoD), and the acquisition method, data format, or processing time used. Research approaches try to further improve LoD and recognition rates as well as the handling of data uncertainty by statistical (thresholds), contextual (semantic networks, relations) or interactive (machine learning) methods (Volk et al., 2014).

4.2.3 BIM uses in heritage sector

Historic England (2017) defines Historic BIM as a multidisciplinary process that involves the contribution and collaboration of professionals with diverse skill sets. Simeone et al. (2014) investigated the potential impact of BIM adoption in heritage renovations in order to enhance the collaboration among specialists and knowledge management. The authors conclude that similar to new construction projects, the BIM models ensuring the availability, accessibility, consistency, and coordination of all the knowledge related to a historical artifact and shared by the different actors involved in the investigation/conservation process; which support the decisions on developing the relevant interventions (Simeone et al. 2014). In the study by Cheng et al. (2015), the authors argue the importance of identify emergencies, schedule intervention activities, and plan routine operation and repairs artifact to raise the production, effectiveness, and accurateness of a project. Access to as-built heritage facilitates interpretation of the building's condition, monitoring of its changes, and documentation of any investigation and intervention in the proposed model.

The initial BIM development in heritage management can be related to the existing BIM experience from the new construction industry. The application of BIM in heritage interventions has led to other terms that have been used almost interchangeably: BIM for heritage, BIM for historic buildings, Heritage Building Information Modeling, and Built Heritage Information Modeling/Management (BHIMM) (Historic England, 2017). The BIM benefits for heritage preservation project management are not currently covered. Almost all research has been written about the potential benefits of using BIM for digital building documentation (Pocobelli et al., 2018, page 06). BIM generate a digital model for the preservation process because of its ability to store interrelated semantic information on promoting the dissemination of a building's intangible values during its life cycle (Angelini et al., 2017). However, BIM effectiveness is subject to greater conversations. It is depending on the challenges of the high effort of modeling/converting captured building data into semantic BIM objects, and the variety/complexity of heritage building components that are not representative in current typical BIM software libraries, but also depending on the level of detail required to perform engineering/design analyses (López et al., 2018; Pocobelli et al., 2018). In addition, few studies have addressed the use of BIM to manage the overall intervention design and renovation processes, such as the generation and assessment of various design alternatives. In addition, some published prototypes with limited use report the distinctly different requirements of BIM in these projects (Angelini et al., 2017; Arayici et al., 2017).

Among others, decision support is a crucial topic in heritage renovation. It is observed that digital technologies such as decision support systems are still at a formative stage, while prototypes and applications are being developed for widespread use in heritage renovation. For instance, Gigliarelli et al. (2017) developed a holistic and multi-scalar methodology for energy intervention at a historic center and buildings of a town in southern Italy. The authors proposed a decision support systems (DSS) using a Multicriteria Analysis (MCA) tool (the Analytical Hierarchy Process) based on four key criteria: economic affordability, compatibility with restoration principles, energy efficiency and environmental sustainability. The proposal was used to evaluate and select the best retrofit solution for a historical pilot building among various alternatives, involving experts of the research team and stakeholders. However, the authors highlight a number of limitations still present in the interoperability between software.

4.2.4 BIM platforms for heritage building

3D virtual modeling of heritage building is carried out in different ways and with different approaches, according to different objectives, level of automation, level of segmentation, etc. Through a literature review, López et al. (2018) classified the tools used for heritage modeling in four categories (see Figure 4.6).

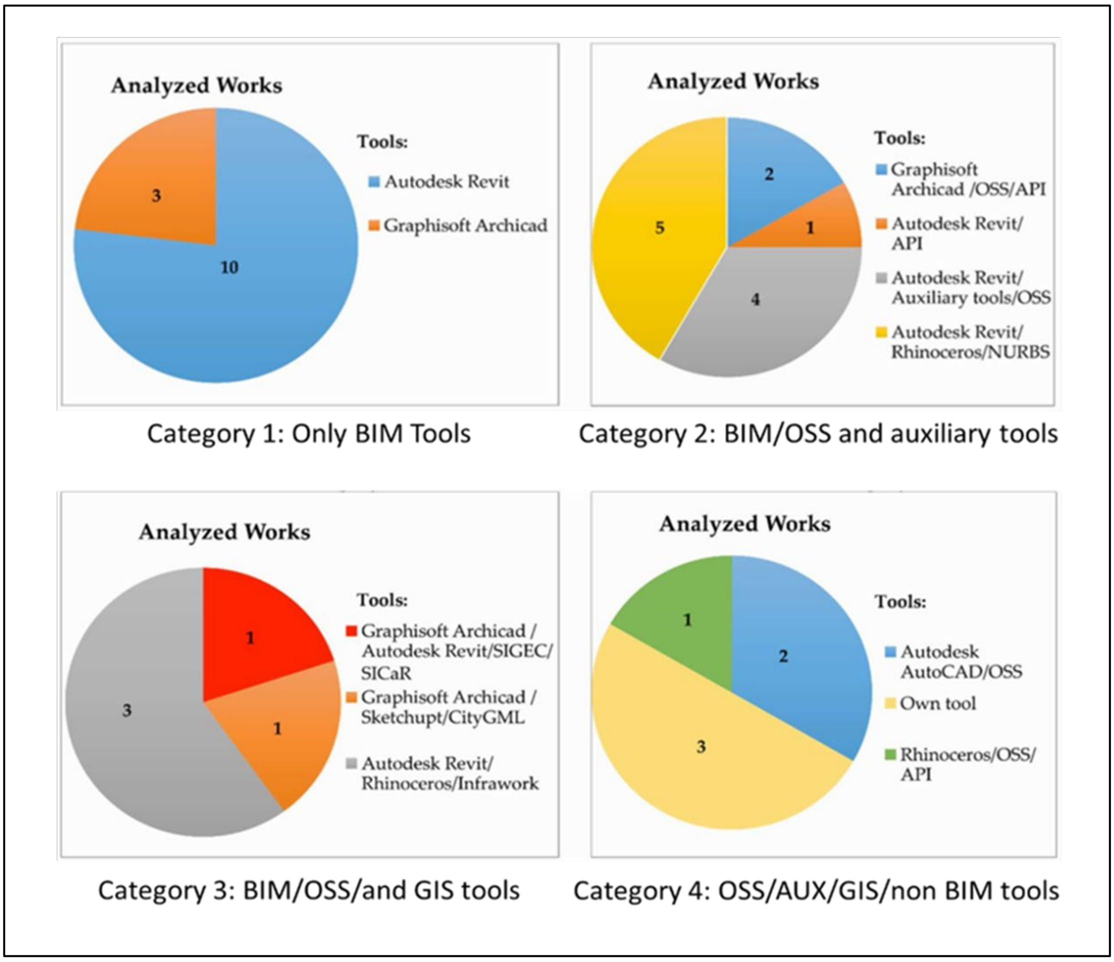

Figure 4.6. Categories of tools and approaches used in heritage buildings modeling (Source: López et al., 2018)

Many researches highlight that Autodesk Revit is the most used BIM software in the heritage sector (López et al., 2018; Logothetis et al., 2015)

4.2.5 Heritage Building Information modeling (HBIM)

In 2007, Murphy et al. identified the new approach of utilizing parametric objects "Historic Building Information Modeling" (HBIM) as a solution to the geometric primitives issue of heritage building in the fact of variety and complexity of its objects things whose are not representative for current typical BIM software libraries (Logothetis et al., 2015). HBIM system is a plug-in for BIM involves a reverse engineering process for modeling historic structures to represent heterogeneous and original existing morphologies (Murphy et al. 2013). It includes a number of stages, starting with the collection and processing of laser scan and photogrammetric survey data, the identification of historical details from architectural model books, the construction of parametric historical components/objects, and finally the correlation and mapping of parametric objects onto scan data in plugin libraries, to get the final get the final production of engineering survey drawings and documentation (orthographic and 3D models) (Murphy et al., 2013). Later, heritage term has begun to be used interchangeably with historic in the acronym HBIM within the complex modeling of cultural heritage in its all types through commercial BIM software.

4.2.6 The challenges of BIM adoption in heritage building projects

Many researchers have reported the lack of BIM implementation in heritage buildings due to the difficulties associated with the high effort of modeling/converting captured building data into semantic BIM objects (Pocobelli et al., 2018). This challenge is due to unavailability of automated processes and the restrictive nature of using BIM for a specific architectural style that is not present in the parametric smart object libraries and must be modified manually (López et al., 2018). HBIM software is expensive and inaccessible for researchers and professionals, as well as to the lack of open-source platforms for HBIM (Cheng, 2015; Khodeir et al., 2016). Recent researches indicate the need for more studies to identify this approach limitation as new libraries for historical styles are developed. In addition, there is a need to develop and adjust of simulation software to accurately represent the conditions of heritage buildings and allow accurate environmental simulations (Khalil, 2017).

Although much has been written on the potential benefits of using BIM in the digital documentation of the heritage building, little progress has been made to address the use of BIM for managing the whole intervention design and the conservation processes such as the generation and evaluation of various design alternatives (Arayici et al., 2017; Gigliarelli et al., 2017; Jordan-Palomar, 2018). Additionally, there is only few standards and insufficiently published prototype with limited use that state the paradigm and the significant requirements of BIM in the heritage sector, including: broad-scale user engagement in the specifications of or development of BIM models (Counsell & Arayici, 2017), the approach of data capture/processing and the development of standard LOD for heritage metric survey specifications and model production (Jordan-Palomar, 2018; Maxwell, 2016). Edwards (2017) highlighted the importance of a standardized HBIM for managing heritage conservation project efficiently

On the other hand, our analysis of existing literature shows both the high importance and lack of Industry 4.0 concepts in facilitating the integrated processes and assuring the quality of the final product of renovation heritage projects concerning BIM application, especially in order to cope with multiple criteria and deal with the projects complexity and values concerning the 3D documentation of the heritage building, the simulation of efficient environmental performance analyses and sustainability enhancement, due to the interoperability issues and, more importantly, lack of open source platforms. Therefore, further research and development are required to extend beyond semantic object properties to include more facilities management, business intelligence, green policies, whole lifecycle costing data, and lean construction principles.

Wong and Zhou (2015) argue that research efforts for environmental performance management of renovation projects are limited, as is the lack of a "cradle-to-grave" BIM-based environmental sustainability simulation tool, as well as insufficient consideration of current cloud computing technology and Big Data management in the Green BIM tool. Gigliarelli et al. (2017) proposed a methodology for linking together Heritage-BIM with diverse digital technologies and simulations like the use of building performance simulation (BPS) and the computational design. However, they reveal the lack of open source platforms for BIM in heritage and the limitation of interoperability between different software environments as either gbXML files or IFC file (Cheng, 2015; Gigliarelli et al., 2017). In the same context, Kassemet al. (2015) discuss that the benefits for BIM and FM have yet to be established, especially for existing buildings. They argue the absence of open standard that link between BIM and CAFM technologies.

Pocobelli et al. (2018) argue the requisite for tools like Rule-based Code Checking within BIM platforms that provides coordination and standardization of policies and controls incorporating the environmental/energy performance and historic preservation codes, as well as automate the Leadership in Energy and Environmental Design (LEED) process for green building certification. With a relational data model that has a unifying control set, it will be possible to collect data and look at it without having to collect it again, to rationalize controls and reduce redundant efforts to comply with multiple regulations, so that the same information can be applied to multiple assessments and audits.

4.3 IPD adoption in existing/heritage buildings

There are limited research about the application and synergy of IPD and BIM especially for Heritage buildings. Counsell and Taylor (2017) report that IPD is particularly helpful as a benchmark against which to analyze the BIM goal in heritages as an integrated building's delivery to conserving the cultural sustainability of built heritage during their lifetime used management mechanism that incorporates all stakeholders. Lucarelli et al. (2019) suggest the IPD methodology to allow the building process improvement due to data sharing and communication between stakeholders before construction to remove any possible delay. Jensen et al. (2018) highlight the benefits of relational contracting and IPD for sustainable renovation projects on creating trust and using a wide range of strategic, tactical and operational tools by collaborative teams. However, Megahed (2015) recommend BIM as support for IPD that enables model-based collaboration between people, systems, structures and business practices.

Unfortunately, Heritage conservation projects are very lack and far between the real-life case studies carried out in the current literature. From the rare examples, Cambeiro et al. (2012) explore the rehabilitation example of an old barn situated in a rural landscape in Spain converted into a modern complex of apartments. They argue the role of IPD elements application as a solution to minimize the occurred budgetary deviations and to reduce the risks assumed by every participant. The team project created collaborative decision-making around the different involved agents, and succeeded in reducing the reworking and errors through iterative design alternatives. However, they were not able to use BIM models because of the differences in the training degrees of the new technologies use among them, so they were obliged to do exhaustive drafting of documentation based on data collection.

4.4 Development of an analytical framework for Qualitative Comparative Analysis (QCA)

4.4.1 Importance of developing a framework

An analytical framework for comparative case study research is developed based on the literature survey, to enable a comprehensive, structured and systematic exploration of IPD and BIM application in different heritage environments, for using a QCA methodology.

Analytical framework is one of several approaches to thematic analysis and qualitative content analysis (Omorogieva et al., 2020). In the 1980s, the National Centre for Social Research was the first who conceptualized framework analysis (Dixon-Woods, 2011). This analysis approach involves the development of a matrix of thematic categories into which the data can then be coded (Dixon-Woods, 2011). Additionally, this approach ensures that themes and concepts identified via knowledge or reasoning can be paired with other new themes or concepts that may arise (Dixon-Woods, 2011).

The framework in this study strives to encompass the multiple perspectives of IPD and BIM synergy and facilitates the complex understanding of the sustainable renovation design process, in light of the highly complex value profile and the many heterogeneous stakeholders. Its development depends on analytical inference rather than statistical inference, where generalization lies not in the replication of results, but rather in the strategies and practices applied. The analytical framework is used to more comprehensively address all strategies, business models and tools used by project teams through the application of IPD and BIM in the context of heritages. It therefore allows us to conduct the case studies in a structured and systematic way to provide both an overview of the cases and a comparison between them. With a set of defined variables, through a coding scheme, we determine the collaborative practices shared across projects and the level at which teams were able to implement tools and processes effectively.

4.4.2 Development of the case study analysis

To develop the analytical framework, we use the well-grounded framework of "collaboration through innovation" in the construction industry of Poirier et al. (2016) study, including the *context, content,* and *outcomes* (Harrison, 2012), combined with Kamari and Kirkegaard (2019a)'s 4P+T model.

Poirier et al (2016) develop a collaboration framework over a critical realist lens. The authors provide a more systemic understanding of collaboration and consider its dynamic and evolutionary character to define a field of expertise in this topic. Here the collaboration is conceptualized as a system composed of four interacting core entities: structure (a relational system), process (from the beginning to the end), agents (social construct) and artefacts (technologies, rules, norms), and conditioned by a fifth: context (a specific environment), to produce specific events and outcomes. The framework was proposed to investigate the current shift to innovative project delivery approaches (such as BIM and IPD), addressing the interactions transformation between and within each of the core entities of the collaboration system.

However, the 4P+T model of Kamari and Kirkegaard (2019) is consisting of the five strands: *People, Product, Process, Policy,* and *Technology*. The model was used as an analytical lens for a comprehensive and systematic exploration of the potential use of integrated design through BIM on sustainable renovation projects.

The combination of the two models helps to represent how collaborative BIM and IPD practices involve transforming the interactions between and within each of the well-known strands that are contextually conditioned to produce the desired outcomes (see Figure 4.7).

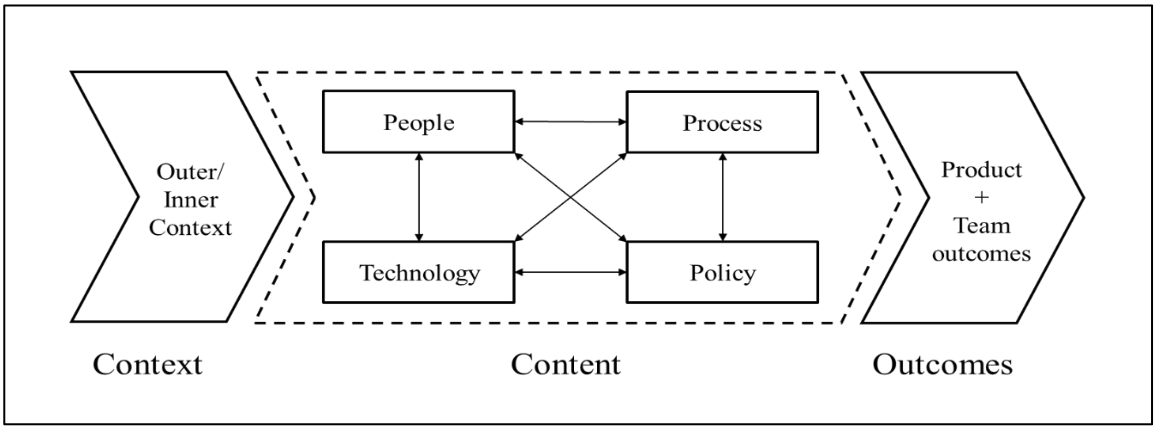

Figure 4.7. The paradigm showing the development of the case study analysis
(Source: Brahmi et al., 2021)

Context

The Context describes the setting in which the IPD and BIM implementation process takes place. There are two aspects to consider: the external context refers to the economic, social, political, and sectoral environment in which the renovation is carried out; and the internal context refers to the characteristics of the project (levels of budget, cost, schedule, risk, and technical complexities).

Content

The content describes the set of collaborative strategies, processes and tools used by the teams to achieve the project objectives (the "how").

Outcomes

The Outcomes include team outcomes that are assessed based on the effectiveness of the applied collaborative strategies, and thus project goals are met.

4.4.3 Coding scheme: Strands, Categories, and criteria

From the 200 documents selected for the literature review, we selected 17 documents (ranging from journal articles, research reports, guidelines, and white papers) that are based on the "Theoretical Integration" approach (Sarhan et al. 2019) or case studies. They mostly comprehensively address the feasibility and multifaceted prospects of integrating BIM and/or IPD on new-brand/renovation projects, focusing on the application of strategies, tools, and processes (see Table 4.2).

Table 4.2. The list of the seventeen documents used on the coding scheme (Source: Author)

Year	Authors	Document title	Key aspects	Document type	Research method
2009	Succar	Building information modelling framework: a research and delivery foundation for industry stakeholders	BIM	Journal article	Framework
2010	NASFA et al.	Integrated Project Delivery for Public and Private Owners	IPD	White paper	Framework
2012	AIA et al.	IPD Case Studies	IPD	Research report	Case studies
2012	Ashcraft	The IPD Framework	IPD	White paper	Framework
2013	CICRP	BIM Planning Guide for Facility Owners. Version 2.0	BIM	Guideline	Framework
2014	AIA California Council	Integrated Project Delivery: A Working Definition (2ed.)	IPD	Guideline	Framework
2015	Cheng	Integration at Its Finest: Success in High-Performance Building Design and Project Delivery in the Federal Sector	IPD+BIM	Research report	Case studies
2015	Cheng, and Johnson	Motivation and Means: How and Why IPD and Lean Lead to Success	IPD+BIM	Research report	Case studies
2015	Megahed	Towards a Theoretical Framework for HBIM Approach in Historic Preservation and Management	BIM heritage	Journal article	Literature review
2016	Barbosa et al.	Towards increased BIM usage for existing building interventions	BIM heritage	Journal article	Literature review/ on-site research experience
2016	Poirier et al.	Collaboration through innovation: implications for expertise in the AEC sector	Collaborati-on	Journal article	Literature review
2017	El-adaway et al.	Framework for Multiparty Relational Contracting	IPD	Journal article	literature review/ case studies
2017	Fischer et al.	Integrating Project Delivery	IPD	Book	Framework / case studies
2017	Yee et al.	An Empirical Review of Integrated Project Delivery (IPD) System	IPD	Journal article	Literature review
2018	ASHRAE et al.,	Zero Energy Schools: Keys to Success.		Guideline	Literature review/ case studies
2018	Maskil-Leitan & Reychav	A sustainable sociocultural combination of building information modeling with integrated project delivery in a social network perspective	IPD+BIM	Journal article	Literature review
2020	Viana et al.	Integrated Project Delivery (IPD): An Updated Review and Analysis Case Study	IPD	Journal article	Literature review/ case studies

To develop a reliable and valid analytical framework, we first extracted all theoretical components and predefined variables and then re-evaluated them. As a result, the data collected after being coded frame the study in a comprehensive, structured and systematic way (see Table 6.2) around:

- Strands: the five core entities identified by Kamari and Kirkegaard (2019): *People, Product, Process, Policy,* and *Technology*, which configure the basis for framing the BIM and IPD collaboration strategies. The five components are mostly in accordance with the literature reviewed. They share the view that the adoption of IPD or/and BIM requires a cultural and organizational change, in how the supply chain itself is shaped, and how projects are delivered through digitization, guided by principles and protocols, to deliver an integrated design and construction process.
- Categories: 15 generic categories of the applied strategies, which employ a range of criteria for their assessment.
- Criteria: 50 universally relevant variables common to the delivery of renovation projects, which investigate and compare how IPD and BIM collaboration tactics or strategies are adapted and applied in different heritage environments throughout their lifecycle, in order to understand different aspects of heritage renovation.

We elaborate on each strand in the following:

- **People**

The IPD is recognized as contracting members come together in the early stages, forming a cross-functional, cross-disciplinary team with clearly defined and synchronized roles and responsibilities (AIA 2014). Maskil-Leitan and Reychav's (2018) study argues for the importance of social integration and the cultural dimension in achieving full synergy between BIM and IPD. Five levels of socio-cultural sustainability were categorized in the proposed corporate social responsibility (CSR) framework: management of project stakeholders; participation of project stakeholders; reference to all project stakeholders; involvement of stakeholders in all stages of the building; and involvement of tenants as a community in the project. Here, given a renovation building, occupant attitudes and behavior are very important to study during the design phase. Cheng (2015) emphasizes the importance of tenant management in maintaining resilient tenant-team relationships during project tensions and challenges, as well as their alignment with project goals and integration into collaborative decision-making processes.

Selecting the team and considering their capabilities and needs is so crucial and challenging to execute the project effectively (ASHRAE et al 2018, Ashcraft 2012). Viana et al (2020) mention the special attention to members' behaviors in the research on team category. According to NASFA et al (2010), the behavioral principle is the key aspect required to achieve success, where the culture of trust and the willingness of the parties to change collaboratively are the critical elements of integration. Here, the client plays a complex role as a change agent, on how to use their power and influence to demand this change among project participants (Vass and Gustavsson 2017, Lindblad 2019). IPD projects involve some form of integrated project leadership where decisions are made by consensus (NASFA et al 2010), which allows for the creation of a culture that fosters creativity, learning, and feedback (Megahed 2015).

