4RinEU

Reliable models for deep renovation

D3.6

WP3

4RinEU management to implement deep renovation

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723829

Foreword

Despite the low energy performances of the European building stock, the yearly renovation rate and the choice to perform a building deep renovation is strongly affected by uncertainties in terms of costs and benefits in the life cycle.

The project 4RinEU faces these challenges, offering technology solutions and strategies to encourage the existing building stock transformation, fostering the use of renewable energies, and providing reliable business models to support a deep renovation.

4RinEU project minimizes failures in design and implementation, manages different stages of the deep renovation process - from the preliminary audit up to the end-of-life - and provides information on energy, comfort, users' impact, and investment performance.

The 4RinEU deep renovation strategy is based on 3 pillars:

- *Technologies* - driven by robustness - to decrease net primary energy use (60 to 70% compared to pre-renovation), allowing a reduction of life cycle costs over 30 years (15% compared to a typical renovation);
- *Methodologies* - driven by usability - to support the design and implementation of the technologies, encouraging all stakeholders' involvement and ensuring the reduction of the renovation time;
- *Business models* - driven by reliability - to enhance the level of confidence of deep renovation investors, increasing the EU building stock transformation rate.

4RinEU technologies, tools and procedures are expected to generate significant impacts: energy savings, reduction of renovation time, improvement of occupants IEQ conditions, optimization of RES use, acceleration of EU residential building renovation rate. This will bring a revitalization of the EU construction sectors, making renovation easier, quicker and more sustainable.

4RinEU is a project funded by the European Commission under the Horizon 2020 Programme and runs for four years from 2016 to 2020.

The 4RinEU consortium is pleased to present this report which is one of the public deliverables from the project work.

Principal Authors

Ignacio González (ACCIONA); Cristina Criado (ACCIONA); Jorge Escribano (ACCIONA); Sandra Hernández (ACCIONA); Miguel Ángel París (ACCIONA); Ana Contreras (ACCIONA); Gonzalo Pinto (ACCIONA); Espen Foss Johansen (Boligbygg); Laurense H. Lie Rypda (Boligbygg); Vera Lukina (Boligbygg); Judith Tillie (Woonzorg); Wim Bakker (Woonzorg); Cristina Cardenete Suriol (AHC); Cristina Casol (AHC); Gerard Valls (AHC); Anna Pujol (AHC).

Document details

Deliverable No: D3.6
Dissemination level: Public
Work Package: WP3
Lead beneficiary: ACCIONA
Date of publication: first version (30/09/2017) second version (28/09/2018) Final version (18/10/2019)
Version: 7.0

Project information

Title: Robust and Reliable technology concepts and business models for triggering deep renovation and residential Buildings in EU (4RinEU)
EC Grant Agreement Number: No 723829
Duration: October 2016 until September 2020 (48 months)
Coordinator: EURAC (IT)
Project Partners: SINTEF (NO), ADERMA (IT), TRECODOME (NL), AIGUASOL (ES), G&M (DE), THERMICS (IT), IES (UK), ACCIONA (ES), BOLIGBYGG (NO), WOONZORG (NL), AHC (ES), R2M (IT).

Disclaimer

Table of contents

1. Executive Summary 13
2. Introduction 16
   2.1 Scope 16
   2.2 Target Group 17
   2.3 Objectives 17
   2.4 Link to other activities in the project 18
   2.5 Guide to this document 19
3. Current overview of Deep Renovation 20
   3.1 Definition, potential benefits and development possibilities 20
      3.1.1 Definition of a Deep Renovation project 20
      3.1.2 Potential benefits of Deep Renovation projects. 21
      3.1.3 Development opportunities of Deep Renovation projects 22
   3.2 Common practices in Deep Renovation projects 27
      3.2.1 Common key phases comprising a Deep Renovation project 28
      3.2.2 Main stakeholders involved in a Deep renovation project 30
      3.2.3 Common procedures and actions adopted in Deep Renovation projects 32
4. Barriers and challenges of Deep Renovation 36
   4.1 Deficient definition of objectives 37
   4.2 Obsolete management scheme and poor interaction between stakeholders . 37
   4.3 Design based on poor schedule and budget criteria 38
   4.4 Non-integrated systems and components design 38
   4.5 Project financing problem in the residential sector 38
5 IPD, BIM and Lean approaches 40
   5.1 Integrated Project Delivery (IPD) 40
   5.2 Building Information Modelling/Management (BIM) 43
   5.3 Lean Construction 46
6 4RinEU Strategy towards Deep Renovation 49
   6.1 Introduction 49
      6.1.1 Strategy application 49
      6.1.2 Integration of IPD, BIM and Lean Construction 49
   6.2 General aspects 52
      6.2.1 Phases of the process 52