In this framework, People is divided into three categories (Team Organization, Team Selection and Capabilities, and Team Behaviors and Social Dimensions) and nine criteria that describe the collaboration schema among the stakeholders involved and their behaviors, including the team selection process, how the culture of collaboration was created through intentional team building, how roles were defined, and how leaders established accountability within the teams.

- **Process**

Viana et al. (2020) illustrated the lack of available material regarding the process within IPD implementation in construction industry. ASHRAE et al. (2018) implement several key steps performed from team building, planning to quality assurance and commissioning to facilitate and improve the success of the zero energy building process based on the collaborative culture and mindset. Maskil-Leitan and Reychav (2018) describe IPD as the simultaneous development of a product and service at the planning stage. Teamwork can examine alternative draft design solutions and value engineering on a collaborative, multilevel, and iterative basis, where they define the connection point between subsystems and negotiate their interfaces (Ashcraft 2012, El-adaway 2017).

The use of the Lean construction system in IPD has a positive effect on several critical areas (AIA, 2012), where Lean principles and tools focus on maximize the value, minimize the non-value added support, and eliminate waste. Cheng and Johnson (2016) explore the powerful complementary strength of IPD and Lean to support success. They conclude that IPD sets the terms and provides the motivation for collaboration, and Lean provides for teams the means to optimize their performance and attain project goals.

In this framework, Process is divided into three categories (Project planning, Quality assurance and commissioning, Lean system) and 13 criteria that describe how the integrated process was operated, including the iterative workflows to generate and operate the building data to design and construct the building, a series of procurement-related questions: How owners developed the request for proposal (RFP), how leadership defined goals, communicated them, the means of compliance, and the creation of a post-occupancy verification phase. Finally, it describes the effectiveness of the lean system on the projects.

- **Policy**

The contract has the largest amount of material in IPD research (Viana et al. 2020, Yee et al. 2017). According to El-adaway et al. (2017), improving the performance of the construction industry should start with the contract and organization. The authors develop a multi-party relational contracting framework, integrating all associated parties to propose a more efficient and effective contracting environment. They address ten critical interrelated aspects of IPD based on a comparison of traditional and relational contracts.

To enable the adoption of BIM, Succar (2009) indicates the significance of policy approaches, including a common vocabulary of terms, benchmarks, and metrics to enable effective communication. Procedures and workflows have been put in place that contain data structure, identification standards, exchange requirement standards, and process model standards to ensure team integration which is measured by the number of BIM uses and capabilities (Computer Integrated Construction Research Program 2013, Barbosa et al 2016). Barbosa et al (2016) investigate the general content and use of existing BIM standards in existing buildings. They describe specifications for BIM deliverables, modeling, and collaboration procedures. The researchers propose some components that should be included in such a standard and/or guideline to be used for interventions in existing buildings at three levels: data modeling, data exchange and process modeling.

In this framework, Policy is divided into three categories (Contract, Regulations, and Guidelines) and 12 criteria that describe simplified steps related to contractual terms, regulations, and industry mandates for performance and sustainability to guide decisions and achieve rational outcomes.

- **Technology**

The IPD process requires an information system to provide broad access to team members and focus on how information will be created, exchanged, and managed (Ashcraft 2012). Viana et al. (2020) cited information and modeling as one of the five major areas of BIM that represent the main changes from traditional methods, where collaborative technologies are needed to integrate different parties, foster information sharing, and encourage effective communication (AIA 2014). BIM records complex heritage structures remotely, efficiently, and accurately (Megahed 2015) and enables complex early-stage analysis through interoperable platforms and software (Kamari et al. 2019a). Megahed (2015) develops a holistic framework of BIM implementation for heritage buildings and Bridges the knowledge gap by linking issues related to the technology of surveying methodology with other technical, informational and organizational issues of BIM in heritages.

In this framework, Technology is divided into three categories (Software, Hardware, and Network) and six criteria that encompass the tools used for information management and processes, including the BIM environment and recording/design documentation strategies.

- **Product**

Succar (2009) viewed BIM as a combination of product and process modeling, along with a set of technologies and processes. He divided the process deliverables into products and services that include: documents, drawings, virtual models/components, physical components, structures, and facilities. On the other hand, Fischer et al.'s (2014, 2017) highly cited simple framework combines four key elements: integrated organization, process integration, integrated information, and finally integrated system to create a high-performance building through Virtual Design and Construction (VDC). The authors position the product as a starting point in their IPD framework. It is a high-performance building that provides metrics against the four categories of stakeholder value criteria (economic, social, environmental, and user value).

In this framework, Product is divided into three categories (Non-structured Output, Structured Output: Physical components, Structured Output: Virtual components) and 10 criteria that refer to the actual design solutions and/or digital prototype of a project that contributes to more sustainable buildings.

Table 4.3 illustrates the analytical framework for the QCA analysis (see Table 4.3).

Table 4.3. The coding scheme of the analytical framework (Source: Author)

Strands	Categories	Criteria	Succar 2009	NASFA et al. 2010	AIA et al. 2012	Ashcraft 2012	CICRP 2013	AIA California Council 2014	Cheng, 2015	Cheng, and Johnson 2015	Megahed 2015	Barbosa et al. 2016	Poirier et al. 2016	El-adaway et al. 2017	Fischer et al. 2017	Yee et al. 2017	ASHRAE et al., 2018	Maskil-Leitan & Reychav 2018	Viana et al. 2020
People	Team Organization	Organizational structure	X		X		X		X	X				X	X				X
		Role definition &			X	X	X		X				X	X	X	X		X	X
		Stakeholders Involvement &		X	X	X		X	X	X	X		X	X	X	X	X	X	X
		Users/occupants involvement							X		X				X		X	X	
		Leadership	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X
	Team Selection & Capabilities	Team Selection	X	X	X		X		X	X					X		X		X
		Education & Training	X				X			X					X				
	Team Behaviors & Social Dimensions	Collaborative Culture & Trust	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X
		Learning & Continuous						X							X	X			
Process	Project Planning	Assessments of existing									X	X							
		RFP Development					X		X						X		X		
		Budgeting and Scheduling			X			X	X					X	X	X	X		X
		Goals and Alignment		X	X	X		X	X	X			X	X	X	X	X		X
		Developing key Performance													X		X		
	Quality assurance and	Commissioning operations													X		X		

	commissioning	Measurement and verification							X						X	X	X		X
		Decision making		X	X	X				X			X	X	X	X			X
		Risks management		X	X	X		X						X	X	X			
		Post occupancy performance													X		X		
		Ongoing commissioning													X		X		
	Lean system	Lean Principles and processes		X	X	X				X					X	X			
		Lean tools		X	X	X				X					X	X			
Policy	Contract	Roles and Responsibilities	X	X	X	X	X		X				X	X	X	X	X	X	X
		rewards	X	X	X	X		X		X			X	X	X	X		X	X
		Risks and Compensation	X	X	X	X		X		X			X	X	X	X		X	X
		Liability and insurance		X	X	X		X		X				X	X	X			X
	Regulations	Heritage codes & regulations									X						X		
		Codes & standards	X	X		X	X		X			X	X		X				
		Protocols	X			X	X		X			X	X		X				
		Performance	X												X		X		
		Sustainability	X	X											X		X		
	Guidelines	Best practices	X																
		Benchmarks	X																X
		Classification systems	X												X				

Technology	Software	Applications	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
		Information exchange and	X			X	X				X	X			X				
	Hardware	Building examination									X	X							
		Workplace & Interactive	X	X	X	X	X	X	X	X			X			X			X
	Network	Data security	X				X				X	X							
		Access control	X				X				X	X							
Product	Non structured output	Profit and Payout	X	X				X		X				X	X				X
		Budget and schedule	X	X				X	X	X				X	X				
	Structured output: Physical components	Energy performance		X					X						X		X		
		Daylight & IAQ							X						X				
		Water cycle & Materials							X						X				
		Users' living conditions and							X						X				
		Heritage Values Preservation									X	X							
		Innovation & creativity				X			X										
	Structured output: Virtual components	Existing condition model									X	X							
		Record model	X			X	X				X	X			X				X

4.5 Summary

Unlike new construction, the review literature show the existing gap in the current researches concerns the simultaneous use of BIM and IPD for heritage renovation projects through the whole lifecycle. BIM due to the interoperability issues and, more importantly, lack of open source platforms. There is significant unexploited existing and growing potential for BIM use yet to be explored for renovation, in order to cope with multiple criteria and deal with the projects complexity and values. Thus, it could extend beyond semantic object properties to include more facilities management, business intelligence, green policies, whole lifecycle costing data, and lean construction principles. In doing so, the experiences from new/existing building can be used as a basis for benchmarking the effects of BIM and IPD in sustainable renovation of heritages.

Drawing from literature review, the analytical framework - developed in this thesis is a retrospective analysis tool that enables the relationships' assessment between the maturity level of teams' projects and the level of benefits they could achieve from BIM/IPD collaborative strategies so far. The developed analytical framework is based on a coding scheme consisting of 50 criteria, classified into 15 categories, and grouped into five thematic strands (people, process, policy, technology, and product) to enable a comprehensive and systematic assessment. The analytical framework strives to encompass the multifaceted perspectives of the IPD and BIM synergy and facilitates the complex understanding of the sustainable renovation design process, given its highly complex value profile and many heterogeneous stakeholders.

The next chapter validates the analytical framework and details the results of the data collection and assessment of the four real-world heritage cases.

CHAPTER V: CASE STUDIES

This chapter provides the Qualitative Comparative Analysis (QCA). In this regard, the chapter conducts an in-depth qualitative case study analysis followed by a cross-case analysis of three projects, on using the analytical framework developed in the previous chapter, to understand the similarities/differences of the best practices in more detail and how the synergy between BIM and IPD enhances the heritage renovation context.

5.1 Single detailed case-study analysis

5.1.1 Presentation of Case 1: Wayne Aspinall Federal Building

The detailed case study is the renovation of the Wayne Aspinall Federal Building (Case 1) in Grand Junction, Colorado. The three-story building, with nearly 42,000 square feet of office space, was constructed in 1918 and originally served as a post office and courthouse (see Figure 5.1), and a large extension was added in 1939. In 1980, the edifice was listed on the National Register of Historic Places. It presently includes nine federal agencies.

Figure 5.1. Wayne N. Aspinall Federal Building and U.S. Courthouse (South Elevation after renovation) (Source: DLR group)

With the Under American Recovery and Reinvestment Act (ARRA) funds, the U.S. General Services Administration (GSA) has initiated a major renovation of the Aspinall Courthouse that consists of approximately $15 million in total project costs and focuses on historic preservation and energy efficiency upgrades. This is in response to the federal government's goal of being carbon-neutral by 2030. The project began in June 2010 and was completed in February 2013. Managing the schedule and keeping the project on track was challenging, given the complexity added by the need to keep the building operational for tenants and uncertainty about the historic-review process. As a result, the project was executed using IPD principles under a design-build approach to ensure on-time delivery and on-budget. Table 5.1 represents an overview of the renovation case, including a brief project description, the renovation budget, and the design team (see Table 5.1).

Table 5.1. Overview of the renovation of Wayne N. Aspinall Federal Building and U.S. Courthouse (Grand Junction, Colorado) (Source: adapted by author)

<table>
<tr><td colspan="2">Building type</td><td>Federal Office Building and Courthouse</td></tr>
<tr><td colspan="2">Listed on</td><td>The National Register of Historic Places in 1980</td></tr>
<tr><td colspan="2">Project scope</td><td>Historic Renovation / Remodel</td></tr>
<tr><td colspan="2">Project size/height</td><td>41,562 GSF (square feet) / 3 Stories</td></tr>
<tr><td colspan="2">Project description</td><td>The project included:</td></tr>
<tr><td colspan="2">Owner</td><td>U.S. General Services Administration – Rocky Mountain Region, Region 8</td></tr>
<tr><td colspan="2">Occupants</td><td>U.S. Courts, U.S. Probation, U.S. Marshals, U.S. Army Corps of Engineers, U.S. Senator Mark Udall, FBI, U.S. Attorneys, IRS and GSA.</td></tr>
<tr><td colspan="2">The year begun-completed</td><td>June 2010- February 2013</td></tr>
<tr><td colspan="2">Total building costs</td><td>$15 M (met budget)</td></tr>
<tr><td colspan="2">Form of arrangement</td><td>Design-Build</td></tr>
<tr><td rowspan="2">Design-Build Partners</td><td>Design-Build Contractor and Architect-of-Record</td><td>The Beck Group</td></tr>
<tr><td>Integrated Engineer, Sustainable Design, Consultant</td><td>Westlake Reed Leskosky</td></tr>
<tr><td colspan="2">Construction Management Assist</td><td>Jacobs Technology, Inc.</td></tr>
<tr><td colspan="2">Commissioning Agent</td><td>M.E. Group</td></tr>
<tr><td colspan="2">Civil Eng.</td><td>Del-Mont Consultants</td></tr>
<tr><td colspan="2">MP/FP Eng.</td><td>Protection Engineering Group</td></tr>
<tr><td colspan="2">Blast Consultant</td><td>Weidlinger Associates</td></tr>
</table>

5.1.2 Assessment of the detailed case analysis

Table 5.2 represents the detailed and holistic assessment of the applied BIM and IPD strategies in the case study, Wayne Aspinall Federal Building, according to the developed analytical framework in Table including 15 categories and 50 criteria. As mentioned in section 1.7.6, the assessment has been done through the accurate review of the project's reports, documents, and technical articles that are published in the contracting firms' websites and other online sources, along with conducting four semi-structured interviews. The online interviews were conducted with representatives of the main contracting parts (two project architects, owner´s representative, and structural design engineer). The interviews were based on more general questions about: (a) how the synergy between BIM and IPD improved the performance of the renovation project; (b) the key elements that fostered collaboration to achieve success in the project; (c) how the interviewees saw the readiness of the their organization to implement these innovative approaches (i.e. BIM and IPD), and what were the barriers (see Table 5.2).

Table 5.2. The detailed and holistic assessment of the used BIM and IPD strategies in Case 1 (Source: Author)

5S	Categories	Criteria	Observations	Assess
People	Team Organization	Organizational structure	• Design-build with integrated firms. The majority of the project team was drawn from Beck Group and Westlake Reed Leskosky (WRL): WRL as lead design architect and Beck as the architect of record.	●
		Role definition & Accountability	• A matrix of project responsibilities from the beginning defining the roles according to the firms' capabilities. The team then assigned each responsibility to the firm best equipped to meet it. • Active contribution and collaboration throughout the project. • High levels of team member accountability through colocation.	●
		Stakeholders Involvement & management	• Early design meetings with the presence of all key participants during this critical phase of project development. • Internal and informal information channels. • Involvement of heritage agencies on the team selection and the RFP. • Work closely with VRF system vendors to understand performance limitations and control specifics.	●
		Users/occupants involvement	• Occupant engagement and education for more significant energy savings in the building: a Tenant guide and monthly meeting of the tenant agencies with to review outlet load data and federal requirements for the procurement of energy efficient office equipment to reduce outlet load energy consumption.	●
		Leadership	• The owner's project manager led the collaboration throughout the project, overseeing decision-making and almost single-handedly managing the complexities of ARRA design guidelines, schedule, reporting procedures, and project budget processes so that the project team could remain focused on design and construction. • A leadership strategy that served to support the team collaborative culture. • WRL served as lead designer.	●
	Team Selection & Capabilities	Team Selection	• The GSA Source Selection Evaluation Board (SSEB) implemented best-value-selection processes based on a combination of past performance, technical capacity, and qualification of key personnel. The selection procedure was a two-step open-solicitation process: a request for qualifications (RFQ) followed by request for proposals (RFP). Two rounds of interviews were conducted with the short-listed firms. • WRL subcontractors were selected based on their specific areas of expertise and previous relationships with WRL. Beck subcontractors were selected in the traditional manner, with the exception of specialized trades with expertise in specific historic preservation or restoration techniques.	●
		Education & Training	• Educate building operators on efficiency strategies.	⊘

	Team Behaviors & Social Dimensions	Collaborative Culture & Trust	• Both Beck and WRL are interdisciplinary firms with aligned cultures that have established a culture of collaboration across disciplines and under unified business goals. Although the firms had not previously collaborated. The level of accountability was high among them. • Open-minded approach. • GSA Project Manager inspired collaboration. • The isolated project location.	●
		Learning & Continuous Improvement	• The teamwork provided an opportunity to share knowledge, learn lessons and capitalize best practices and strategies to apply in future similar projects, and shape the 2014 Public Building Service (PBS) P100, which is the GSA's design standard for projects. • WRL conduct research concerning accurate data from product manufacturers.	●
Process	Project Planning	Assessments of existing conditions/usage	• The BIM model was used to quickly analyze the existing building design. For this work, separate models were created from the BIM to capture the building geometry, as this proved more appropriate as it allowed faster changes to the geometry than importing the entire geometry of the building, much of which was unrelated to the construction of these particular areas.	
		RFP Development	• A Peer review and interactive process that allows the bidders to provide innovative solutions, pushing this project in terms of its sustainability goals. The original prospectus required the whole building project to be completed for under $15 M and achieved LEED-NC Silver and a 30% reduction below ASHRAE 90.1-2007. The design-build team chose to significantly exceed the requirements of the prospectus without exceeding the target budget and schedule. Beck and WRL's design-build team showed in their proposal how the project could exceed commanded goals to achieve net-zero certification and LEED Platinum certification. • Involvement of GSA's Regional Historic Preservation Officer (RHPO) and a peer with historic preservation expertise in the SSEB review. • BIM use to make assumptions required for early parametric building energy simulation.	●
		Budgeting and Scheduling	• Merging the designer and builder under one team allowed for rapid cost feedback, with each design iteration verified with energy simulation. • Budget decisions were considered integrally with schedule and scope. • A digital model demonstrated the expected phases. • BIM use to attach the 3-D phasing model to the schedule, the scope of work and tenant-move plan and then to illustrate each phase with input from the whole team.	⃠
		Goals and Alignment	• Early design meetings (the presence of the owner, architects, builder, engineers, commissioning agent, and construction manager). • Collaborative revising of the project scope before work began. • Exchange of ideas between the parties. • With a focus on historic preservation and energy efficiency upgrades: a life-cycle cost analysis aimed at achieving 30% better performance than ASHRAE Standard 90.1-1999; 68.7% reduction in energy costs compared to ASHRAE Standard 90.1-2007; realization of a net ZEB; "LEED Platinum" certification; 40% reduction in water use. • Communication with the tenants to bridge the gap between their needs and the project team ´s goals that provided positive buy-in of the new design.	●

		Developing key Performance Criteria	• Development of a set of metrics: the preplanning process includes two types and building simulation that simulates the facility´s projected performance and impacts of various energy-efficiency measures.	●
	Quality assurance and commissioning	Commissioning operations	• A 3rd-party commissioning agent was engaged by the owner during the preliminary design phase. • The design-build approach ensured constructability was also reviewed very early in the design stage. • The use of BIM avoids the conflicts that may impede equipment access. • Multiple design reviews, the design-build team was very open to PEER review comments made by commissioning activities team, many suggestions were incorporated into the design.	●
		Measurement and verification	• Development of an M&V plan. • Formal weekly meetings with discussing complexities and positive achievements: once a week during design and Bi-weekly during construction. Key team members attended all structured meetings. • The building manager has access to the design and construction team to review performance and maintenance items. • Informal meetings encouraged to address issues. • Verification of the facilities performance with submeter data to effectively manage the building and reduce energy consumption.	●
		Decision making	• The owner supervised decision making. • The decision was based on a combination of the ability to create a high-quality indoor environment, energy savings, and constructability in a historic building.	●
		Risks management	• The early definition of risks. • Construction of flex spaces to temporarily support displaced tenant agencies during construction. • BIM mock-ups to identify issues early on and to reduce risk.	●
		Post occupancy performance	• The consultant and commissioning agent were engaged for an extended 18-month post-occupancy, to evaluate actual building performance and make suggestions for further systems optimization. • A pre-renovation occupant survey was performed and was compared to a new occupant survey one year after the building's dedication.	●
		Ongoing commissioning	• GSA Managed Tenant Energy Targets. • Post occupancy monitoring of occupant comfort.	●
	Lean system	Principles and processes	• Maximizing values and reducing wastes. • Multi-attribute evaluation. • User-centered design: Involvement of the facility managers in all the phases.	●
		Tools	•	○

Policy	Contract	Roles and Responsibilities	• Design-build project delivery: developing the contract in an interactive manner. • Incorporate performance goals into the agreement, with a supplemental agreement for the design/engineering firm specific to the performance measures.	●
		Rewards	• The contract was a firm fixed price.	⊘
		Risks and Compensation	• The contractor bore the risks associated with accepting a fixed-price contract based on a program of requirements, scope of work, policies, agency design guidelines, and the design-build proposal. The risks to the Design-Builder related to the uncertainty obtainable by the innovative renovation project where the contract required the Design-Builder to maintain pricing over design development based on the contract documents and during construction. • The GSA did assume the risk that the conceptual design proposal that formed the basis for the selection of the design-build team could be significantly altered as a result of the historic preservation reviews.	⊘
		Liability and insurance	• Open book policy.	●
	Regulations	Heritage codes & regulation	• The Secretary of the Interior's Standards for Rehabilitation. • Section 106 of the National Historic Preservation Act of 1966 (NHPA).	●
		Codes & standards	• Adaptation of standard GSA practices to the design-build contract required additional time investment and support. • ARRA design guidelines. • BACnet standard for building automation and control system networks. • Americans with Disabilities Act (ADA).	●
		Protocols	• Development of a BIM-execution document at the beginning of the project.	●
		Performance	• GSA's Minimum Performance Criteria for Recovery Projects for new construction and major renovations.	●
		Sustainability	• ASHRAE Advanced Energy Design Guide Standard 90.1-2007 as a reference energy standard. • ASHRAE Standard 55-2010 for thermal comfort. • The government requirements for net-zero and energy independence by 2030.	●
	Guidelines	Best practices	• GSA Building Information Modeling Guide Series. • Use of BIM model based on best practices that Beck had developed during the last decade.	●

		Benchmarks	• IESNA for acoustics and daylight. • Energy Star Portfolio Manager Benchmark for site energy use intensity.	●
		Classification systems	• LEED Platinum certification.	●
Technology	Software	Applications	• 3D BIM technology: Revit, NavisWorks, and Innovaya. • For energy model: TRACE 700, DOE-2, Autodesk Ecotect, Integrated Environmental Solutions Virtual Environment, GLHE-PRO	●
		Information exchange and interoperability	• Development of a BIM-execution document at the beginning of the project. • Coordination of BIM models with WRL energy models: a gbXML file export from the BIM was used for preliminary load and energy analysis. • BIM and building analysis software data were appropriately viewed and exported in a limited and controlled way to assist the process of designing a net-zero energy building.	⊘
	Hardware	Building examination tools	• The teamwork used laser scanning, photogrammetry, and other materials and technologies for the building examination.	●
		Workplace & Interactive artifacts	• Colocation: the increase in face-to-face working relationships and the opportunity to get a direct contact and increase trust/respect. • Web conferencing: Webex.	⊘
	Network	Data security	• As a federal project, security requirements considerably impede access to data.	○
		Access control	• Development of a plan during schematic design and determine how access to building automation systems will be provided.	⊘
Product	Non-structured output	Profit and Payout	• Energy conservation measures (which excludes the PV system) were evaluated to have under 10-year overall payback. The owner's primary goal for the project was to utilize the lessons learned to transform practices across an 8700 building portfolio, rather than seeing a short payback for all measures, this particularly applies to GeoExchange and PV system, both crucial to the net-zero energy goal, but having greater than a 20 years individual payback period. • A 50–year renewed life cycle, which allowed the higher capital cost of the geothermal well system to be justified by its future energy cost savings in the life cycle cost analysis required by GSA, compared to some other considered systems.	⊘

		Budget and schedule	• The project met the budget and schedule parameters: the total project cost was $15 M, including soft costs and excluding land.	●
	Structured output: Physical components	Energy performance	• Far exceeded ARRA high-performance goals, LEED Platinum certified, 84% energy saving over national average, 68,7% improvement over ASHRAE Standard 90.1-2007 • The first net-zero historic preservation project.	●
		Daylight & IAQ	• 50% of full daylight. Lighting was upgraded to higher-efficiency fluorescent and LED technology, including replication of historic fixtures. Task ambient lighting schemes are used in most work areas. • Lighting and HVAC are driven by the same wireless controls as an automatic detection of building occupancy. • An outside air monitoring unit provides fresh air to the building depending on the indoor CO2 levels, which increase with occupancy.	●
		Water cycle & Materials	• 40% potable water reduction over a LEED for New Construction 2009 baseline.	●
		Users' living conditions and safety	• Separated zoned space for each tenant, allowing greater occupancy-driven control through conditioning of spaces, as well as by activities specific to tenants. • Improved safety record.	●
		Heritage Values Preservation	• The project restores and showcases historic volumes and finishes, on preserving the historical significance of Grand Junction's crown jewel, while modernizing the landmark.	●
		Innovation & creativity	• The design of the PV canopy. • Creates a "green proving ground" and achieved the goal to advance the building industry as an exemplary project establishing how to deliver an existing historic building perform at net-zero energy 15 years ahead of schedule.	●
	Structured output: Virtual components	Existing condition model	• ---	⊘
		Record model	• A full As-built energy model.	⊘

● Done well, used often, helpful to the team
⊘ Done, but only somewhat helpful or mixed comments on its effectiveness
○ Did it, but most of the team didn’t find it particularly effective
╲ Did not have it

We observed that the collaborative environment allowed an extensive and continuous planning and problem-solving process to manage risks and address technical and spatial constraints that incited changes in the primary design plan to preserve heritage values.

Collaborative BIM and IPD strategies preserved the project's heritage values, while dealing with technical and spatial constraints through effective change management in early design.

The most significant change was to modify the PV (photovoltaic) system design. GSA's Regional Historic Preservation Officer (RHPO) determined that the PV canopy that covered the entire roof was having an adverse effect, and so alerted the Colorado State Historic Preservation Office (SHPO) and other outside agencies in a timely manner. To help manage the risk and uncertainty of the SHPO historic-review process, the project team, pending approval, approached the SHPO and developed a strategy with them to phase their review process. The project team resolved its demolition plans (of some interior walls) with SHPO first (see Figure 5.2). Then, the team began demolition after received approval while the rest of the project was still under review.

Figure 5.2. Level 1 - Before and After Renovation, Level 2 and Level 3 Floor Plans
(Source: https://www.aiatopten.org/node/367)

The design team then focused on the next phase of the building and worked to incorporate SHPO's input. The team was able to use this process to move the project forward and manage the risks associated with the SHPO review. Here, the leadership skills of GSA's project manager played a critical role in the success of the project. GSA conducted further analysis and determined that a different mix of green technologies could achieve the intended performance goals. Subsequently, the consultation focused on a limited set of adverse effects, managed by RHPO (see Figure 5.3 and 5.4).

Figure 5.3. North Elevation before renovation
(Source: Westlake Reed Leskosky, 2019)

Figure 5.4. North Elevation after renovation and installation of photovoltaic array at canopy (Source: https://www.aiatopten.org/node/367)

The project team was able to redesign the PV canopy, using BIM-based energy simulation, as an "additive" structure so that it could be removed without negative impact to the property after 25 years, and completely eliminate its visual impact. The modifications reduced the PV system from 170 kW to 123 kW (a 35% reduction). This impacted the overall energy generation system that forced the design team to incorporate additional measures, including several deep retrofit measures and two additional geothermal ground-source heat pumps, to accommodate the smaller PV canopy that resulted from the revision process, helping the project team meet net zero energy goals (see Figure 5.3 and 5.4). The team far exceeded ARRA's high performance goals, to achieve LEED Platinum certification with 84% energy reduction compared to the national average, to be the first net-zero historic preservation project in the United States.

Table 5.3 illustrates the "truth table" as the overall results of the assessment of the used BIM and IPD strategies on the Case 1. In this study, we illustrated the “Truth tables” on using the 15 categories in all the projects cases to improve the visibility for comparing the variety of the applied BIM and IPD collaborative practices amongst them, as well as to comparing the relative assessment for each category against the other categories on the same project (see Table 5.3).

Table 5.3. Truth table of Case 1 (Source: Author)

5S	People			Process			Policy			Technology			Product		
Subcategories	Team Organization	Team Selection & Capabilities	Team Behaviors & Social Dimensions	Project Planning	Quality assurance & commissioning	Lean system	Contract	Regulations	Guidelines	Software	Hardware	Network	Non structured output	Structured output: Physical components	Structured output: Virtual components
Case 01	●	●	●	●	●	○	●	●	●	●	⊘	○	●	●	⊘

●	**Done well, used often, helpful to the team**: at this level, the almost collaborative strategies were applied and continuously improved over incremental and innovative process and technology enhancements, based on a quantitative understanding of performance objectives and needs and linked to overall project performance.
⊘	**Done, but only somewhat helpful or mixed comments on its effectiveness:** : at this level, the collaborative strategies were planned and executed accordingly; produced monitored, controlled, and reviewed outputs; and were evaluated for adherence to their processes description.
○	**Did it, but most of the team didn’t find it particularly effective**: at this level, the collaborative strategies produced outcomes in which the specific goals were satisfied, however, they were usually ad hoc and chaotic.
⟍	**Did not have it:** at this level, the collaborative strategies did not incorporated into business processes and did not established goals and objectives.

To generalize the findings, we conduct a multiple case analysis of another three projects in the next section.

5.2 Multiple case study analysis

5.2.1 Presentation of cases 2, 3, 4

The selected case studies located in different context (USA or Canada) and have different sizes, e.g. medium and large buildings. The details of the cases are presented in Table 5.4.

Table 5.4. Key factual information about the three projects (Source: Author)

Cases	**Case 2**	**Case 3**	**Case 4**
Place	Washington, USA	Toronto, Canada	Ottawa, Canada
Type (built on)	Museum (1859)	Mixed-use (1950)	Federal building (1916)
Listed on	the National Register of Historic Places in 1969	Local heritage sites register in 2012	Classified Federal Heritage Building in 1986
Project scope	Renovation/Remodel, Interiors	Renovation and expanding	Major rehabilitation
Gross SF	46,800 sq.ft.	158,520 sq.ft.	543,580 sq. ft.
Owner	Smithsonian Institution	The Town of Oakville	The Public Works and Government Services Canada
Time frame	2012- July 2015	March 2014-September 2018	2018- in progress
Total costs	$30 M	$41 M	In progress
Form of contract	Design-Bid-Build	IPD tri-party contract	Architectural & Engineering Service

Case 2: The Renwick Gallery of the Smithsonian Art Museum

The Smithsonian Art Museum's Renwick Gallery, a 46,800-square-foot building, is located on Pennsylvania Avenue in Washington, DC, USA. The building is the first purpose-built art museum in the United States. It was designed in the ornate Second Empire style by James Renwick Jr. and completed in 1859 as the Corcoran Gallery of Art (see Figure 5.5). The structure was last renovated between 1967 and 1972. The building was listed on the National Register of Historic Places on March 25, 1969, and is considered one of the earliest buildings in the modern historic preservation movement. The building underwent a cultural interior renovation, with a budget of approximately $20 million and an overall project cost of $30 million, funded by a 50-50 public-private partnership, supported in part by a Save America's Treasure Grant. The core group for the project included the following companies: *Smithsonian Institution* (owner), *DLR Group-Westlake Reed Leskosky* (architects) and *Consigli Construction Co.* (general contractor). Team selection began in 2012, and the Smithsonian Institution took possession of the building in July 2015, while it opened to the public on November 2015. The renovation project scope included:

- Restoration of two long-concealed vaulted ceilings.
- Upgrades to art-storage areas and restrooms, as well as to the security, phone, and data communication systems.
- The re-creation of the original 19th-century window configuration.
- Repairs to the roof, roof drainage system, and exterior façade.
- Replacement of all HVAC, plumbing electrical, fire suppression, and life safety systems.
- Enhancements of visitor entrance accessibility.

Figure 5.5. The façade of the Smithsonian Art Museum during the construction phase (Source: https://www.consigli.com/project/renwick-gallery-renovation-2/)

Case 3: The Oakville Arena Redevelopment project

The Oakville Arena is a long-established local institution. Designed by architect William Armstrong and built between 1950 and 1951, the arena was intended for year-round use, including field hockey, seven-month skating, dance, roller skating, community events, boxing and lacrosse. The structure was a two-story, 41,000 square foot concrete block building with an asphalt shingle roof. It was considered a significant landmark developed by the Ontario politician and builder “Norman Otto Hipel”, who patented the system in 1928. The arena was managed by a group of volunteers until the late 1970s and early 1980s when the town of Oakville took over management. Since 1951, the Oakville Arena has played a key role in the history and activity of Trafalgar Park, maintaining and supporting the character of the park and surrounding area through its scale, orientation and function. The project was very complex as the site is "tight" and a historical building is involved. The total budget amount for the project was $41,044,000. The project required the support of other town departments including Planning, Building Services, Finance and Legal. Planning for the Oakville Arena Redevelopment project began in 2014, and it opened to the public on September 2018.

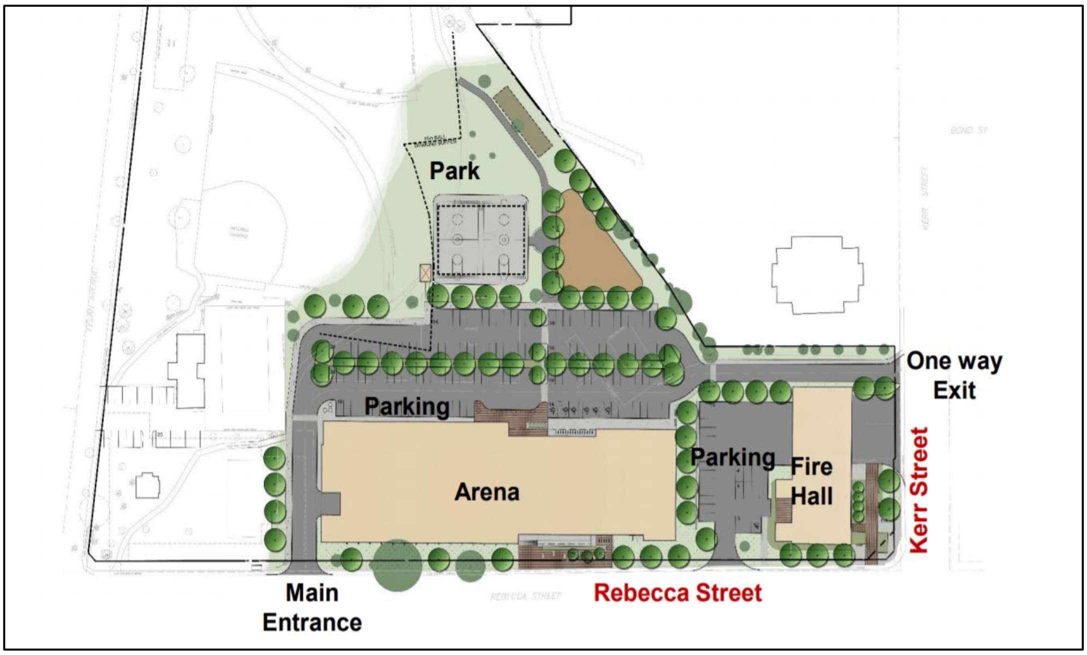

Figure 5.6. Site plan of the Oakville Redevelopment Project
(Source: https://www.oakville.ca/townhall/oakville-arena-redevelopment.html)

Early in the planning phase, staff identified a variety of technical, budgetary and schedule risks, including:

- The requirement to maintain the designated hipel roof trusses intact.
- Construction on a narrow and constrained site while retaining existing park amenities.
- Incorporating a new fire station at the south-east corner of the property.
- The plan maintains heritage value.
- A new steel enclosed roof structure constructed over the existing arena.
- The life expectancy of the renovated structure is estimated to be 50 years.
- The new arena roof structure would allow for an NHL (the National Hockey League) sized arena.
- Balance of edifice to be new steel framed construction.

Given these constraints, staff recommended used the IPD approach to mitigate project risk and the council approved the recommendation in September 2015. The core group for the project included the following firms: *Diamond Schmitt* (architect), *the Town of Oakville* (owner), and *Graham Construction* (contractor), making them the first Lean IPD projects by a Canadian municipality.

Case 4: The Centre Block of the Parliament Hill National Historic Site

The Centre Block of the Parliament Hill National Historic Site considers one of Canada's most significant heritage assets (Ottawa, Canada). The Centre Block is the centerpiece of the Parliament Hill complex, occupying a central position between the West Block, East Block, Library of Parliament and the new Visitor Centre. The Gothic Revival style of the original mid-19th style building was specially chosen to allow for a rich and complex relationship between the wild bluff to the north and the Great Lawn to the south. When it was rebuilt after the disastrous fire of 1916, the exterior style was retained and a new Beaux-Arts style interior was created to update the building and allow for an increased public presence. It features a variety of stone carvings, including gargoyles, grotesques, and friezes, consistent with the Victorian style of the High Gothic period. The building is connected to the Peace Tower, built between 1919 and 1927, and the Library of Parliament. It houses the Senate and House of Commons chambers and the offices of many Senators, Members of Parliament and senior staff of both legislative chambers, as well as numerous ceremonial spaces such as the Hall of Honour, the Memorial Chamber and Confederation Hall.

Figure 5.7. The construction site outside the Centre Block, as seen from the East Block, in November 2020 (Source: Public Services and Procurement Canada, 2021)

In the 1960s, the original electrical and mechanical systems were already over 40 years old and required a major renovation. A complete renovation was proposed in the mid-1970s, but was postponed, and only emergency exits in the Peace Tower were upgraded. In 1998, the CBUS was constructed. Since 1999, only emergency repairs and regular maintenance have been carried out to allow the building's continued use. The last major rehabilitation was the repair of the Peace Tower and south façade, completed in late 1990s. Building repairs like the courtyard parapets and some of the penthouses have been finished and other similar interventions are underway.

The Center Block, including the Peace Tower, was in need of significant rehabilitation, as many of its major systems and components are at risk of critical failure by 2019, with total failure expected by 2025. Because of the interdependence of the core block's building systems, it must be decommissioned at one time and emptied before any invasive work can begin. One of the challenges of this project will be to integrate the Visitor Center Complex (VWC), aligning with the long-range vision and plans that call for a pedestrian lobby column and independent but connected material handling facilities.

As defined in the Long-Term Vision and Plan for Ottawa's Parliamentary Precinct, the Centre Block Rehabilitation Project is the result of two decades of planning. The vision is to modernize the physical environment, security and support infrastructure, while honoring the Centre Block's heritage as the epicenter of Canadian democracy, as well as to reduce the environmental footprint and optimize energy use. The scope of the extensive Centre Block Rehabilitation (CBR) project comprises the complete restoration of the Centre Block and its integrated Peace Tower, as well as the completion of the Visitor Welcome Centre Complex, and over 25 enabling and 40 investigative sub-projects. Among other, the project scope includes:

- New information technology, multimedia, and security systems.
- Seismic upgrades.
- Basement excavation, subject to viability and cost-benefit.
- Broadcast-capable parliamentary offices and committee rooms.
- Adjustment to accommodate additional seating in the Senate Chamber and House Chamber.
- Restoration of designated heritage spaces.
- Complete building fit-up.

A joint venture partnership was created, named *"CENTRUS"* that is leading by *WSP*, who provides all engineering and design management services, however their partner *HOK* leads all architectural and conservation tasks. In addition, strategic partners *Architecture49* and *DFS Inc. architecture & design* are supporting this partnership. The Architectural and Engineering Services are required from the time the contract is awarded (winter 2017), for a duration of eight to twelve years, depending on the options approved for implementation. Active construction began in 2018, once the building was cleared.

5.2.2 Assessment of the multiple case analysis

As mentioned in section 1.7.6, concerning the data collection in terms of willingness, the assessment in the three cases has been done only through of the review of project's reports, documents, and technical articles that are published in the contracting firms' websites and other online sources. In addition, it is worth mentioning the variation in the data collected in terms of different criteria depending on their availability.

Case 2: The Renwick Gallery of the Smithsonian Art Museum

The owner's representatives had extensive experience from previous major renovation projects over the past decade. The Smithsonian Institution selected the design-bid-build contract for the project, and several elements of IPD were incorporated. Best value selection processes were followed, and several factors influenced the member selection process, increased team participation, high performance goals, and economic incentive. The owner selected DLR+Westlake Reed Leskosky Group (WRL), an integrated design firm, advocate for sustainable design in all types of projects worldwide.

The team was expanded its definitions of project stakeholders to include subcontractors, manufacturers, facility managers, and the community (participatory conservation). The increased number of engagement points allowed for more aspects of building products and building use to influence overall performance. The design team and contractor worked with external agencies to minimize the external impact of changes to the building's appearance. However, the project team faced a major challenge with the building's cooling plant. The vendor performed very poorly on the project with slow, incomplete, and inconsistent responses to design, construction, and operational comments. In contrast, the LED lighting manufacturer was considered excellent in its collaborative work. Additional time has been invested in research and development to create a product that meets a number of demanding attributes: Cost, color stability, luminous efficacy, light output, beam control and flexibility.

Building relationships was essential to extend trust and share ideas among team members. The experience of the owner's representatives allowed them to set reasonable contingencies for construction and provide an effective decision-making structure. Decisions were made in a systematic and coordinated manner to set careful planning, focusing on the "best for the project" that creates a balance between preservation goals and interior systems. The teamwork allowed for knowledge sharing, learning and capitalizing on best practices and strategies to apply IPD in future projects, as well as achieving continuous improvement in the renovation of historic structures and increasing cultural awareness among them. This gave them business advantages over those who had never used it before.

The key participants who became involved early on the integrated design process were the major success of the project. The collective team had a deep appreciation for the "why" of the project, rather than the "how" of the project. An overall 50-year life cycle, before another major renovation, was targeted. During the planning phase, the design team worked closely with the contractor and owner's team to gather existing documentation on the building through interviews, site surveys and review of historical documents dating back to the mid-1800s. It also conducted a comparative analysis of operations, including attendance, energy and water consumption, and exhibit needs. The project goals were outlined in the Owner's Program Requirements (OPR) document, which was developed within the first 60 days of the project and continually updated. For example, the required environmental control envelope for temperature and humidity was discussed in the first 30 days and maintained for the remainder of the project period.

The design team encouraged the facility operations team and owner's representatives to participate in the process early in the design to identify and understand life cycle costs. The process began with a series of partnership meetings to prioritize goals and develop more meaningful relationships among team members. The design team was provided with six formal design proposals, each with its own review processes. This allowed all stakeholders sufficient opportunity to contribute to the design. The integration of MEP engineering directly into the WRL architectural team allowed for spatial and historic preservation constraints to be considered early in the project. Lean construction principles and techniques were incorporated to facilitate the IPD process; all decision making was done using a multi-attribute evaluation. These attributes aligned closely with the attributes supported by NIBS for the whole building design process. Lean management practices were also subsequently used by the general contractor to reduce risk in construction activities.

Cost estimates and energy analysis were also rigorously used in all of these phases to ensure a responsive approach to design. The team dissected the Smithsonian design standards and provided feedback on each element from an operations, cost, and resource impact perspective. Life-cycle analysis of costs associated with performance improvement measures (e.g., energy cost recovery, water savings, measured productivity gains); for example, life-cycle analysis of LED lighting was evaluated, focusing on fixture life versus initial cost.

Specific policies and incentives around performance provided an important framework for organizing the work in the project. The project incorporated systems designed to provide an ASHRAE Class A museum environment: Activity levels (met = 1.0 to 1.5), clothing insulation levels (clo = 0.5 or 1.0), air velocities (target 40 fpm), space air temperature (typical range 70°F to 74°F), radiant temperature (within 5°F of ambient), (45%±8%) for humidity and condensation control were carefully considered. The design team used benchmarking software and methodology such as ENERGY STAR Portfolio Manager. It used energy, water, and environmental data collected prior to the renovation to set project goals in the context of the Architecture 2030 Challenge and the Smithsonian's sustainability framework that was formed by Executive Order 13514 for Federal Sustainability Leadership. The project achieved a 26% improvement over ASHRAE 90.1-2007, and a Class D net zero energy building (a net zero energy building purchased off-site).

In addition to the Whole Building Design Guide's high performance design principles, LEED rating system was also used as a frame for tracking integrated design and construction measures for a sustainable process in the renovation process. As a result, in July 2017, the U.S. Green Building Council certified the building as "LEED for New Construction and Major Renovations (LEED-NC)."

To effectively analyze environmental performance and improve sustainability, team members used a sophisticated set of technologies, including design software (Autodesk AutoCAD and Revit, Trimble Sketchup, photorealistic rendering), energy simulation software (Trane Trace 700, NIST's BLCC tool), and lighting simulation software (AGI-32 lighting assessment tool). The exchange of data between them facilitated efficient information management and provided transparency to the project to meet the high levels of complexity of the building.

The design team continued to engage with the operations team during commissioning, and they worked closely together for two years to ensure full understanding of the design intent to enable optimized performance. Because the building is listed on the National Register of Historic Places, the design work incorporated compliance with the Secretary of the Interior's Standards for Rehabilitation, consisting of 10 Guiding Principles for Historic Building Projects. Significant tax incentives and grants available through federal and state programs were contingent upon successful implementation of these standards.

The teamwork utilized laser scanning, photogrammetry, and other materials and technologies to examine the building. The laser scanning process allowed for the development of a high fidelity existing spatial condition model of the structure, which was not previously possible, allowed for final system integration and greater clarity for system maintenance. A massive amount and stores of interrelated semantic information were represented as well as external documents, and it integrated geometric and non-geometric data sets. Virtual modeling was essential to enable conflict detection between art and building systems as it moved from the building entrance through the basement to the workshop.

Cost and schedule predictability were important factors in using the IPD mindset and BIM on this project, in addition to its technical complexity, which required interdisciplinary teamwork. The team's success was measured by its ability to stay within the project budget and schedule while meeting the goals defined in the owner's program requirements (OPR). Managing the schedule and keeping the project on track was a challenge given the technical complexity of the building. The total construction cost budget was $20 million ($427/square foot), excluding exhibit development support infrastructure, in contrast to the average cost of 137 museum projects which was $772/square foot according to American Alliance of Museums data (2003-2010).

On the other hand, the collaborative environment has allowed teamwork to preserve heritage values and address technical and spatial constraints. The museum encountered problems with surface condensation, due to a lack of air movement and stable control of the supply air dew point. These spatial constraints required strong coordination and open communication among team members to provide optimal solutions. The most significant achievement of the IPD mindset was to avoid increasing the building's roof height by 10 feet (Chang, 2017). Fortunately, the structure created by the Smithsonian's processes was beneficial in anticipating documentation expectations and capturing change in an orderly and transparent manner. This allowed for a focus on reducing cooling load demand, contributing to facility operations, reducing risk to the art, and overall space utilization.

The Renwick's improvements provided comfortable energy savings through creative renovations. The renovation brought daylight to 90% of staff areas, the measured net EUI was reduced by 49% compared to the national average and achieved LEED Silver certification. The design team worked closely with the Smithsonian's lighting designer:

Scott Rosenfeld, to develop a flexible and efficient LED lighting system. The team also worked with multiple LED lighting manufacturers (meetings included joint visits to manufacturers, meetings with other leaders in the discipline, and review of precedents at other institutions), resulting in the development of a new type of LED source specifically for the Renwick's specialized needs (narrow-spot, highthrow). This resulted in approximately 60% savings on initial costs and a payback of less than three years compared to using halogen sources alone. The structure is one of the first museums in the United States to have an all-LED solution for gallery lighting, and the supply is now being sold for use in other markets, such as retail and hospitality.

The building incorporates modern life safety systems, while improving the quality of the indoor environment. The building's systems can now support a wide range of exhibits with greater structural, HVAC, and electrical flexibility. The Renwick Gallery has quickly surpassed its previous average annual attendance from 175,000 visitors per year in 2012 to 800,000 visitors per year since the museum reopened in 2015.

The Virtual Product - The project was one of the first to use a full virtual building model, which has now become a prerequisite for future Smithsonian Institute modernization projects. The contractor worked closely with the design team and subcontractors to develop a detailed 3D model at a 400-level definition of all building systems. This process allowed for the final integration of the systems with a dimensional fidelity that was not previously possible (see Figure 5.8, 5.9, and 5.10).

Figure 5.8. Pre-Renovation Condition of the Mechanical Room.
(Source: Courtesy of Westlake Reed Leskosky,2019)

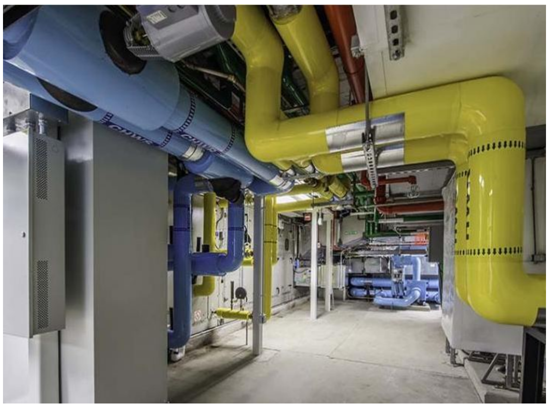

Figure 5.9. Basement Mechanical Room after restoration.
(Source: Courtesy of Westlake Reed Leskosky,2019)

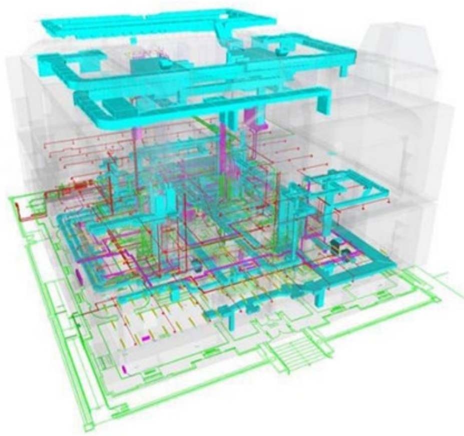

Figure 5.10. The 3D coordination model of the different building systems.
(Source: Courtesy of Consigli Construction, Co., Inc.
https://www.consigli.com/project/renwick-gallery-renovation-2/)

Similar to the analysis of the detailed case study in section 5.1.2, Table 5.5 illustrates the "truth table" as the result of the assessment of the BIM and IPD strategies used on the Case 2 (see Table 5.5).

Table 5.5. Truth table of Case 2 (Source: Author)

5S	People			Process			Policy			Technology			Product		
Subcategories	Team Organization	Team Selection & Capabilities	Team Behaviors & Social Dimensions	Project Planning	Quality assurance & commissioning	Lean system	Contract	Regulations	Guidelines	Software	Hardware	Network	Non structured output	Structured output: Physical components	Structured output: Virtual components
Case 02	○	●	●	●	⃠	⃠	○	●	●	●	●	⃠	●	●	●

●	**Done well, used often, helpful to the team**: at this level, the almost collaborative strategies were applied and continuously improved over incremental and innovative process and technology enhancements, based on a quantitative understanding of performance objectives and needs and linked to overall project performance.
⃠	**Done, but only somewhat helpful or mixed comments on its effectiveness:** : at this level, the collaborative strategies were planned and executed accordingly; produced monitored, controlled, and reviewed outputs; and were evaluated for adherence to their processes description.
○	**Did it, but most of the team didn't find it particularly effective**: at this level, the collaborative strategies produced outcomes in which the specific goals were satisfied, however, they were usually ad hoc and chaotic.
╲	**Did not have it:** at this level, the collaborative strategies did not incorporated into business processes and did not established goals and objectives.

Case 3: The Oakville Arena Redevelopment project

Planning for the Oakville Arena Redevelopment project began in 2014. Early in the planning phase, staff identified various technical, budget and schedule risks including: the requirement to maintain the designated hipel roof trusses intact (see Figure 5.11); construction on a narrow and constrained site while retaining existing park amenities; and incorporating a new fire station at the south-east corner of the property. Based on these constraints, staff recommended used the IPD method to mitigate project risks and council approved the recommendation in September 2015. The town Oakville (owner) selected the architect and general contractor at the beginning of the project. The town issued a Request for Prequalification in October 2015. The town received 15 submissions, an Evaluation Committee made up of representatives from the four departments involved in the project reviewed them in response to the prequalification call and ranked them based on their experience: with IPD and lean construction; with the design and construction of community centers, arenas and fire halls; and with the requirements of heritage and LEED construction. Therefore, 05 teams were pre-qualified and finally Diamond Schmitt

Architects Incorporated and Graham Construction and Engineering were selected based on the selection criteria set out in the Request for Proposal followed by an interview process.

Figure 5.11. The arena under renovation with retaining the distinctive wooden roof truss system (Source: https://www.oakville.ca/townhall/oakville-arena-redevelopment.html)

The values and goals of the Oakville Arena Redevelopment Project were aligned with the town's strategic objectives and focused on financial and environmental sustainability through reduced life-cycle costs and improved operations; enhanced natural, cultural and social environments through improved programming and user experience; fully accessible programs and services; and a process that is as satisfying as the outcome for the public and staff. As being the first municipality to use the IPD model, they created their own IPD tri-party contract adapting a model developed in the U.S. best suited their needs. Compensation during validation was based on time and material plus overhead for the consultant and the general contractor teams. Profit was deferred and was at risk, and payment terms was negotiated during the validation phase.

The goal of the IPD Team was to facilitate collaborative planning during the validation phase of the project. To enable IPD Team members to benefit from an open and creative learning environment, each IPD Team member made reasonable commercial efforts to:

(a) Share information/ideas and build of tolerance and respect.

(b) Work together and individually to achieve a transparent and cooperative exchange of relevant project information and share ideas to improve project delivery.
(c) Provide traditional and exceptionally collaborative preconstruction services throughout the validation phase to facilitate an integrated and collaborative design process.
(d) Provide traditional and exceptionally collaborative preconstruction services throughout the validation phase to facilitate an integrated and collaborative design process.

As part of the validation phase, the owner, the prime consultant, the general contractor conducted a joint site investigation on or regarding the project site to review all existing site information, conducted investigations and surveys, documented all site-related information necessary to design and construct the project, verified existing conditions on the project site, including all points of connection, the location of all utilities, and the accuracy of existing surveys and other documentation provided by the town. In addition, transparency and the collocation of the team (Oakville) in a big-room were really useful and tied heavily into the collaboration.

The IPD process ("validation") revealed that the original 2014 budget estimate (of $38,195,000) was missing a significant and necessary scope. The town's standards in energy management, storm water management and accessibility have changed. Unexpected site conditions also added cost and risk to the project, as did the falling Canadian dollar. At one point in the iterative design process, the project's market value exceeded the budget by $4 million. Through Target Value Design (TVD), the project team redesigned the facility, validated the scope and programming requirements with the user groups, identified and quantified all project risks, and determined the budget needed to achieve the desired results. Through this process, the team was able to save over $3 million. The council approved this budget of $41 M in 2016, along with some project improvements, and began construction. The validation process allowed the team to have a high level of understanding of potential problems and how to solve them in the most cost-effective manner. The team examined numerous options to identify efficiencies to reduce costs and provide better value to the town. On the other hand, the weather was a particular challenge during the construction phase (28 days of heavy rain), but everyone on the team pitched in and they were able to overcome the weather delays.

The project (Oakville) was completed on September 2018 on time and on budget, and achieved LEED Silver certification. The project involved expanding a heritage arena to NHL size with the conservation of the wooden roof truss system, all in a brand new, high quality facility.

Table 5.6 illustrates the "truth table" as the result of the assessment of the BIM and IPD strategies used on the Case 3 (see Table 5.6).

Table 5.6. Truth table of Case 3 (Source: Author)

5S	People			Process			Policy			Technology			Product		
Subcategories	Team Organization	Team Selection & Capabilities	Team Behaviors & Social Dimensions	Project Planning	Quality assurance & commissioning	Lean system	Contract	Regulations	Guidelines	Software	Hardware	Network	Non structured output	Structured output: Physical components	Structured output: Virtual components
Case 03	●	●	●	●	⊘	●	●	○	⊘	⊘	○	○	●	⊘	○

●	**Done well, used often, helpful to the team**: at this level, the almost collaborative strategies were applied and continuously improved over incremental and innovative process and technology enhancements, based on a quantitative understanding of performance objectives and needs and linked to overall project performance.
⊘	**Done, but only somewhat helpful or mixed comments on its effectiveness:** : at this level, the collaborative strategies were planned and executed accordingly; produced monitored, controlled, and reviewed outputs; and were evaluated for adherence to their processes description.
○	**Did it, but most of the team didn't find it particularly effective**: at this level, the collaborative strategies produced outcomes in which the specific goals were satisfied, however, they were usually ad hoc and chaotic.
\	**Did not have it:** at this level, the collaborative strategies did not incorporated into business processes and did not established goals and objectives.

Case 4: The Centre Block of the Parliament Hill National Historic Site

The rehabilitation of the Centre Block is a significant undertaking and a legacy project on Canada. As this building is an important symbol of the country, the Public Works and Government Services Canada- PWGSC (owner) remains committed to architectural quality and heritage preservation through the use of highly qualified teams of dedicated specialists and professionals. The PWGSC selected the Architectural & Engineering Service team and Construction manager-CM through a two-phase selection process. Phase 1 entailed a Request for Qualification that led to the selection of the three highest-ranked Proponents. Phase 2 entailed a Request for Proposal where “Centrus” was selected, using a combination of rated criteria and price to get the best value. PWGSC selected an IPD lean design construction consultant for the Centre Block Rehabilitation Project. In addition, aspects of IPD from various delivery methodologies were also considered in the mandates of the consulting and construction management teams. PWGSC have a dedicated multi-disciplinary team to manage all contracts related to the Centre Block Rehabilitation Project. Due to the long duration of the project, the contract contains economic price adjustment provisions for the specific labor rates specified in the contract. All construction cost charges are inherently reflective of economic fluctuations.

The PWGSC team is co-located with the A&E and CM teams in Ottawa, near the site in an integrated project delivery office. A strong governance structure for this project, including representatives from all key stakeholders, is established and shared with all qualified respondents during the Commercial in-Confidence Meeting. Third party expertise is a part of the design approval process, given the work product properly developed and coordinated by the consultant. The owner is working closely with its parliamentary partners: the Senate, the House of Commons and the Library of Parliament. The owner keeps external stakeholders such as the National Capital Commission, the City of Ottawa and Ottawa Tourism informed. These commitments are essential to delivering a building that meets the needs of a modern Parliament and will still be relevant 100 years from now.

BIM is used as an enabler of IPD implementation in the Centre Block project. The goal of BIM use is to generate complex 3D historical objects within heterogeneous datasets. In early 2017, the Centre Block BIM was delivered to CENTRUS. After the handover, the CENTRUS team engaged Carleton University's Immersive Media Studio -CIMS- to complete the as-built model and explore the application of new digital technologies for historic preservation through additional research projects. An Advanced Modeling Tools (AMT) was used to manage the structural and architectural elements of Centre Block's in details to facilitate the integrated delivery of the project. The Centre Block BIM required the synthesis of large, diverse data sets (these include elements like light fixtures, walls, wiring, ductwork and plumbing). The primary data source was georeferenced point cloud data from photogrammetry and terrestrial laser scanning. Data were collected by CIMS in collaboration with HCS using a Leica C10 and P40 (outdoor and large indoor spaces) and a Faro Focus (small and medium indoor spaces) (see Figure 5.12, 5.13, and 5.14). BIM supports the design process and helps construction planning. BIM models helps everyone involved in the project to understand and track the work that has been done and the work that remains to be done. CSPP and the design team continue to refine the model to ensure that it captures the various states of the Center Block as the work progresses. The details of the new mechanical, electrical, ventilation, plumbing and other systems will all be incorporated into the BIM. This will greatly facilitate the maintenance and upkeep of the systems for years to come. An advanced, analytical, nonlinear modeling was performed for Seismic Modeling in response to seismic shaking. Various seismic retrofit strategies are investigated, including the use of seismic isolation technology as a means to minimize structural intervention and its effect on the building's heritage finishes.

The owner works closely with heritage architects and other specialists. Together, they ensure that the buildings are safe and meet the technical requirements of a 21st century democracy, as well as respect the heritage nature of the buildings. Significant heritage and architectural features are removed and stored or protected and retained in place while construction proceeds around them. However, the heritage elements that could not be safely removed are protected in place (see Figures 5.12, 5.13, 5.14, and 5.15).

Figure 5.12. Photogrammetry: in February 2020, a worker takes photos of the Hall of Honour
(Source: Public Services and Procurement Canada, 2021)

Figure 5.13. Surveying the exterior of the Centre Block in February 2020
(Source: Public Services and Procurement Canada, 2021)

Figure 5.14.In this photo taken in January 2020, a worker scans the Memorial Chamber
(Source: Public Services and Procurement Canada, 2021)

Figure 5.15. Workers install plywood to protect the First World War altar in the Memorial Chamber
(Source: Public Services and Procurement Canada, 2021)

Table 5.7 illustrates the "truth table" as the result of the assessment of the BIM and IPD strategies used on the Case 4 (see Table 5.7).

Table 5.7. Truth table of Case 4 (Source: Author)

5S	People			Process			Policy			Technology			Product		
Subcategories	Team Organization	Team Selection & Capabilities	Team Behaviors & Social Dimensions	Project Planning	Quality assurance & commissioning	Lean system	Contract	Regulations	Guidelines	Software	Hardware	Network	Non structured output	Structured output: Physical components	Structured output: Virtual components
Case 04	⦸	●	●	●	●	●	●	⦸	⦸	●	●	⦸	●	○	●

●	**Done well, used often, helpful to the team**: at this level, the almost collaborative strategies were applied and continuously improved over incremental and innovative process and technology enhancements, based on a quantitative understanding of performance objectives and needs and linked to overall project performance.
⦸	**Done, but only somewhat helpful or mixed comments on its effectiveness:** : at this level, the collaborative strategies were planned and executed accordingly; produced monitored, controlled, and reviewed outputs; and were evaluated for adherence to their processes description.
○	**Did it, but most of the team didn't find it particularly effective**: at this level, the collaborative strategies produced outcomes in which the specific goals were satisfied, however, they were usually ad hoc and chaotic.
\	**Did not have it:** at this level, the collaborative strategies did not incorporated into business processes and did not established goals and objectives.

5.3 Cross case analysis

The main finding of this research based on the applied research methodology on the four case studies with a focus on investigating the changes that occurred when using BIM and IPD to renovate heritage buildings is summarized in this section. In order to address the findings systematically, and by following the developed analytical framework as well as the results presented in the form of "truth tables" in sections 5.1.2 and 5.2.2, here the discussion is categorized using the five strands of people, process, product, policy, and technology. The following subsections elaborate on each strand.

5.3.1 People

Common to all of the case studies considered, the composition (and selection) of the key team was a critical factor in facilitating the trust established and building a strong culture of collaboration. Team selection processes ranged from a sequential process (in Case 2) to the selection of a joint architects-contractors team requiring pre-organization to jointly submit proposals (in Cases 1, 3 and 4). All projects adopted a two-phase selection process: a Request for Qualifications (RFQ) followed by a Request for Proposal (RFP).

However, the basis for selecting team members was different. Cases 1 and 2 used a best-value selection procedure, requesting a proposal that more directly addressed the scope of the project in terms of sustainable, high-performance goals. In contrast, Cases 3 and 4 used a qualifications-based selection procedure, requested a proposal that addressed collaborative strategies and IPD/lean experience in Case 3, and focused on commitment to architectural quality and heritage preservation in Case 4. In addition, the guidance and leadership that the project owners provided to the selected participants was critical to the team culture developed.

The increased number of engagement points in the projects allowed for more aspects of building products and building use to influence overall performance, organizations to minimize the external impact of changes to the building's appearance. Significantly, the design-build team (in Case 1) was very open to feedback from the commissioning activities team regarding the PEER review; many suggestions were incorporated into the design. In addition, community members (in Cases 2 and 3) and tenants (in Cases 1 and 4) were encouraged to become active players and collaborators in the renovation process to encourage participatory conservation. Users were aligned with the projects' goals and were integrated into the decision-making processes in collaboration with the team members. Impressively, the owner in Case 1 invested time with tenant groups and in partnership sessions to align their policies and generate detailed programs that meet the high performance goals of the whole project.

The collocation of the teams could have an impact on the success of the collaboration. The teams in Cases 1 and 3 were collocated in a big-room. In Case 4, the design team was located near the site with the client, construction management team, and user representatives in an integrated project delivery office.

5.3.2 Process

In addition to the technical complexity of the heritage buildings, cost and schedule predictability was a key factor in using the IPD and BIM approach in all cases. The high performance goals motivated the teams to align their work, proposing new methodologies and innovative solutions to achieve the ambitious goals.

Early involvement of key participants in all projects allowed stimulate the design of integrated interventions, established effective environmental performance analyses and improved sustainability, at an early stage. The design teams encouraged the facility operations team and owner's representatives to be involved in the process early in the design to identify and understand life cycle costing. BIM supports the design process and helps plan phasing. BIM models have been linked to construction schedules and scopes of work, as well as tenant relocation plans.

Lean construction principles and techniques were incorporated into the projects to varying degrees. In Case 4, the owner is paying particular attention to the lean implementation of the project. It solicited bids to engage the services of an IPD Lean Design and Construction (LD&C) consultant to design, implement, and monitor a purpose-built project delivery model that combines LD&C principles and IPD with construction management (CM) delivery in support of the Central Block Rehabilitation project. In the other projects, its use consists solely of the application of certain tools and principles such as value maximization and multi-attribute assessment in decision making (Case 2), target value design and lean 5S implementation (Case 3).

5.3.3 Policy

The results of the study, in particular, reveal that the type of contractual arrangement is not an overriding factor in the success of renovation projects. Cases 1 (design-build) and 2 (design-bid-build) followed a more conventional format. However, in Case 3, staff recommended using the IPD contract to mitigate project risk, and the board approved this recommendation. The Town of Oakville (owner) placed considerable emphasis on the legal and commercial terms, being the first municipality to use the IPD model. In this model, the owner had to invest considerable time in creating its own tri-partity IPD contract by adapting a model developed in the United States to best meet its needs. Compensation during validation was based on time and materials, plus overhead, for the consultant and general contractor teams. Benefits were deferred and at risk, and payment terms were negotiated during the validation phase. Nevertheless, in Case 4, a HOK-WSP joint venture called CENTRUS led the design of the expansion, conservation, and rehabilitation.

Specific policies and performance incentives provided a critical framework for organizing work on the projects. The projects incorporated different regulations and guidelines, including heritage preservation requirements, depending on the building's use and location. LEED rating system was used in Cases 1, 2 and 3.

5.3.4 Technology

Laser scanning was used for 3D documentation of all four buildings. In Case 2, augmented reality allowed the team to visualize the new systems against the backdrop of the existing architecture, and to facilitate the understanding of other stakeholders who are not traditionally involved in large construction projects. In Case 4, the team's project faced a challenge early on: the process of verifying the BIM model created from point clouds involved creating several cross-sectional views with elements in Revit and measuring what appeared to be the most significant discrepancies between the point cloud and the model element. This method was time consuming and limited the model verification to specific sections. As a result, the developed verification system significantly improved communication and collaboration efforts among team members; the system increased the speed and workflow of translating heterogeneous datasets into building blocks and helped determine model integrity and accuracy through visual quality checks. Advanced Modelling Tools (AMT) was used to manage the structural and architectural elements of the building with a high level of detail to facilitate integrated project delivery. In addition, seismic isolation technology was used to minimize physical interference.

For effective environmental performance analyses and sustainability improvements, team members used a sophisticated set of technologies, including design, energy simulation and lighting simulation software. Here, BIM enabled collaboration through the IPD implementation framework in all four projects. The energy modeling processes used for the Aspinall Federal Building are an sample of how BIM and building analytics software data can be visualized and exported in an appropriate, limited, and controlled manner to facilitate the design process for a net zero energy building. However, additional analytical tools required calculation of the thermal performance of existing building components, and there was no adequate BIM workflow for these tools and performance analysis.

5.3.5 Product

Cost and schedule predictability were important factors in using the IPD mindset and BIM on the projects, in addition to the technical complexity, which required interdisciplinary teamwork. Upon completion of the projects (Cases 1, 2, and 3), the teams were successful in keeping the projects on budget and on schedule.

The collaborative environment allowed the teams to address technical and spatial constraints that incited changes in the primary design plans to preserve heritage values. Specifically, in Case 1, this involved the design of the photovoltaic canopy. In Case 2, the museum encountered problems with surface condensation, due to a lack of air movement and stable control of the supply air dew point. The most significant achievement of the IPD mindset, according to project participants (Chang 2017), was to avoid increasing the height of the building roof by 10 ft. As such, this led to a strong focus on reducing cooling load demand, entry of facility operations, reducing risk to the art, and overall usability of the space. However, in Case 3, the project was able to retain the wooden roof truss system, all in a brand new, high-quality facility. In all cases, these spatial limitations required strong coordination and open communication among team members to provide the optimal solutions. The collaborative culture of the teams was beneficial in capturing change in a seamless manner, focusing on the "best for the project", where good ideas are retained.

While all cases were successful in achieving appropriate sustainability outcomes, the results were uneven. Cases 1 and 2 achieved a high level of innovation and advanced sustainable building technologies. Case 1 achieved the most significant results; with an 84% energy reduction compared to the national average and achieved LEED Platinum certification. Case 2 achieved 49% energy reduction compared to the national average and earned LEED Silver certification. However, Cases 3 and 4 (an ongoing project) have lower sustainability scores. At the same time, all four buildings have incorporated modern life safety systems and improved indoor environmental quality.

Case 2 was one of the first to use a full virtual building model at a definition level of 400 of all building systems using laser scanning, this process allowed for the final integration of systems with previously impossible dimensional fidelity, which the model uses for operation and maintenance, as well as for future building upgrades. The current digital model of Case 4 has also successfully merged all available information, including structural and architectural components, as well as building systems and infrastructure, but at a lower level of detail.

5.4 Summary

This chapter has accomplished the main objective of the study by investigating holistically four real-world heritage cases to further understand the impact of IPD and BIM in achieving the balance between sustainable design and historic preservation, and enhancing process productivity and final project performance. We determined the shared collaborative practices across projects, and the level at which teams were able to effectively implement IPD and BIM tools and processes.

All the case studies had various feedback and observations. The results demonstrated the significant benefits of applying IPD and BIM collaborative strategies across different thematic strands and contract types. It was revealed that the application of IPD and BIM achieves sustainability goals while preserving heritage building values through holistic decision-making frameworks, ensuring on-time and on-budget project delivery. The collaborative environment allows for the stimulation of integrated design intervention at the earliest stage, among multiple participants. BIM enables design teams to provide faster complex analysis and rapid evaluation of energy simulations through BIM coordination with energy models to produce a complete virtual construction model.

The next chapter provides discussion of the key findings, the contribution of this research as well as recommendations for improvements and future research.

CHAPTER VI: CONCLUSIONS AND FURTHER RESEARCH

This chapter discusses and presents the Key research findings and contributions. Recommendations for future implementation of IPD and BIM in International and Algerian context are outlined. Finally, this chapter concludes with possible future areas of research.

6.1 Discussion

The review of sustainable renovation of heritage buildings highlights the need for using cross-disciplinary sophisticated processes and methodologies to cope with the contradiction between sustainable design and preservation of heritage values. While previous research has discussed the potential benefits of implementing IPD+BIM in construction projects, this research focused on a new contribution to this need, focusing on the intersection of IPD and BIM for heritage building renovation, which fills this knowledge gap by reporting on different real-world projects. The results demonstrate that shifting into IPD and BIM could be an effective way to go beyond achieving the target balance (such as preserving heritage values, improving user living conditions and safety, and energy efficiency) to achieve high-performance buildings (i.e., a zero-energy building in Case 1). Although few heritage buildings have been renovated using IPD and BIM, the results confirmed that significant developments and changes have already taken place in recent years in existing practices and differ from project to project. There is also a large unexplored potential of IPD+BIM in the current renovation literature and in particular the renovation of heritage buildings, which needs to be investigated.

According to the results, IPD and BIM synergies allow understanding and integrating heritage values into decision-making frameworks that revolve around energy performance improvement, via the preparation of better collaboration and integration processes. With this limited sample size of projects, we cannot approve a causal path that IPD and BIM have led to success, but we do have a body of collected data that allows us to extract some inferences. Regarding changes occurred on the planned designs in Cases 1, 2, and 3 to limit adverse impacts on heritage values, the simultaneous use of BIM and IPD allowed for streamlined real-time decision making and approvals, response to unforeseen conditions, review of heritage agencies, and evolution over time. Early involvement of key participants in the various projects facilitated the generation of various simulations and addressed spatial and historic preservation constraints at an early stage, maximizing positive outcomes and saving time and cost. The teams' collaborative culture and limited liability allowed changes to be captured in a transparent way, focusing on "best for the project." Creative and novel ideas/solutions were retained through open communication, and thus opportunities for innovation were increased. Within this framework, BIM was found as an enabler of IPD that fostered collaboration and allowed design teams to provide faster complex analysis and rapid assessment of energy simulations through coordination of BIM with energy models, as well as performance of renovated buildings in operation. All stakeholders were able to see what was being proposed through the virtual building models. Nevertheless, and similar to other heritage cases in previous studies, the effectiveness of BIM was limited by the complexity of the heritage structures. BIM does not seem to work as well for clash detection in this context, compared to its application for newly branded buildings. In this regard, Case 4 confirmed that incorporating other emerging technologies within BIM and finding innovative solutions could overcome this problem. On the other hand, it is important to develop, upgrade, and adjust BIM simulation software to accurately represent heritage building conditions and allow accurate environmental simulations within BIM modeling.

Contrary to the literature, the results reveal that the type of contractual arrangement is not an overriding factor in project success. Although all four projects used different types of contracts (design-bid-build, design-build, tri-partite IPD contract, Architectural & Engineering service), they succeeded in achieving proper team collaboration and sustainability. In turn, the search of best value and the teamwork motivation (architect, engineers, owner, and general contractor) were the drivers for defining the level at which the teams could implement the tools and processes effectively and, therefore, achieve sufficient outcomes. The selection of qualified integrated firms committed to the collaborative process alongside the owner on such complex projects facilitated the trust established among team members. The guidance and leadership provided by the owners to the participants was crucial to the development of the team culture. Similarly, the willingness of the owners, particularly in Cases 1 and 2, played a specific role in using their education, leadership, and collaborative project delivery skills to guide and cooperate with the project participants.

6.2 Conclusion

The sustainable renovation of heritage buildings deals with multiple criteria and values, heterogeneous stakeholders, and the selection of renovation alternatives. As such, the complexity of renovation projects requires the adoption of more sophisticated technologies and project management models to cope with the contradiction between sustainable design and preservation of heritage values, as well as to improve project productivity and final performance.

This research aims to evaluate the application of several IPD strategies and tools through BIM, to improve sustainability aspects and efficiency of heritage renovation. The focus is to determine the collaborative practices shared across projects and the level to which teams were able to effectively implement the tools and processes.

Therefore, an extensive literature review and mixed methodology including QCA principles in addition to triangulation approaches for data collection and validity of the research work was conducted. A coding scheme was developed consisting of 50 criteria, categorized into 15 categories and grouped into five thematic strands (*People, Process, Policy, Technology,* and *Product*) to allow a comprehensive and systematic exploration of the potential use of IPD and BIM in different real-world heritage renovation projects.

The findings present considerable advantages of IPD and BIM collaborative strategies application over different thematic strands and contract types. Although few heritage buildings have been renovated using IPD and BIM, the results confirm that significant developments and changes have already taken place in recent years in existing practices and differ from project to project. The application of IPD and BIM technologies for the renovation of heritage buildings changes the team culture and organization, on how the supply chain itself is shaped, and projects are executed, through digitalization, guided by principles and protocols, to propose an integrated design and construction process.

The hypothesis has been proven correct. This thesis revealed that shifting towards the application of IPD and BIM collaboration strategies in heritage renovation allows integrating heritage values into holistic decision-making frameworks that turn around energy performance improvement, thereby achieving the target balance between sustainable design and heritage values preservation, as well as enhancing process productivity and final performance. Shifting into IPD and BIM could be an effective way to go beyond achieving the target balance (such as preserving heritage values, improving user living conditions and safety, and energy efficiency) to achieve high-performance buildings (i.e., a zero-energy building). The collaborative environment allowed an extensive and continuous planning and problem-solving process to manage risks and address technical and spatial constraints that incited changes in the primary design plan to preserve heritage values. Collaborative BIM and IPD strategies preserved the project's heritage values, while dealing with technical and spatial constraints through effective change management early in the design process. IPD and BIM application lead to more effective decision-making on exploring and selecting among a large number of renovation alternatives and approaches available in the mark, and thus leading to cost savings, time-saving, and improving quality and sustainability.

The BIM integration enables to gain *in automation and data manipulation* at different phases of a project's life cycle. In addition to the *knowledge sharing* opportunities (people) through the introduction of technologies that more efficiently support information sharing, the *interoperability* between BIM applications and energy simulation tools (technology) improve the *visualization* and *virtual simulation* of the renovation practices through a full virtual-construction model, which can be used for operation and maintenance, as well as future upgrading of the building (process and product).

Figure 6.1 summarized 31 benefits of the potential shift of IPD+BIM in the sustainable renovation of heritages through the analytical five strands (see Figure 6.1).

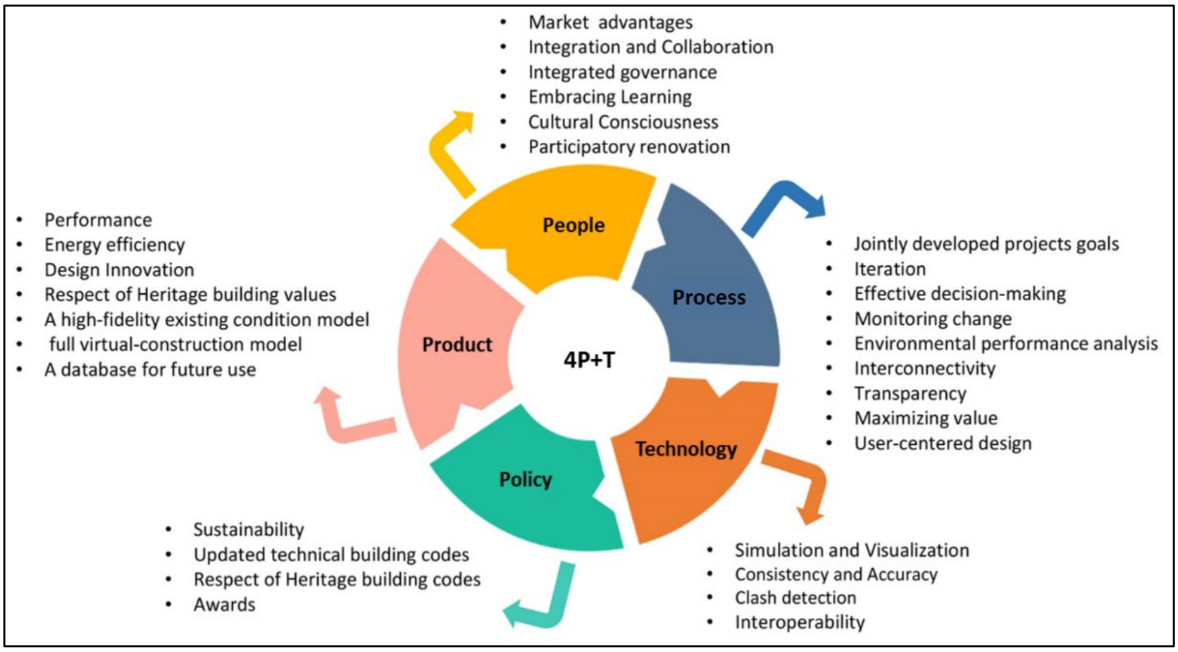

Figure 6.1. The potential shift of IPD+ BIM in the renovation of heritage buildings (Source: Author)

It is fundamental to understand the challenges and potential for value creation/addition of using IPD and BIM in the early design stages. The search of best value and the teamwork motivation (architect, engineers, owner, and general contractor) are the drivers for defining the level at which the teams could implement the tools and processes effectively and, therefore, achieve sufficient outcomes. The selection of qualified integrated firms committed to the collaborative process alongside the owner on such complex projects facilitated the trust established among team members. Trust among team members is critical and a key element on the collaboration built. Trust/psychological safety turns out to be a vital factor. The way to achieve this is to create a vulnerability base trust alignment between the team members even in a complex building scenario.

On the other hand, the owners play a specific role in how to use their education, leadership, and competency relative to collaborative project delivery, to guide and co-operate with the project participants. The lack of education, leadership, and owner competence are very significant issues limiting the use of IPD and similar innovative approaches in heritage projects. Some of the most significant barriers to this type of implementation are related to the following:

(1) Lack of understanding of what these methodologies offer,

(2) The reluctance of owners to invest based on life cycle analysis versus immediate upfront costs,

(3) Inertial resistance generated by conventional processes and construction standards.

In implementing IPD and BIM, the choice of organizational and business structure must be aligned with the characteristics of sustainable renovation and match the capabilities and needs of the participants to implement the heritage projects effectively and in an applicable trend. Here, the challenge is to embrace that pace of change, apply new methods to measure progress, and close the gap between the promise of innovation and reality. Finally, we identified below some lessons learned that would be useful to consider in future implementation of IPD and BIM for successful heritage renovation projects.

Lessons learned:

From all the above, many lessons can be learned. They are summarized below:

1. BIM and IPD Adoption levels vary according to delivery and management processes, as well as via education and training.
2. The composition of teamwork plays a vital role in enabling the adoption of an IPD approach in an efficient track. The selection of qualified integrated firms committed to the collaboration process, along with the owner in complex projects, could facilitate the trust built among team members to achieve project goals.
3. The owner should take responsibility for creating a culture for change and leading the integration and collaboration. The owner ensures the good communication and respect among stakeholders and that project goals are met. Training may also be needed to improve this area.
4. The choice of industrial manufacturers should be taken after careful consideration to avoid any disrupts in the project and maximizing their values.
5. The integration of the constructor into the team from the design process for cost estimating and constructability reviews. The precise model for this integration is flexible.
6. Setting goals and measurable performance targets early in the renovation project allows achieving better and exceptional performance for projects. By modifying metrics and measurements, and prioritizing goals, the team will stay on track to meet the goals set at the beginning.

7. Include a performance guarantee and confirmation clause for at least one year after construction. This allows the owner to require the design team to prove that they have met the contracted energy goals, which is important to define in the contract.
8. The high level of collaboration among project team members is essential, regardless of the procurement method.
9. Contract terms must be clearly defined to show that contractors and manufacturers are encouraged to participate in the design phase
10. An incentive system development by the owner is recommended along with compensations.
11. Users' involvement in the establishment of effective control mechanisms or measures to check and reduce negative user's behavior.

6.3 Contribution to knowledge

This contribution is relevant to heritage preservation research and practitioners in Algeria and worldwide, who can use the results of the study to better understand and navigate IPD through BIM and its potential shift in the sustainable renovation of heritage buildings with multiple stakeholders (e.g. designers, engineers, contractors, etc.). In addition, it provides decision support for professionals and the government to choose the suitable delivery method (contract and legal terms) and best practices for carrying out similar projects to achieve high-performance buildings.

The study has three several points of focus (i) the use of IPD and BIM; (ii) sustainability measures, and; (iii) the renovation of heritage buildings. However, it intended predominantly to add value on the renovation of heritage buildings. The integration of IPD and BIM collaborative strategies were suggested as response to the need for using cross-disciplinary sophisticated processes and methodologies in heritage renovation projects in order to cope with the contradiction between sustainable design and heritage values preservation. The simultaneous use of IPD and BIM together in construction is already well-known in the literature. However, this study is comprehensive discussion of the impact of their simultaneous use on a different context (project type). This study addressed this knowledge gap on conducting a holistic and multi-faced analysis of different case studies. In addition, new insights have been added to empirical research on IPD+BIM and collaborative design.

The findings demonstrate evidence that shifting into IPD and BIM could be an effective way to exceed the target balance achievement (such as heritage values preservation, users living conditions and safety enhancement, and energy efficiency) toward delivering high-performance buildings (i.e. zero energy building in case 1). Although few heritage buildings have been renovated using IPD and BIM, the findings confirmed that significant developments and changes have already occurred during the last years in existing practices and differ from project to project. There is also a large unexplored potential of IPD+BIM in current literature on renovation and in particular renovation of heritage buildings, which needs to be investigated.

On the other hand, IPD and BIM synergy was proposed as an innovative solution for heritage renovation projects in the Algerian context. The findings of this study are proposed as a basis and helpful references to evaluate the necessary steps to implement IPD and BIM successfully for renovation in pilot projects.

6.4 Limitation of the research study

The thesis has presented a broad theoretical and practical overview of the use of IPD in junction with BIM for sustainable renovation of heritage buildings. Nevertheless, the scope of this research discuss the phenomena in the general context, it doesn't address the Algerian context in particularly. The study scope is not limited to renovation projects in a specific region (such as the United States or Canada in the cases studied) as the criteria studied were recorded in a variety of projects and locations. The research serves heritage renovation projects worldwide, although each project is unique and certain requirements (e.g. legislation, environmental conditions) may vary depending on the location.

Significant limitations to this study concerned also the data collection in terms of willingness, as well as the availability of heritage case studies that have been renovated using IPD and BIM, where missing data could have led to different results. In addition, although the sustainability is part of the overall goal of the project, this research is qualitative and focused mainly in the assessment of the applied IPD and BIM collaborative strategies and tools. A detailed checklist in quantitative terms is not provided regarding green conformity of the case building. Instead, the sustainable measures are mostly provided in means and percentage to improve the visibility of the buildings outcomes importance.

6.5 Recommendations for future improvements

Given the lack of IPD+BIM use in heritage renovation, this research makes the following recommendations both in the International and Algerian context:

6.5.1 International context

- Owners and developers of heritage projects should mandate BIM and IPD adoption in contracts. In addition, owners should measure and reward IPD and BIM adoption in their pilot projects to build confidence, starting with small projects and building capacity with medium-sized projects.
- The involvement of Heritage governmental bodies during design phase.
- More education and training opportunities especially for the heritage preservation community and project managers, to become digitally adept.
- Future academic research should study and publish papers on the subject.
- More incentives on the part of client for interdisciplinary cooperation.
- The choice of the organizational and business structure should smoothly be adapted towards the sustainable renovation characteristics and best suited to the capabilities and participants' needs to implement the heritage projects efficiently, and in an applicable tendency.
- Creation of an approach that combines different methodologies, techniques and software to open up new possibilities of elevating IPD and BIM synergy to attain sustainability and high-performance outcomes. In this regard, the advancement of digitalization can be used as a basis for the industry 4.0 adoptions in the new/existing building (or the manufacturing industry in general) for benchmarking the effects of digital technologies.
- Development of Rule-based Code Checking to implement design verification and validation comparing BIM models against current codes and regulations translated into parametric rules.
- Conception of intelligent algorithms capable of automatically converting point clouds into parametric objects.
- Include the standard deliverable information requirements for heritage renovation at three levels: data modeling, data exchange, and process modeling. As such, it is required to further develop standard Level of Development (LOD) and Level of Information (LOI) for heritage metric survey specifications and model production.

6.5.2 Algerian context

- Innovation adoption is not a simple matter of tools and equipment. It carries within itself the need for cultural change, for a profound evolution of expected skills. This means reconsidering the issues of new collaborative technologies and delivery methods, namely BIM and IPD, in the light of local specificities.
- Awareness and involvement of the actors in the construction industry, who, in the end, are the only ones who can decide to make the effort to change their working methods. The current finding is that this effort is long in coming.
- Awareness of the owners that IPD and BIM need investment and a cost that some owners are reluctant to pay, but fragmented traditional approaches have a delay and a cost even more important at the time of their realization or/and during the life/operation of the building.
- The Financial support from the federal government, especially for experts from construction companies on setting up venture capital funds to help the best start-ups grow and to connect them with developers and contractors to facilitate the use of BIM in heritage.
- Government should be the primary driver for implementing better renovation work, as the majority of heritage renovation work considering on public properties.
- The Algerian government needs to develop and deploy a policy framework for the successful implementation of digital strategies and innovative methods. It is recommended that Algerian construction actors, work together for regulation enrichment and creation of industry standardized (i.e. provisions and norms), adapted to the Algerian legislation, to ensure that the enablers of BIM and IPD.
- Creation and development of new contracts and legal frameworks to achieve collaboration and benefit fully from BIM and/or IPD.
- There is a significant lack of a common and operationalized understanding on the concept of BIM, IPD and energy management. Therefore, it is primordial launching education and training courses as well as reorientation the existing ones. BIM and IPD should also be integrated into all tertiary institutions curriculum in Algeria that offer courses related to heritage preservation and construction, to address well-trained professionals lack to manage BIM and IPD tools and strategies in construction organizations.

6.6 Potential for future research

Due to time constraints and the research scope, it is recommended that some areas of work be further investigated and broadened, as follows:

- Although we consider the research approach and findings to be robust, we expect that expanding the investigation to other cases and applying a different research methodology may provide additional information. In this sense, future research could explore the current research questions within a quantitative research framework to expand the study's investigations and provide more evidence to validate the practicality within X ways, and generalize the results.
- Future researches should consider the sustainability measures in a broader perspective.
- The analytical framework - developed in this thesis - is a retrospective analysis tool that enables the relationships' assessment between the maturity of teams' projects and the level of benefits they could achieve from BIM/IPD collaborative strategies so far. However, it is proposed that the developed framework can serve to manage projects, and therefore play a leading role (instead of a lagging role), in supporting the collaborative innovative approaches implementation for heritages, namely in the Algerian context.
- We highly recommend that future research address the establishment of assessment matrix that investigates the level of maturity of organizations with the BIM/IPD applications.
- We highly recommend studying the willingness, capabilities, and readiness of the Algerian heritage industry to improve its project delivery process by implementing the synergy between IPD and BIM.
- The understanding of the high-performance outcomes generated from other digital technologies within BIM investment is appeared to be fundamental, as well as overcoming barriers. In this regard, future efforts should focus on examining more case studies that implement technological innovations, their successful processes/actions, and challenges.
- Finally, our perspective is to develop a conceptual framework of a *Cloud-BIM-Based Decision Support System*, which includes multiple criteria decision making to allow faster complex analyses, commissioning and make the appropriate decisions, through advancing interoperability between design team applications.

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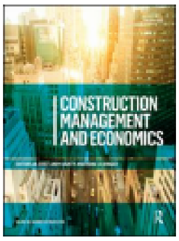
APPENDICES

APPENDIX A - The published journal article



Construction Management and Economics

Routledge
Taylor & Francis Group

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rcme20

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To cite this article: Bani Feriel Brahmi, Souad Sassi Boudemagh, Ilham Kitouni & Aliakbar Kamari (2021): IPD and BIM-focussed methodology in renovation of heritage buildings, Construction Management and Economics, DOI: 10.1080/01446193.2021.1933557

To link to this article: https://doi.org/10.1080/01446193.2021.1933557

Published online: 05 Jul 2021.

CONSTRUCTION MANAGEMENT AND ECONOMICS
https://doi.org/10.1080/01446193.2021.1933557

IPD and BIM-focussed methodology in renovation of heritage buildings

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ABSTRACT

Complexity in the sustainable renovation of heritage buildings requires adoption of more sophisticated technologies and project management models to deal with the contradiction between sustainable design and heritage values preservation, as well as enhancing process productivity and final performance. This research aims to assess the application of several Integrated Project Delivery (IPD) strategies and tools through Building Information Modelling (BIM), determining shared collaborative practices across the projects and the level to which the teams were able to implement the tools and processes effectively to enhance sustainability aspects and efficiency of renovating heritages. The research adopts a mixed methodology, Qualitative Comparative Analysis triangulating the collected data. An intensive review of related literature is carried out, besides data collection and analysis of four real-world heritage cases (in different contexts). The research study enables a comprehensive and systematic exploration of the potential use of IPD and BIM within the development of an analytical framework consisting of a set of defined variables including 50 criteria, classified into 15 categories, and grouped into five thematic strands (*people*, *process*, *policy*, *technology*, and *product*). The findings reveal that IPD and BIM simultaneous use allows integrating heritage values into holistic decision-making frameworks attaining high-performance outcomes in heritage renovations.

ARTICLE HISTORY
Received 27 February 2020
Accepted 19 May 2021

KEYWORDS
Integrated Project Delivery (IPD); Building Information Modelling (BIM); Heritage building; sustainable renovation; heritage renovation

Introduction

Heritage buildings are substantial social capital to any country. They are defined as existing building with significant architectural, aesthetic, historic or cultural values that require conservation (People's Democratic Republic of Algeria 2005).[1] These assets demonstrate the history and culture of people and countries. Renovating the heritage buildings holds massive potential to preserve the sense of identity and continuity in a fast-changing world for future generations. Nowadays, the renovation of heritage buildings has become a revivification pathway to promote sustainability as well as to protect the heritage buildings' significance and values (Fouseki and Cassar 2014). It puts out economic, cultural, social, and environmental advantages to urban communities (Tweed and Sutherland 2007).

Sustainable renovation is influenced by international economies, community interest and involvement. Research about energy renovation is expected to reduce the CO2 emissions and achieve added benefits, such as the reduction of life cycle cost, and decreasing maintenance costs. From the environmental perspective, heritage buildings are categorized to have a very high energy demand, as well as a very low indoor climate standard, particularly when it comes to a desirable indoor climate (Rasmussen *et al.* 2015, Tomšič *et al.* 2017). For instance, 35% of the European unions' buildings are over 50 years old and almost 75% of the building stock (including heritages) is energy inefficient (European Commission 2019). The same statistics show existing buildings renovation can lead to significant energy savings, as it could reduce the EU's total energy consumption by 5–6% and lower CO2 emissions by about 5%. Contrariwise, only about 1% of the building stock is renovated each year (European Commission 2019). In addition, the debate around the contradiction between the principle of "minimum intervention" and the current objectives of energy performance, as they have a high impact on the architectural values, which should be preserved through the renovation intervention (Fouseki and Cassar 2014).

The sustainability of a heritage renovation project is affected and depended on a long list of aspects

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(Kamari *et al.* 2017a). Given a building, renovation task concerns deciding on how to change or improve building components and parts, e.g. through the replacement of new windows, the insulation of building envelope, or even change of use of a building. On one side, this often leaves the clients (or owners) with a relatively large number of choices to make decisions about what and which intervention levels and renovation alternatives to pursue the renovation. On the other side, the design team must deal with increasing requirements for energy demand and indoor environment while addressing the architectural aspects and qualities in developing appropriate renovation scenarios (design options). Doing it requires handling enormous complexity concerning both multiple involved stakeholders (Buser and Carlsson 2016, Kamari *et al.* 2019b) (i.e. related to their demands and priorities) and the renovation objectives and criteria (Marija *et al.* 2015, Kamari *et al.* 2017a, 2017b) (i.e. energy consumption) that need to be met, together with exploring and selecting among a large number of renovation alternatives and approaches available in the market (Kamari *et al.* 2019c, Lidelöwa *et al.* 2019). In addition, the complexity is more intensified during early design phases, and significant changes can be made because of information unavailability about the original structure or pre-existing/unforeseen building conditions identified late, and as such, resulting in (i.e.) increased documentation time, and reduced cost control and budget management.

To deal with aforementioned challenges, the sustainable renovation of heritage buildings requires cross-disciplinary sophisticated processes and methodologies (Kamari *et al.* 2019b) to develop holistic decision-making frameworks (Kamari *et al.* 2018a, 2018b) that will help professionals decide on the most appropriate renovation solution (Kamari *et al.* 2019c, 2021, Schultz and Kamari, 2021), to strike a balance by bringing further improvement to (i.e.) the users' living conditions, the safety of the building, safeguarding heritage values, and reducing the energy consumption (Fouseki and Cassar 2014, Tomšič *et al.* 2017). Likewise, finding an optimal number of interrelating policies, processes, and technologies that will contribute to this success with many involved stakeholders, are yet another remaining challenges.

Integrated Project Delivery (IPD) (AIA and AIA California Council 2007) and Building Information Modelling (BIM) (Eastman *et al.* 2008) are two innovative project management methods driven by advances in technology and the redrawing of social relationships (Rowlinson 2017). IPD and BIM were emerged and being evolved to improve the quality in the construction projects, increase their performance, and eliminate weaknesses of current project delivery systems (Azhar *et al.* 2014, Rowlinson 2017). However, many studies revealed that synergy between IPD and BIM provide more pragmatic and effective solutions to complex project issues (Fakhimi *et al.* 2016).

Contrary to new construction, our analysis of existing literature indicates towards the lack of researches that explore the IPD and BIM simultaneous use for heritage renovation in a broader perspective. Therefore, the aim of this paper is primarily to study the potential shift of IPD combined with BIM to achieve the target balance of the sustainable renovation of heritage buildings as well as to enhance project performance and efficiency via preparing better collaborative and integrating processes, assumed as the key for the successful delivery of building renovation projects. The focus is to determine the shared collaborative practices across the projects lifecycle and the level to which the teams are able to implement the IPD and BIM tools and processes effectively.

Research methodology

An abductive research approach seemed most suitable in the current project given the nature of the research objectives. Abductive reasoning consists of a pragmatic approach through a process of "systematic combining" in academic research, as a possibility to capture and take advantage not only of the systemic character of the empirical world, but also of the systemic character of theoretical models (Dubois and Gadde 2002).

To thoroughly understand the extent of using IPD and BIM collaborative practices in the sustainable renovation of heritage buildings, and also to increase the validity of the study and generalising the knowledge, we adopt a frequently used qualitative research strategy called "methodological triangulation" (Denzin 1978, Love *et al.* 2002), which involves the use of multiple methods of data collection and analysis to develop a comprehensive understanding of a phenomenon. At first, a brief review of related literature is carried out. Then, the application of triangulation approach in this paper activates Qualitative Comparative Analysis – QCA (Ragin 1987, 2000) of the subject matter.

Literature review

Based on narrative literature review, it is carried out on different steps. Initially, the search of scientific contribution sources is carried out through the reliable database Scopus. The keywords that were used (using "Title/Abstract/Keyword") are: "Heritage BIM", "IPD and Heritage", "BIM for renovation", "IPD and BIM", "IPD and BIM for renovation", and "IPD and BIM for heritage". We collected a total of 748 peer-reviewed documents (including article journal, books, and conference papers) which were published between 2008 and mid-2020 (from the first publication about "heritage BIM" in Scopus to the time of conducting the research). Here, it is worth highlighting the unavailability of documents relevant to "IPD and Heritage", "IPD and BIM for renovation", and "IPD and BIM for heritage" keywords.

Then, we selected only 180 documents with the highest citations (60 documents per keyword) to analyse them. This filter helped in recognising the most effective publications, the evolution of the interest in those subjects over time, and the relationship between them. Besides, we used non-conventional databases of universities and recognized international associations (e.g. The University Digital Conservancy) to collect practical publications. As the outcome, we selected 20 documents from the most relevant and comprehensive, ranging from research reports, guidelines, and white papers.

Many researchers investigate the potential of using IPD and/or BIM to address specific industry problems. Some researches deliver theoretical frameworks, while others investigate IPD and BIM current use and their implementation. The studies investigated used varied methods: case studies, interviews, surveys, and literature reviews. In this paper, we focus mainly to determine the knowledge gaps and position around the research's goal.

Qualitative comparative analysis

QCA is undertaken when there is not sufficient data to statistically consider a case study, but when the richness of the information about each case allows powerful and compelling stories about the likely causes for desired outcomes to be told (Ragin 2000). Application of QCA principles besides triangulation approaches for data collection increases the validity of this study by:

a. Development of an analytical framework: In employing a QCA method, an analytical framework for comparative case study research is developed based on the literature survey, using a coding scheme, to enable a comprehensive, structured, and systematic exploration of the IPD and BIM application in different heritage environments through their lifecycle (see more details in section). The framework strives to encompass the multifaceted perspectives of the IPD and BIM synergy and facilitates the complex understanding of the sustainable renovation design process, given its highly complex value profile and many heterogeneous stakeholders. Its development depends on analytical inference rather than statistical inference, where generalisability lies not in replicating the outcomes but rather the strategies and practices applied. And,
b. Analysis of case studies: the study uses an exploratory case study design (Yin 2003) through the use of the analytical framework to investigate the changes undertaken when using IPD and BIM to renovate heritage buildings and within different types of contracts. Regarding data availability, four projects (from USA and Canada) were selected due to the used IPD and BIM collaborative practices, and project goals to achieve sustainability targets, as well as their relatively new insights on the topic, which allow the effectiveness of the comparative analysis. Hereafter, the descriptive analysis and in-depth cross-case analysis are supplemented with a "truth table" (Cheng and Johnson 2016) based on "low detail discovery assessment" (Succar 2010) displaying graphically how each of the cases leveraged the BIM and IPD framework.

Background

IPD and collaboration levels

The traditional delivery methods have shown to be inefficient and litigious (Azhar *et al.* 2014, El-adaway *et al.* 2017). The fragment of traditional approaches and the fights for individual benefits results in delays, increased cost, wastage of materials, and reduction in productivity/quality control (Ashcraft 2012). Therefore, IPD emerged as an alternative delivery method to reduce the current inefficiencies and wastes of the construction industry and to improve its performance (AIA 2014). The sustainability and high-performance goals serve as positive drivers of IPD adoption to create interdisciplinary development of appropriate solutions (Sive and Hays 2009). AIA *et al.* (2012) considers six "markers" representing the characteristics unique to full IPD model (Pure IPD) including: relational contracts, protection from litigation, joint validation of goals and target, collaborative decision making, open communication, and risks identified and accepted early.

Today, many projects use IPD as a philosophy (IPDish) via incomplete models of integration. Numerous variations of IPD approaches could occur through application of different IPD strategies, principles, and tools (commercial, social, environmental or technological) to a variety of contractual arrangements, such as the early involvement of key participants and BIM use (Sive and Hays 2009). As such, current IPD approaches can be defined as proactive approaches to tying the multiple participants towards the goals outlined in a collaborative environment to deliver high-performance outcomes (schedule, budget, sustainability).

The synergy between IPD and BIM

BIM is a Digital delivery method to generate a systematic approach for managing critical information within a unique and shared platform, forming a reliable basis for decisions throughout the building life cycle (Succar 2009, Bradley *et al.* 2016). Many studies and documents highlight several connections and the benefits of using BIM and IPD together (Becerik-Gerber *et al.* 2012, Azhar *et al.* 2014, Kahvandi *et al.* 2017). They argue the integration requirement that can be effectively accomplished by BIM implantation to achieve better decision-making and remove its implementation barriers to deliver high-performance buildings (Azhar *et al.* 2014, Fischer *et al.* 2014). Contrariwise, IPD is proposed as the best project management method to leverage BIM functionalities (AIA 2007). Migilinskasa *et al.* (2013) and later Fischer *et al.* (2014) discuss that BIM adoption supported by the integrated arrangement, can remove collaboration barriers, and enables the project team to function as a virtual organisation within the search for better project delivery solutions and alternatives rather than the fights for individual benefits. Figure 1 illustrates the ability of the IPD design process through BIM to make changes and provide optimal solutions, at an early design stage, to deal with the project complexity at a much lower cost than is otherwise possible.

Based on current IPD and BIM implementation experience in new construction and existing buildings, lessons learned from best practice examples can be extracted (AIA *et al.* 2012, Cheng 2015). Ilozor and Kelly (2012) and Nawi *et al.* (2014) conducted literature review on the subject. The authors highlight the need for more evidences of IPD + BIM success to achieve sustainable projects within high performing and collaborative teams, especially in quantitative terms. The integrated and collaborative supply chain management through a shared platform can provide optimal solutions, at an early stage, for the current

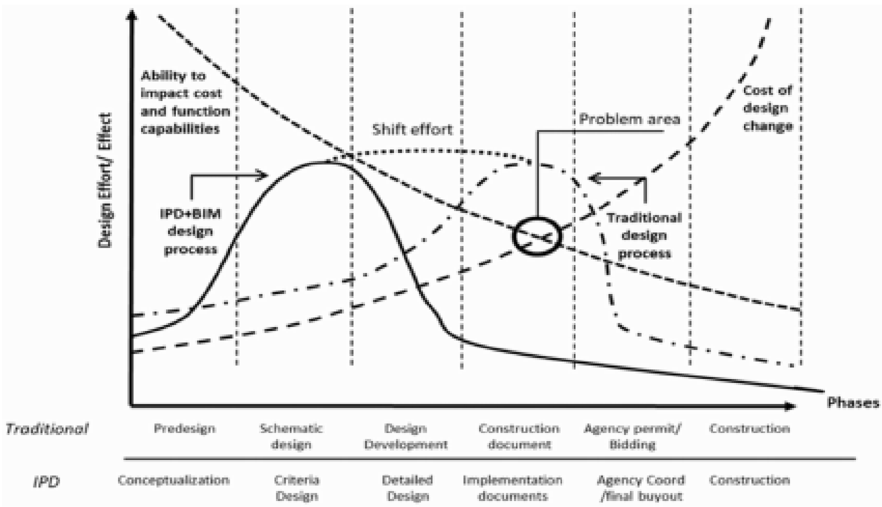

Figure 1. MacLeamy curve of the potential shift into IPD and BIM for construction projects (Source: adapted from Smith and Tardif 2009, Kamari and Kirkegaard 2019a).

construction projects issues and deal with their complexity (Fakhimia *et al.* 2016). It could significantly enhance the proper communication for efficient environmental performance analyses and sustainability-enhancement (Wong and Fan 2013), reduce the confusion between the project participants on supporting the decision-making process (Nawi *et al.* 2014), and therefore, reducing errors and assuring cost and time optimisation (Becerik-Gerber *et al.* 2012, Ilozor and Kelly 2012). Despite these insights, limited researches explore IPD + BIM on different projects type and contexts, especially for heritages. There is a need to verify this synergy on discussing the different projects' requirements.

IPD and BIM in heritage building projects

Recently, BIM field has become a topic of great interest in heritage renovation within technology and methods development, notably 3D laser scanning and photogrammetry. Almost all researches have been written on the potential benefits of using BIM for the digital documentation of buildings (Pocobelli *et al.* 2018). It is subject to larger conversations of its effectiveness, depending on challenges of high modelling/conversion effort from captured building data into semantic BIM objects, and variety/complexity of heritage building components that are not representative for current typical BIM software libraries, but also depends on the required level of details for conducting engineering/design analysis (López *et al.* 2018, Pocobelli *et al.* 2018). Contrariwise, little studies have addressed BIM use for managing the whole intervention design and the renovation processes, such as the generation and evaluation of various design alternatives.

Lucarelli *et al.* (2019) recommend IPD methodology to allow building process improvement due to data sharing and communication between stakeholders before work begins to eliminate any possible delay. Cambeiro *et al.* (2012) discuss the role of IPD elements application, through a case study, as a solution to minimize the budgetary deviations and risks assumed by every participant, in reducing the reworking and errors through iterative design alternative. In addition, Jensen *et al.* (2018) highlight the benefits of relational contracting and IPD for sustainable renovation projects on creating trust and using a wide range of strategic, tactical, and operational tools by collaborative teams.

The impact of IPD and BIM use is not really covered through the heritage renovation lifecycle. Very few researches have addressed the simultaneous use of BIM and IPD in a sporadic and limited manner. Megahed (2015) recommend BIM as support for IPD in heritages to allow model-based collaboration between people, systems, and business structures and practice. Conversely, Counsell and Taylor (2017) consider IPD as a helpful benchmark against which to analyse the BIM goal in heritages, as an integrated building's delivery to conserving the cultural sustainability of built heritage during their lifetime, by using management mechanism incorporating all stakeholders.

In contrast to new construction, very few renovation real case studies (including heritages) were carried out in the current literature. In the next sections, we shall conduct a qualitative comparative analysis on real cases to exploring in more detail how the synergy between BIM and IPD enhance the heritage renovation context and achieve sustainability within different projects' change process and outcomes to gain new insight.

Development of an analytical framework for qualitative comparative analysis – QCA

In employing a QCA method, an analytical framework for comparative case study research is developed to enable a comprehensive and systematic exploration of the IPD and BIM application in different environments. To develop the analytical framework, we use the well-grounded "collaboration through innovation" framework in the construction industry including *context*, *content*, and *outcomes* from the study by Poirier *et al.* (2016) based on Harrison (2012), combined with the 4P + T model in (Kamari and Kirkegaard 2019a) consisting of five strands: *people*, *product*, *process*, *policy*, and *technology*. This combination allows representing how BIM and IPD collaborative practices entail the transformation of the interactions between and within each of the well-known strands that are conditioned by context to produce desired outcomes (See Figure 2). In this framework,

- *The context* describes in which the IPD and BIM implementation process takes place. There are two aspects to consider: the outer context refers to the economic, social, political, and sectorial environment in which the renovation realized; and the inner context refers to the project characteristics (levels of budget, cost, schedule, risks, and technical complexities).
- *The content* describes the range of collaborative strategies, processes, and tools that are used by

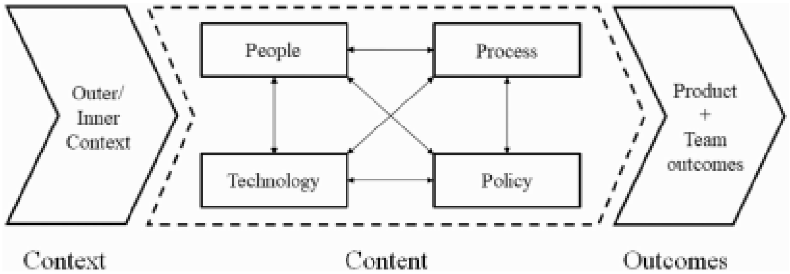

Figure 2. The paradigm showing the development of the case study analysis.

the teams to achieve the project's goals (the "How").

- *The outcomes* includes team outcomes that are measured by looking at how well the teams collaborate and so project's goals are achieved.

The analytic framework is used to more holistically address all the strategies, business models, and tools applied by the project teams through the application of IPD and BIM in heritages context, including all the stakeholders and project phases. It, therefore, enables us to carry out the case studies in a structured and systematic manner to provide both a comprehensive view of the cases and comparison between them. With a set of defined variables, through a *coding scheme*, we determine the shared collaborative practices during the whole lifecycle across the projects and the level to which the teams were able to implement the tools and processes effectively.

Coding scheme

From the 200 selected documents (see research methodology section), we selected 17 documents (ranging from journal articles, research reports, guidelines, and white papers) that are based on "Theoretical Integration" approach (Sarhan *et al.* 2019) or case studies. They mostly discuss comprehensively the feasibility and multifaceted perspectives of integrating BIM and/or IPD on new brand/renovation projects, with focus on application of strategies, tools, and processes. To develop reliable and valid analytical framework, we extracted all the predefined theoretical components and variables. As a result, the collected data after being coded frame the study in a comprehensive, structured, and systematic manner (see Table 1) around:

- Strands: five core entities, which configure the basis for framing the BIM and IPD collaborative strategies.
- Categories: 15 generic categories on the applied strategies, which employ a range of criteria for their assessment.
- Criteria: 50 variables universally relevant and common to renovation project delivery, which investigate and compare how IPD and BIM collaborative tactics or strategies are adapted and applied in different heritage environments through their lifecycle, towards understanding the different aspects of heritage renovation.

We elaborate on each strand in the following.

People

IPD is recognized while the contracting members get together at the earliest stages, forming a cross-functional and interdisciplinary team with clearly defined and synchronized roles and responsibilities (AIA 2014). The study of Maskil-Leitan and Reychav (2018) elaborates the importance of the social integration and cultural dimension to achieve a full synergy between BIM and IPD. The study identifies a separation in an IPD project between technical use and social application. Five levels of socio-cultural sustainability are classified in the proposed corporate social responsibility (CSR) framework: management of stakeholders in the project; stakeholder participation in the project; reference to all project stakeholders; stakeholders' involvement at all stages of the building; and tenant involvement as a community in the project. Here, given a renovation building, the occupants' attitudes and behaviour are very important to be investigated during the design stage. Cheng (2015) highlights the importance of managing tenants to maintain resilient relationships between tenants and the team during project tensions and challenges, along with their alignment with project goals and integrating them into collaborative decision-making processes.

The selection of the team and consideration of its capabilities and needs are so crucial and challenging

Table 1. The coding scheme of the analytical framework.

Strands	Categories	Criteria	Succar 2009	NASFA *et al.* 2010	AIA *et al.* 2012	Ashcraft 2012	CICRP 2013	AIA California Council 2014	Cheng 2015	Cheng, and Johnson 2016	Megahed 2015	Barbosa *et al.* 2016	Poirier *et al.* 2016	El-adaway *et al.* 2017	Fischer *et al.* 2017	Yee *et al.* 2017	ASHRAE *et al.*, 2018	Maskil-Leitan and Reychav 2018	Viana *et al.* 2020
People	Team Organisation	Organisational structure	X		X		X		X	X				X	X				X
		Role definition & Accountability			X	X	X		X				X	X	X	X		X	X
		Stakeholders Involvement & management		X	X	X		X	X	X	X		X	X	X	X	X	X	X
		Users/occupants involvement							X		X				X		X	X	
		Leadership	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X
	Team Selection & Capabilities	Team Selection	X	X	X		X		X	X					X		X		X
		Education & Training	X				X			X					X				
	Team Behaviours & Social Dimensions	Collaborative Culture & Trust	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X
		Learning & Continuous Improvement						X							X	X			
Process	Project Planning	Assessments of existing conditions/usage									X	X							
		RFP Development					X		X						X		X		
		Budgeting and Scheduling			X			X	X					X	X	X	X		X
		Goals and Alignment		X	X	X		X	X	X			X	X	X	X	X		X
		Developing key Performance Criteria													X		X		
	Quality assurance and commissioning	Commissioning operations													X		X		
		Measurement and verification							X						X	X	X		X
		Decision making		X	X	X				X			X	X	X	X			X
		Risks management		X	X	X		X						X	X	X			
		Post occupancy performance													X		X		
		Ongoing commissioning													X		X		
	Lean system	Lean Principles and processes		X	X	X				X					X	X			
		Lean tools		X	X	X				X					X	X			
Policy	Contract	Roles and Responsibilities	X	X	X	X	X		X				X	X	X	X	X	X	X
		rewards	X	X	X	X		X		X			X	X	X	X		X	X
		Risks and Compensation	X	X	X	X		X		X			X	X	X	X		X	X
		Liability and insurance		X	X	X		X		X				X	X	X			X
	Regulations	Heritage codes & regulations									X						X		
		Codes & standards	X	X		X	X		X			X	X		X				
		Protocols	X			X	X		X			X	X		X				
		Performance	X												X		X		
		Sustainability	X	X											X		X		
	Guidelines	Best practices	X																
		Benchmarks	X																X
		Classification systems	X												X				
Technology	Software	Applications	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
		Information exchange and interoperability	X			X	X				X	X			X				
	Hardware	Building examination tools									X	X							
		Workplace & Interactive artefacts	X	X	X	X	X	X	X	X			X			X			X
	Network	Data security	X				X				X	X							
		Access control	X				X				X	X							
Product	Non structured output	Profit and Payout	X	X				X		X				X	X				X
		Budget and schedule	X	X				X	X	X				X	X				
	Structured output: Physical components	Energy performance		X					X						X		X		
		Daylight & IAQ							X						X				
		Water cycle & Materials							X						X				
		Users' living conditions and safety							X						X				
		Heritage Values Preservation									X	X							
		Innovation & creativity				X			X										
	Structured output: Virtual components	Existing condition model									X	X							
		Record model	X			X	X				X	X			X				X

to execute the project efficiently (ASHRAE *et al.* 2018, Ashcraft 2012). Viana *et al.* (2020) mention the special focus on member's behaviours in the team category research. According to NASFA *et al.* (2010), the behavioural principle is the key aspect required to achieve success, where the culture of trust and the willingness of parties to change in collaboration are the critical elements of integration. Here, the client has a complex role as a change agent, on how to use their power and influence to demand that change among project participants (Vass and Gustavsson 2017, Lindblad 2019). IPD projects involve some form of integrated project leadership where decisions are made by consensus (NASFA *et al.* 2010), which allows for the creation of a culture that promotes creativity, learning, and feedback (Megahed 2015).

In this framework, People is divided into three categories (Team Organisation, Team Selection & Capabilities, Team Behaviours & Social Dimensions) and nine criteria that describe the collaborative schema between involved stakeholders and their behaviours, including the process of team selection, how the collaborative culture was created through intentional team building, how roles were defined; and how leaders established accountability within the teams.

Process

Viana *et al.* (2020) illustrated the lack of materials available regarding the process in IPD application in the construction industry. ASHRAE *et al.* (2018) implement several key steps carried out from the team building, planning through quality assurance and commissioning, to facilitate and enhance the success of the process to establish zero energy building based on culture and collaborative mindset. Maskil-Leitan and Reychav (2018) describe IPD as the simultaneous development of a product and service at the planning stage. The teamwork can look at alternative outline design solutions and value engineering on a collaborative, multi-level, and iterative basis, where they define the connection point between subsystems and negotiate their interfaces (Ashcraft 2012, El-adaway *et al.* 2017).

The use of Lean construction system in IPD project has a positive effect on several critical areas (AIA *et al.* 2012), where Lean principles and tools focus on maximising value, minimising non-value-added support, and eliminating waste. Cheng and Johnson (2016) explore the powerful complementary strength of IPD and Lean to support success. They conclude that IPD sets the terms and provides the motivation for collaboration, and lean provides the means for teams to optimize their performance and achieve project goals.

In this framework, Process is divided into three categories (Project Planning, Quality assurance and commissioning, Lean system) and 13 criteria that describe the ways the integrated process was leveraged, including iterative workflows for generating and leveraging building data to design and construct the building, a range of issues related to procurement: how the owners developed the request for proposals (RFP), how leaders defined goals, communicated them, and the ways to achieve alignment with them, alongside with the creation of a verification phase post-occupancy. Finally, it describes the lean system's effectiveness on the projects.

Policy

The contract has the highest amount of materials in IPD researches (Viana *et al.* 2020, Yee *et al.* 2017). According to El-adaway *et al.* (2017), the performance improvement of the construction industry should start from the contract and organisation. The authors develop a framework for multiparty relational contracting, incorporating all associated parties to propose a contractual environment more efficient and effective. They address ten critical interrelated aspects of IPD based on a comparison between traditional and relational contracts.

To enable the BIM adoption, Succar (2009) indicates the importance of policy approaches, including the common vocabulary of terms, metrics, and benchmarks, to allow efficient communication. Work procedures and methods were put in place that contain data structure, identifier standards, exchange requirement standards, and process model standards to ensure the team integration that is measured by the number of BIM uses and capabilities (Computer Integrated Construction Research Program 2013, Barbosa *et al.* 2016). Barbosa *et al.* (2016) investigate the general content and usage of existing BIM standards in existing buildings. They describe specifications about BIM deliverable documents, modelling, and collaboration procedures. The authors suggest some components that should be included in such a standard and/or guideline to be used for interventions in existing buildings at three levels: data modelling, data exchange, and process modelling.

In this framework, Policy is divided into three categories (Contract, Regulations, and Guidelines) and 12 criteria that describe the streamlined steps related to contract terms, regulatory, and industry mandates around performance and sustainability to guide decisions and achieve rational outcomes.

Technology

The IPD process requires an Information system to provide broad access to team members and focus on how the information will be created, exchanged, and managed (Ashcraft 2012). Viana *et al.* (2020) cited information & modelling as one of the five major areas of IPD that represent the main modifications from traditional methods, where the collaborative technologies are needed to integrate different parties, foster sharing information, and encourage effective communication (AIA 2014). BIM records complex heritage structures remotely, efficiently, accurately (Megahed 2015), and allows complex analyses at an early stage through interoperable platforms and software (Kamari and Kirkegaard 2019a). Megahed (2015) develops a holistic framework of BIM implementation for heritage buildings and bridges the knowledge gap by articulating issues regarding the technology of surveying methodologies with other informational, technical, and organisational issues of BIM in heritages.

In this framework, Technology is divided into three categories (Software, Hardware, and Network) and six criteria that capture the tools used for information management and processes included BIM environment and recording/design documentation strategies.

Product

Succar (2009) considers BIM as an integration of product and process modelling, and not just as a disparate set of technologies and processes. He divided the process deliverables into products and services, including drawings, documents, virtual models/components, physical components, structures, and facilities. On the other hand, the highly cited Simple Framework of Fischer *et al.* (2014, 2017) combines four key elements: integrated organisation, process integration, Integrated Information, and finally integrated system to create a high-performing building through virtual design and construction (VDC). The authors position the product as a starting point in their IPD framework. A high-performance building that provides measures against the four categories of criteria for the value stakeholders seek (economic, social, environmental, and user value).

In this framework, Product is divided into three categories (Non-structured output, Structured output: Physical components, Structured output: Virtual components) and 10 criteria that refer to the real design solutions and/or digital prototype of a project which contributes to more sustainable buildings.

Analysis of case studies

In this section, we conduct an in-depth qualitative case study analysis followed by a cross-case analysis of three projects (using the analytical model developed in the previous section), to understand the similarities/differences of the applied practices in more detail and how the synergy between BIM and IPD enhances the heritage renovation context. The project studies four cases, and a detailed analysis of one of the cases is presented. As such, the benefit of the strategies, business models, and tools applied by the team project (owner, Architects, engineers, and general contractor) to achieve collaboration success through specific examples are addressed. That leads to facilitate exploring different outcomes and producing new insight.

Subsequently, the descriptive analysis and in-depth cross-case analysis are supplemented with a "truth table" (Cheng and Johnson 2016) that displays how each of the cases leveraged IPD and BIM processes and strategies. The assessment has been made holistically (low detail discovery assessment) (Succar 2010) in the "truth table" analysis and enables us to illustrate the variables in a way that allows the audience to grasp the complexity of the cases rapidly. In addition, by creating a graphic visualisation of the data on building projects, hereby, the variety amongst the cases as they implemented BIM and IPD tools and processes are revealed.

Single detailed case-study analysis

The detailed case study in this paper is Wayne Aspinall Federal Building, with nearly 42,000 square feet of office space, is located in Grand Junction, Colorado. The three-story building was constructed in 1918 and originally functioned as a post office and courthouse. A large extension was added in 1939, and the building was listed on the National Register of Historic Places in 1980. It currently houses nine Federal agencies. With funding from the Under American Recovery and Reinvestment Act (ARRA), The U.S. General Services Administration (GSA) initiated a major renovation of the Aspinall Courthouse, consisting of roughly $15 million overall project cost and focussing on historic preservation and energy efficiency upgrades. The approach acknowledges the federal government's goal to be carbon-neutral by 2030. The project began in June 2010 and was completed in

February 2013. Managing the schedule and keeping the project on track was a challenge given the complexity added by the need to keep the building operational for the tenants and the uncertainties about the historic-review process. Therefore, the project used IPD principles through a design-build delivery method to ensure an on-time award and meet the budget.

The detailed and holistic assessment of the used BIM and IPD strategies using the developed analytical framework in Table 1 is presented in Appendix A. The assessment has been done through conducting four semi-structured interviews with representatives of the main contracting parts (two project architects, owner's representative, and structural design engineer), as well as the accurate review of the project's reports, documents, and technical articles that are published in the contracting firms' websites and other online sources.

It is observed that the collaborative environment allowed extensive and ongoing planning and problem-solving process to manage risks and preserve heritage values while dealing with technical and spatial constraints. The most considerable change was resulting in the modification of the PV (photovoltaics) system design. GSA's Regional Historic Preservation Officer (RHPO) determined that the PV canopy that covered the entire roof posed an adverse effect, and alerted the Colorado State Historic Preservation Office (SHPO) and other external agencies in a timely manner. To help manage the risk and uncertainty of the SHPO's historic-review process, as the project team awaited approval, the team reached out and developed a strategy with the SHPO to phase their review process. The project team focussed on resolving their demolition plans (of some interior walls) with the SHPO first. After receiving approval, the team began demolition while the rest of the project was still under review. The design team then focussed their efforts on the next phase of the building and worked to incorporate feedback from the SHPO. The team was able to use this process to keep the project moving forward and manage the risks associated with the SHPO review. Here, the GSA project manager's leadership skills played an essential aspect of the project's success. The GSA did further analysis and determined that a different combination of green technologies could achieve the targeted performance goals. Thereafter, consultation focussed on a limited set of adverse effects, managed by the RHPO. The project team was able to redesign the PV canopy, using BIM-based energy simulation, as an "additive" structure so that it could be removed without adverse impact to the property after 25 years, and completely eliminate its visual impact. The alteration reduced the PV system from 170 kW to 123 kW (a 35% reduction). This had an impact on the overall energy generation system that required the design team to incorporate additional measures included several deep retrofit measures and two additional geothermal heat pumps, to accommodate the smaller PV canopy that resulted from the review process, helping the project team reach net-zero energy goals. The team has far exceeded ARRA high-performance goals, to obtain LEED Platinum certified with 84% energy reduction from the national average, to be the first net-zero historic preservation project in the U.S.

Table 2 illustrates the "truth table" as the overall assessment's results of the used BIM and IPD strategies on the studied case.

To generalize the findings, we conduct a cross-case analysis of another three projects in the next section.

Multiple case study analysis

The selected case studies located in different context (USA or Canada) and have different sizes, e.g. medium and large buildings. The details of the cases are presented in Table 3.

Similar to the analysis of the detailed case study in section 5.1, Table 4 illustrates the "truth table" as the result of the assessment of the used BIM and IPD strategies on the selected studied cases. The assessment has been done through the accurate review of their related published reports, documents, and technical articles that are published in the contracting firms' websites, and other online sources.

The "truth tables" presented in Table 2 and Table 4 are used as the basis for discussing the overall findings and lessons learned in the next sections.

Findings

The main finding of this paper based on the applied research methodology on the four case studies with a focus on investigating the changes that occurred when using BIM and IPD to renovate heritage buildings is summarized in this section. In order to address the findings systematically, and by following the developed analytical framework as well as the results presented in the form of "truth tables" in the single detailed case-study analysis and the multiple case study analysis, here the discussion is structured using the five strands of *people*, *process*, *product*, *policy*, and *technology*. The following subsections elaborate on each strand.

Table 2. "Truth table" of the detailed case analysis.

5S	People			Process			Policy			Technology			Product		
Subcategories	Team Organization	Team Selection & Capabilities	Team Behaviors & Social Dimensions	Project Planning	Quality assurance & commissioning	Lean system	Contract	Regulations	Guidelines	Software	Hardware	Network	Non structured output	Structured output: Physical components	Structured output: Virtual components
Case 01	●	●	●	●	●	○	●	●	●	●	⊘	○	●	●	⊘

● **Done well, used often, helpful to the team**: at this level, the almost collaborative strategies were applied and continually improved through incremental and innovative process and technological improvements based on a quantitative understanding of objectives and performance needs and tied to the overall project performance.

⊘ **Done, but only somewhat helpful or mixed comments about its effectiveness**: at this level, the collaborative strategies were planned and executed accordingly; produced monitored, controlled, and reviewed outputs; and were evaluated for adherence to their processes description.

○ **Did it, but it was not seen as particularly effective by most of the team**: at this level, the collaborative strategies produced results in which the specific goals were satisfied, however, they were usually ad hoc and chaotic.

\ **Did not have it**: at this level, the collaborative strategies did not incorporated into business processes and did not established goals and objectives.

Table 3. Key factual information about the three projects.

Cases	Case 2: The Renwick Gallery of the Smithsonian Art Museum	Case 3: Oakville Arena redevelopment project	Case 4: the Centre Block of the Parliament Hill National Historic Site
Place	Washington, USA	Toronto, Canada	Ottawa, Canada
Type (built on)	Museum (1859)	Mixed-use (1950)	Federal building (1916)
Listed on	The National Register of Historic Places in 1969	Local heritage sites registered in 2012	Classified Federal Heritage Building in 1986
Project scope	Renovation/Remodel, Interiors	Renovation and expanding	Major rehabilitation
Gross SF	46,800 sq.ft.	158,520 sq.ft.	543,580 sq.ft.
Owner	Smithsonian Institution	The Town of Oakville	The Public Works and Government Services Canada
Time frame	February 2012–July 2015	March 2014-September 2018	2018- in progress
Total costs	$30 M	$36.7 M	In progress
Form of contract	Design-Bid-Build	IPD tri-party contract	Architectural & Engineering Service

People

Common to all analyzed case studies, the key team composition (and selection) was a key factor in facilitating the trust built and establishing a strong collaborative culture. The team selection processes ranged from a sequential process (in Case 2) to select a joint architect-contractor team that required pre-organizing to jointly submit proposals (in Cases 1, 3, and 4). All projects adopted a two-phase selection process: a request for qualifications (RFQ) followed by a request for proposals (RFP). However, the basis for selecting team members was different. Cases 1 and 2 used a best-value selection procedure, requesting a proposal that more directly addressed the project scope in terms of sustainable and high-performance goals. On the contrary, Cases 3 and 4 used a qualification-based selection procedure, required a proposal that addressed collaboration strategies and IPD/lean experience in Case 3, and focussed on commitment to architectural quality and heritage preservation in Case 4. In addition, the guidance and the leadership that the owners provided to the selected participants were crucial for the team culture built.

The increased number of engagement points in the projects leveraged more aspects of the building products and building use to influence the overall performance. The teams worked closely with a significant number of heritage external agencies to minimize the external impact of changes to the building's appearance. Significantly, the design-build team (in Case 1) was very open to PEER review comments made by commissioning activities team; many suggestions were incorporated into the design. In addition, community members (in Cases 2 and 3) and tenants (in Cases 1 and 4) were encouraged to become active actors and collaborators in the renovation process to incite participatory conservation. The users were aligned with the projects goals and were integrated into collaborative decision-making processes with team members. Impressionably, the owner of Case 1 invested time with each tenant group and in partnering sessions to align their policies and create detailed programs that meet the high-performance goals of the overall project.

The collocation of the teams was potentially impacting a successful collaboration. The teams in Cases 1 and 3 were assembled in a big-room. In Case 4, the design team was located close to the site with the construction management team, client, and user representatives in an integrated project delivery office.

Process

Cost and schedule predictability were essential drivers of using the IPD mindset and BIM in all the cases besides the technical complexity of the heritage buildings. The high-performance goals motivated the teams to align their work, advancing new methodologies and innovative solutions to achieve the challenging goals.

The early involvement of key participants in all the projects allowed the stimulation of integrated intervention design, establishing efficient environmental performance analyses and sustainability-enhancement, at an early stage. The design teams encouraged the facility operations team and owner representatives to be involved in the process from early conceptual design to ascertain and understand the life cycle cost. BIM supports the design process and helps to plan phasing. BIM models were linked to schedules and scopes of work, as well as tenant-move plans.

Lean Construction principles and techniques have been incorporated into the projects in different degrees. In Case 4, the owner gives special attention to the lean implementation of the project. The owner issued a request for proposals to contract the services of an IPD lean design and construction consultant to design, implement and monitor a purpose-built project delivery model, which combines the principles of lean design & construction and IPD with construction manager (CM) delivery in support of the Centre Block Rehabilitation project. In the other projects, its use consists only on the application of some tools and principles like maximising-value and multi-attribute evaluation in decision-making (Case 2), target value design, and the setup of 5S lean (Case 3).

Policy

The study results, in particular, reveal that the contractual agreement type is not an overweight factor to the success of the renovation projects. Case 1 (design-build) and 2 (design-bid-build) followed a more conventional format. However, in Case 3, staff recommended using the IPD contract to mitigate project risks, and the council approved the recommendation. The Oakville municipality (owner) has attributed considerable importance to the legal and commercial terms, as being the first municipality to use the IPD model. In this model, the owner had to invest a significant amount of time creating its own IPD tri-party contract by adapting a model developed in the U.S. to best suit its needs. Compensation during validation was planned based on time and materials plus overhead for the consultant and the general contractor teams. Profit was deferred and at risk, and payment terms were negotiated during the validation phase. Nevertheless, in Case 4, an HOK-WSP joint venture called CENTRUS led the design of the expansion, conservation, and rehabilitation.

The specific policies and incentives around performance were a critical framework for organizing the work on the projects. The projects incorporated different regulations and guidelines, including heritage preservation requirements, according to the building's use and location. The LEED rating system was also used as a framework for tracking sustainable design and construction measures in Cases 1, 2, and 3.

Technology

Laser scanning was used for 3D documentation of the four buildings. In Case 2, Augmented reality allowed the team to visualize new systems against the backdrop of existing architecture, and facilitate the understanding for the other stakeholders who are not traditionally engaged in major building projects. In Case 4, the team project faced a challenge in the beginning. The process of verifying the BIM model was created from point cloud data involved creating multiple sectional views along with elements in Revit, and measuring the deviations that appeared to be the greatest between the point cloud and the model element. This method was time-consuming, and it limited the verification of the model to specific section locations. Therefore, the developed verification system significantly enhanced communication and collaboration efforts amongst team members. The system increased the speed and workflow of the translating heterogeneous datasets into building components as

Table 4. "Truth table" of the multiple case analysis.

5S	People			Process			Policy			Technology			Product		
Subcategories	Team Organization	Team Selection & Capabilities	Team Behaviors & Social Dimensions	Project Planning	Quality assurance & commissioning	Lean system	Contract	Regulations	Guidelines	Software	Hardware	Network	Non structured output	Structured output: Physical components	Structured output: Virtual components
Case 02	○	●	●	●	⊘	⊘	○	●	●	●	●	⊘	●	●	●
Case 03	●	●	●	●	⊘	●	●	○	⊘	⊘	○	○	●	⊘	○
Case 04	⊘	●	●	●	●	●	●	⊘	⊘	●	●	⊘	●	○	●

● Done well, used often, helpful to the team
⊘ Done, but only somewhat helpful or mixed comments about its effectiveness
○ Did it, but it was not seen as particularly effective by most of the team
\ Did not have it

well as assisted in determining the model integrity and accuracy through visual quality control cheques. Advanced Modelling Tools (AMT) was used to manage the structural and architectural elements of the building with a high level of detail to facilitate the integrated delivery of the project. In addition, seismic isolation technology was used as a means of minimising structural intervention and its impact on the building's heritage finishes.

For efficient environmental performance analyses and sustainability enhancement, the team members used a set of sophisticated technologies, including design software, energy simulation, and lighting simulation software. Here, BIM activated collaboration through IPD implementation framework in all four projects. The energy modelling processes utilized for the Aspinall Federal Building are an example of how BIM and building analysis software data can be appropriately viewed and exported in a limited and controlled manner to help the process of designing a net-zero energy building. However, additional analytical tools were required to calculate the upgrades' thermal performance of existing building components, and there was no adequate BIM workflow to those tools and so performance analysis.

Product

Cost and schedule predictability were important drivers of using the IPD mindset and BIM on the projects, in addition to the technical complexity, which required interdisciplinary teamwork. As projects completed (Cases 1, 2, and 3), the teams succeeded in keeping the projects on budget and schedule.

The collaborative environment allowed the teams to deal with technical and spatial constraints that incited changes in the primary design plans to preserve heritage values. In particular, in Case 1, this involved the design of the PV canopy. In Case 2, the most significant achievement of the IPD mindset, according to the project participants (Chang 2017), was the avoidance of raising the building's roof height by 10 ft. In Case 3, the project was succeeded to conserve the wooden roof truss system, all within a brand new, high-quality facility. These spatial limitations demanded strong coordination and open communication among team members to provide optimal solutions. The collaborative culture of the teams was beneficial to capture the change in a transparent way, focussing on "best for the project", where the good ideas are held back.

Although all the cases succeeded in obtaining proper results regarding sustainability achievement, the outcomes were uneven. Case 1 and Case 2 achieved a high level of innovation and advanced sustainable-building technologies. The first one achieved the most important outcomes, with an 84% energy reduction compared to the national average, and obtained LEED Platinum certification. Case 2 achieved 49% energy reduction from the national average and obtained LEED Silver certification. However, Case 3 and Case 4 (ongoing project) have less important sustainability outcomes. While at the same time, the four buildings have incorporated modern life-safety systems and improved indoor environmental quality.

Case 2 was one of the first to use a full virtual-construction model to a 400 level of definition of all building systems using laser scanning, this process allowed for the final integration of systems with a dimensional fidelity not previously possible which the model is using for operation and maintenance, as well as future upgrading of the building. The current digital model of Case 4 also succeeded to merge all available information, including structural and architectural components, as well as buildings systems and infrastructure, but in a lower level of details.

Discussion

The review of sustainable renovation of heritage building challenges points towards the need to use cross--disciplinary sophisticated processes and methodologies in order to cope with the contradiction between sustainable design and heritage values preservation. Although previous research discusses the potential advantages of IPD + BIM implementation in construction projects, this paper focussed on a new contribution towards the above need, focussing on the intersection of IPD and BIM for renovation of heritage buildings, which bridges this knowledge gap by reporting on different real-world projects. The findings demonstrate evidence that shifting into IPD and BIM could be an effective way to exceed the target balance achievement (such as heritage values preservation, users living conditions and safety enhancement, and energy efficiency) towards delivering high-performance buildings (i.e. zero energy building in Case 1). Although few heritage buildings have been renovated using IPD and BIM, the findings confirmed that significant developments and changes have already occurred during the last years in existing practices and differ from project to project. There is also a large unexplored potential of IPD + BIM in current literature on renovation and in particular renovation of heritage buildings, which needs to be investigated.

According to the results, IPD and BIM synergies allow understanding and integrating heritage values into decision-making frameworks that revolve around energy performance improvement, via preparing better collaborative and integrating processes. With our limited sample size of projects, we cannot confirm a causal path that IPD and BIM led to success, but we have a set of collected data that enable us to extract some inferences. Concerning changes occurred on the designs planned in Cases 1, 2, and 3 to limit adverse effects on heritage values, the simultaneous use of BIM and IPD allowed streamlined decision-making and approvals in real-time, response to unforeseen conditions, heritage agencies review, and evolution along time. The early involvement of key participants in the different projects facilitated the generation of various simulations and tackled of challenging spatial and historic preservation constraints at an early stage, enabling to maximize the positive outcomes and save time and cost. The collaborative culture of the teams and limitation of liability were beneficial to capture the changes in a transparent way, focussing on "best for the project". Creative and novel ideas/solutions were held back through open communication, and opportunities for innovation were, therefore, augmented. In this framework, BIM was found as an enabler of IPD that foster the collaboration and caused the design teams to provide faster complex analyses and rapid assessment of energy simulations through the coordination of BIM with energy models, as well as performance of the renovated buildings in operation. All stakeholders could see what was proposed through virtual-construction models. However, and similar to other heritage cases in previous studies, there were some constraints of BIM effectiveness depending on the heritage structures' complexity. BIM is appeared to not function so well for clash detection in this context, comparing its application for new brand buildings. In this regard, Case 4 confirmed that integrating other emerging technologies within BIM and searching for innovative solutions could overcome this issue. On the other hand, it is important to develop, upgrade, and adjust BIM simulation software to accurately represent the conditions of heritage buildings and allow accurate environmental simulations within BIM modelling.

Unlike literature, the results reveal that contractual agreement type is not an overweight factor for the projects' success. Despite the four projects using different types of contracts (design-bid-build, design-build, IPD tri-party contract, Architectural & Engineering Service), they succeeded in obtaining proper team collaboration and sustainability achievement. Instead, the search on best-value and the motivation of the teamwork (architect, engineers, owner, and general contractor) were the drivers to define the level to which teams could implement the tools and processes effectively, and therefore, to achieve sufficient outcomes. The selection of qualified integrated firms committed to the collaboration process, along with the owner in such complex projects, facilitated the trust built among team members. The owners' guidance and leadership provided to the participants, was crucial for the team culture building. Likewise, the owners' willingness, especially in cases 1 and 2, played a specific role in using their education, leadership, and competency concerning collaborative project delivery, to guide and co-operate with the project participants.

Conclusion and future study

This study aimed to further understand the impact of IPD and BIM to achieve the balance between sustainable design and historic preservation, and to enhance process productivity and final project performance. To this end, a mixed methodology consisting of QCA principles besides triangulation approaches for data collection and validity of the research work was carried out. The authors developed a coding scheme consisting of 50 criteria, classified into 15 categories, and grouped into five thematic strands (*people*, *process*, *policy*, *technology*, and *product*) to enable a comprehensive and systematic exploration of the potential use of IPD and BIM in different real heritage renovation projects.

The findings presented considerable advantages of IPD and BIM collaborative strategies application over different thematic strands and contract types. It was revealed that IPD and BIM application allows reaching sustainability goals together with preserving the heritage buildings' values via holistic decision-making frameworks, ensuring on-time and budget project delivery. The collaborative environment admits the stimulation of integrated intervention design from the earliest stage, within multiple participants. BIM enables design teams to provide faster complex analyses and rapid assessment of energy simulations through BIM coordination with energy models, to produce a full virtual construction model.

The analytical framework – developed in this paper – is a retrospective analysis tool that enables the relationships' assessment between the maturity of teams' projects and the level of benefits they could achieve from BIM/IPD collaborative strategies so far. However, it is proposed that the developed framework can serve to manage projects, thus take a leading role (instead of a lagging one), in supporting the implementation of collaborative innovative approaches in heritages. At this stage, the understanding of the challenges and potential for creating/adding values in using IPD and BIM in the early design is fundamental. The results indicate that the lack of owner education, leadership, and competency are very substantial issues limiting the use of IPD and similar innovative approaches in heritage projects. Some of the more considerable barriers were found as:

1. A lack of understanding of what these methodologies offer.
2. Owners' unwillingness to invest based on the life cycle analysis versus immediate upfront costs.
3. The inertial resistance engendered by the conventional processes and construction standards.

Furthermore, the choice of the organisational and business structure should smoothly be adapted towards the sustainable renovation characteristics and best suited to the capabilities and participants' needs to implement the heritage projects efficiently, and in an applicable tendency. In addition, it is of great importance to investigate the heritage industry's readiness to improve its project delivery process through the implementation of the synergy between IPD and BIM.

A significant limitation to this study concerned the data collection in terms of willingness, as well as the availability of heritage case studies that have been renovated using IPD and BIM, where missing data could have led to different results. In addition, the analysis of data was primarily descriptive, using means and percentages. In this regard, future efforts could focus on conducting quantitative studies, and considering the sustainability measures in a broader perspective, to further validate and generalize the results.

This contribution is relevant to heritage preservation research and practitioners, who can use the study outcome to better understand and navigate the IPD through BIM and its potential shift in the sustainable renovation of heritage buildings with multiple stakeholders. Moreover, it provides decision support for professionals and the government to choose the suitable delivery method (contract and legal terms) and best practices for carrying out similar projects to achieve high-performance buildings.

Note

1. Although the contribution of this study deal specifically with listed buildings that have official protection, it can also encompass more recent structures which potentially may be perceived as a heritage of cultural value by specific groups of people.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendix A. The detailed and holistic assessment of the used BIM and IPD strategies in the case study, Wayne Aspinall Federal Building, according to the developed analytical framework in Table 2 including 15 categories and 50 criteria (see Section 5).

SS	Categories	Criteria	Observations	Assess
People	Team Organisation	Organisational structure	• Design-build with integrated firms. The majority of the project team was drawn from Beck Group and Westlake Reed Leskosky (WRL): WRL as lead design architect and Beck as the architect of record.	●
		Role definition & Accountability	• A matrix of project responsibilities from the beginning defining the roles according to the firms' capabilities. The team then assigned each responsibility to the firm best equipped to meet it. • Active contribution and collaboration throughout the project. • High levels of team member accountability through colocation.	●
		Stakeholders Involvement & management	• Early design meetings with the presence of the owner, builder, architects, engineers, commissioning agent, and construction manager during this critical phase of project development. • Internal and informal information channels. • Involvement of heritage agencies on the team selection and the RFP. • Work closely with VRF system vendors to understand performance limitations and control specifics.	●
		Users/occupants involvement	• Occupant engagement and education for more significant energy savings in the building: a Tenant guide and monthly meeting of the tenant agencies with GSA to review plug load data, as well as Federal requirements for energy efficient office equipment procurement as a way to reduce plug load energy consumption.	●
		Leadership	• The owner project manager spearheaded the collaboration throughout the project, supervised decision making, and almost single-handedly managed the complexities of the ARRA design guidelines, schedule, reporting procedures, and project- budget procedures so the project team could remain focussed on design and construction. • A leadership strategy that served to support the team collaborative culture. • WRL served as lead designer.	●
	Team Selection & Capabilities	Team Selection	• The GSA Source Selection Evaluation Board (SSEB) implemented best-value-selection processes based on a combination of past performance, technical capacity, and qualification of key personnel. The selection procedure was a two-step open-solicitation process: a request for qualifications (RFQ) followed by request for proposals (RFP). Two rounds of interviews were conducted with the short-listed firms. • The selection of WRL subcontractors was according to their specific areas of expertise and previous relationships with WRL. Subcontractors for Beck were selected using conventional means, with the exception of specialized trades with expertise in particular historic preservation or restoration technique.	●
		Education & Training	• Educate building operators on efficiency strategies.	⊘
	Team Behaviours & Social Dimensions	Collaborative Culture & Trust	• Both Beck and WRL are interdisciplinary firms with aligned cultures, and they established cultures of working collaboratively between disciplines and under unified sets of enterprise goals. Although the firms had not worked together previously. The level of accountability among team members was a key to developing trust. • Open-minded approach. • GSA Project Manager inspired collaboration. • The isolated project location.	●
		Learning & Continuous Improvement	• The teamwork provided an opportunity to share knowledge, learn lessons and capitalize best practices and strategies to apply in future similar projects, and shape the 2014 Public Building Service (PBS) P100, which is the GSA's design standard for projects. • WRL conduct research concerning accurate data from product manufacturers.	●
Process	Project Planning	Assessments of existing conditions/usage	• The BIM model was used to quickly analyse the existing building construction. For these efforts, separate models from the BIM were created in order to capture the building geometry, since that was determined to be more suitable by allowing more rapid changes to the geometry than by importing all the geometry of the building, much of which was unrelated to the design of those particular areas.	●
		RFP Development	• A Peer review and interactive process that allows the bidders to provide innovative solutions, pushing this project in terms of its sustainability goals. The original prospectus required the whole building project to be completed for under $15 M and achieved LEED-NC Silver and a 30% reduction below ASHRAE 90.1-2007. The design-build team chose to significantly exceed the requirements of the prospectus without exceeding the target budget and schedule. The design-build team of Beck and WRL demonstrated in their proposal how the project might exceed the mandated goals to reach net-zero and LEED Platinum certification.	●

(*continued*)

Appendix A. Continued.

SS	Categories	Criteria	Observations	Assess
			• Involvement of GSA's Regional Historic Preservation Officer (RHPO) and a peer with historic preservation expertise in the SSEB review.	
		Budgeting and Scheduling	• BIM use to make assumptions required for early parametric building energy simulation. • The fusion of designer and constructor under one team allowed for rapid cost feedback, with each design iteration checked with energy simulation. • Budget decisions were considered integrally with schedule and scope. • A digital model demonstrated the expected phases. • BIM use to attach the 3D phasing model to the schedule, the scope of work and tenant-move plan and then to illustrate each phase with input from the whole team.	⊘
		Goals and Alignment	• Early design meetings (the presence of the owner, builder, architects, engineers, commissioning agent, and construction manager). • Collaborative revising of the project scope before work began. • Exchange of ideas that elevated common interests over the positions of the parties. • focussing on historic preservation and energy efficiency upgrades: a life cycle cost analysis with a goal of reaching 30% better performance than ASHRAE Standard 90.1-1999; 68.7 % reduction in energy cost compared to ASHRAE Standard 90.1-2007; Realisation of a net ZEB; LEED Platinum® certification; 40% Water use reduction. • Communication with the tenants to bridge the gap between their needs and the goals of the project team, that provided positive buy-in of the new design.	●
		Developing key Performance Criteria	• Development of a set of metrics: the predesign process involves two types of tasks: data analysis which looks at project parameters (consumption data from similar projects, climate data for the site, etc.) and building simulation which simulates projected performance of the facility and impacts of various energy-efficiency measures.	●
	Quality assurance and commissioning	Commissioning operations	• A 3rd-party commissioning agent was engaged by the owner during the preliminary design phase. • The design-build approach ensured constructability was also reviewed very early in the design stage. • The use of BIM avoids the conflicts that may impede equipment access. • Multiple design reviews, the design-build team was very open to PEER review comments made by commissioning activities team, many suggestions were incorporated into the design.	●
		Measurement and verification	• Development of an M&V plan. • Formal weekly meetings with discussing complexities and positive achievements: once a week during design and Bi-weekly during construction. Key team members attended all structured meetings. • The building manager has access to the design and construction team to review performance and maintenance items. • Encouraged informal meetings to address issues as they occurred directly. • Verification of the facilities performance with submeter data to effectively manage the building and reduce energy consumption.	●
		Decision making	• The owner supervised decision making. • The decision was based on a combination of energy savings, the ability to deliver a high-quality indoor environment, and constructability in a historic building.	●
		Risks management	• The early definition of risks. • Construction of flex spaces to temporarily support displaced tenant agencies while their portions of the building were under construction. • BIM mock-ups to identify issues early on and to reduce risk.	●
		Post occupancy performance	• The consultant and commissioning agent were engaged for an extended 18-month post-occupancy, to evaluate actual building performance and offer suggestions for further optimisation of systems. • A pre-renovation occupant survey was performed and was compared to a new occupant survey one year after the building's dedication.	●
		Ongoing commissioning	• GSA Managed Tenant Energy Targets. • Post occupancy monitoring of occupant comfort.	●
	Lean system	Principles and processes	• Maximising values and reducing wastes. • Multi-attribute evaluation. • User-centered design: Involvement of the facility managers in all the phases.	●
		Tools		○
Policy	Contract	Roles and Responsibilities	• Design-build project delivery: developing the contract in an interactive manner.	●

(*continued*)

Appendix A. Continued.

SS	Categories	Criteria	Observations	Assess
		Rewards	• Built the performance goals into the base contract, with a supplemental agreement for the design/engineering firm specifically focussed on performance measures. • The contract was a firm fixed price.	⊘
		Risks and Compensation	• The contractor bore risks of its acceptance of a firm-fixed-price contract based on a program of requirements, scope of work, agency design guidelines, policies, and the design-build proposal. The risks to the design-builder related to the uncertainty presented by the innovative renovation project, where the contract required the design-builder to maintain pricing through design development based on the contract documents and through construction. • The GSA did assume the risk that the conceptual design proposal which informed the selection of the design-build team could be changed substantially as a result of the historic preservation reviews.	⊘
		Liability and insurance	• Open book policy.	●
	Regulations	Heritage codes & regulation	• The Secretary of the Interior's Standards for Rehabilitation. • Section 106 of the National Historic Preservation Act of 1966 (NHPA).	●
		Codes & standards	• Adaptation of standard GSA practices to the design-build contract required additional time investment and support. • ARRA design guidelines. • BACnet standard for building automation and control system networks. • Americans with Disabilities Act (ADA).	●
		Protocols	• Development of a BIM-execution document at the beginning of the project.	●
		Performance	• GSA's Minimum Performance Criteria for Recovery Projects for new construction and major renovations.	●
		Sustainability	• ASHRAE Advanced Energy Design Guide Standard 90.1-2007 as a reference energy standard. • ASHRAE Standard 55-2010 for thermal comfort. • The government requirements for net-zero and energy independence by 2030.	●
	Guidelines	Best practices	• GSA Building Information Modelling Guide Series. • Use of BIM model based on best practices that Beck had developed during the last decade.	●
		Benchmarks	• IESNA for acoustics and daylight. • Energy Star Portfolio Manager Benchmark for site energy use intensity.	●
		Classification systems	• LEED Platinum certification.	●
Technology	Software	Applications	• 3D BIM technology: Revit, NavisWorks, and Innovaya. • For energy model: TRACE 700, DOE-2, Autodesk Ecotect, Integrated Environmental Solutions Virtual Environment, GLHE-PRO	●
		Information exchange and interoperability	• Development of a BIM-execution document at the beginning of the project. • Coordination of BIM models with WRL energy models: a gbXML file export from the BIM was used for preliminary load and energy analysis. • BIM and building analysis software data were appropriately viewed and exported in a limited and controlled manner to help the process of designing a net-zero energy building.	⊘
	Hardware	Building examination tools	• The teamwork used laser scanning, photogrammetry, and other materials and technologies for the building examination.	●
		Workplace & interactive artefacts	• Colocation: the increase in direct working relationships and the ability to get to know each other on a personal basis strengthened communication, trust, and respect among the core team members. • Web conferencing: Webex.	⊘
	Network	Data security	• As a federal project, security requirements considerably impede access to data.	○
		Access control	• Development of a plan during schematic design and determine how access to building automation systems will be provided.	

(*continued*)

Appendix A. Continued.

SS	Categories	Criteria	Observations	Assess
				⊘
Product	Non-structured output	Profit and Payout	• Energy conservation measures (which excludes the PV system) were evaluated to have under 10-year overall payback. The owner's primary goal for the project was to utilize the lessons learned to transform practices across an 8700 building portfolio, rather than seeing a short payback for all measures, this particularly applies to GeoExchange and PV system, both crucial to the net-zero energy goal, but having greater than a 20 years individual payback period. • A 50–year renewed life cycle, which allowed the higher capital cost of the geothermal well system to be justified through its future energy cost savings in the life cycle cost analysis required by GSA, as compared to a few other systems which were considered.	⊘
		Budget and schedule	• The project met the budget and schedule parameters: the total project cost was $15 M, including soft costs and excluding land.	●
	Structured output: Physical components	Energy performance	• Far exceeded ARRA high-performance goals, LEED Platinum certified, 84% energy reduction from the national average, 68.7% improvement over ASHRAE Standard 90.1-2007, The first net-zero historic preservation project in the US.	●
		Daylight & IAQ	• 50% of full daylight. Lighting was upgraded to higher-efficiency fluorescent and LED technology, including replication of historic fixtures. Task ambient lighting schemes are used in most work areas. • Lighting and HVAC are driven by the same wireless controls as an automatic detection of building occupancy. • An outside air monitoring unit provides fresh air to the building depending on the indoor CO2 levels, which increase with occupancy.	●
		Water cycle & Materials	• 40% potable water reduction over a LEED for New Construction 2009 baseline.	●
		Users' living conditions and safety	• Separated zoned space for each tenant, permitting greater occupancy-driven control over conditioning of spaces, as well as by activities specific to tenants. • Improved safety record.	●
		Heritage Values Preservation	• The project restores and showcases historic volumes and finishes, on preserving the historical significance of Grand Junction's crown jewel, while modernising the landmark.	●
		Innovation & creativity	• The design of the PV canopy. • Creates a "green proving ground" and achieved the goal to advance the building industry as an exemplary project demonstrating how to make an existing historic building perform at net-zero energy, 15 years ahead of schedule.	⊘
	Structured output: Virtual components	Existing condition model	–	
		Record model	• A full As-built energy model.	⊘

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Titre: Integrated Project Delivery and Building Information Modeling Assessment for Sustainable Renovation of Heritage Building

Thèse en vue de l'Obtention du Diplôme de Doctorat L.M.D

en Management de Projets

Abstract

Renovation of heritage buildings has become a revivification pathway to promote sustainability as well as to protect the heritage buildings' significance and values. The complexity of sustainable renovation of heritage buildings requires the adoption of more sophisticated technologies and project management models to deal with the contradiction between sustainable design and heritage values preservation, as well as enhancing process productivity and final performance. This research aims to assess and evaluate the application of Integrated Project Delivery (IPD) strategies and tools through Building Information Modelling (BIM) to enhance the sustainability aspects and efficiency of renovating heritages via better collaboration and integration. That is a vital key to the successful delivery of building projects. The research adopts a mixed methodology, Qualitative Comparative Analysis triangulating the collected data. An intensive review of related literature is carried out, besides data collection and analysis of four real-world heritage cases (in different contexts). The research study enables a comprehensive and systematic exploration of the potential use of IPD and BIM, within the development of an analytical framework consisting of a set of defined variables including 50 criteria, classified into 15 categories, and grouped into five thematic strands (people, process, policy, technology, and product). The focus is to determine the shared collaborative practices across the projects and the level to which the teams are able to implement the IPD and BIM tools and processes effectively. The findings presented considerable advantages of IPD and BIM collaborative strategies application over different thematic strands and contract types. It was revealed that IPD and BIM application allows reaching sustainability goals together with preserving the heritage buildings' values via holistic decision-making frameworks, ensuring on-time and budget project delivery. The collaborative environment admits the stimulation of integrated intervention design from the earliest stage, within multiple participants. BIM enables design teams to provide faster complex analyses and rapid assessment of energy simulations through BIM coordination with energy models, to produce a full virtual construction model.

Mot clés : Building Information Modelling (BIM); Integrated Project Delivery (IPD); Heritage Building; Sustainable Renovation; Heritage renovation.

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Année universitaire 2021-2022