6.2.2 Holistic approach: link to other activities in the project 54

6.2.3 Main stakeholders 56

6.2.4 Key Performance Indicators (KPIs) 58

6.2.4.1 Design KPIs 58

6.2.4.2 Construction KPIs 59

6.2.5 Collaborative Design Platform (CDP) 60

7 Phase development 62

7.1 Phase [0] Base case analysis 64

7.2 Phase [1] Procurement 69

7.3 Phase [2] Planning 77

7.4 Phase [3] Design 86

7.5 Phase [4] Construction 91

7.6 Phase [5] Operation & Maintenance 99

8. Conclusions 104

9. Annex 1. Construction KPIs 107

10. References 111

List of figures

Figure 1 Share of dwellings according to construction date... 24
Figure 2 Share of space heating in total residential consumption 25
Figure 3 Space heating unit consumption per dwelling5.. 25
Figure 4 Average building walls U-values... 26
Figure 5 Key Phases in a Suitable Building Retrofit Programme (source: Ma et. al., 2012). 30
Figure 6 Main potential improvements detected in the classic Deep Renovation projects' management scheme.. 36
Figure 7. Integrated project delivery compared to traditional Design-Bid-Build or Design-Build (CMAA 2012).. 41
Figure 8 Traditional vs integrated design process (AIA 2007) 41
Figure 9 AIA's documents for different IPD agreements (AIA 2015) 42
Figure 10 BIM main concepts illustration (buildingSMART) 45
Figure 11 Lean Project Delivery System (Ballard 2000) 47
Figure 12. The three pillars of 4RinEU deep renovation strategy.................................. 50
Figure 13. MacLeamy curve (AIA 2007) 51
Figure 14. Phases of the 4RinEU strategy for deep renovation...................................... 53
Figure 15. PAS1192-2 project delivery procedure 54

List of tables

Table 1 Linked tasks 18
Table 2 Guide to the document 19
Table 3. Tasks from 4RinEU strategy related to the deep renovation strategy 55
Table 4. Main stakeholders involved in deep renovation 56
Table 5. Example of contact information matrix 58
Table 6. Example of responsibility matrix 58
Table 7 KPIs from the 4RinEU project supporting the deep renovation strategy 58
Table 8. Main stakeholders involved in Base case analysis 65
Table 9. Main stakeholders involved in Tender process 70

Abbreviations

AC	Accidents cost
AECO	Architecture Engineering Construction Operations
AF	Accidents frequency
AIA	American Institute of Architects
AR	Accidents rate
B	Budget
BEP	BIM Execution Plan
BIM	Building Information Modelling
BOD	Bases of Design
CAFM	Computer aided facilities management
CCF	Change cost factor
CDE	Common Data Environment
CDP	Collaborative Design Platform
CMAR	Construction Management At Risk
CMMS	Computerized Maintenance Management System
CPD	Collaborative Project Delivery Team
CSFs	Critical Success Factors
CSR	Corporate Social Responsibility
CxA	Commissioning Agent
DB	Design-Build
DBB	Design-Bid-Build

DDI	Delay due to inventory
EC	Electricity consumption
EE	Energy Efficiency
EEM	Energy Efficiency Measures
EIRs	Employers Information Requirements
EPC	Engineering Procurement Construction
EPCM	Engineering Procurement Construction Management
ESCO	Energy Service Company
EU	European Union
FM	Facility Manager
GDP	Gross Domestic Product
GHG	GreenHouse Gas
GMP	Guaranteed Maximum Price
HS	Health and safety
HVAC	Heat, ventilation and air contioning
IAQ	Interior Air Quality
IE	Inventory Excess
IF	Incidents frequency
IPD	Integrated Project Delivery
IPMVP	International Performance Measurement & Verification Protocol
IR	Incidents rate
IRe	Impacts of repairs

KPI	Key Performance Indicator
LCA	Life Cycle Analysis
LCC	Life Cycle Cost Analysis
LOD	Level of Development
LPS	Last Planner System
LR	Landfill rate
M&V	Measurement and Verification
MBEE	Multiple benefits of energy efficiency
NPM	Net profit margin
O&M	Operation and Maintenance
OC	Oil consumption
PPP	Public Private Partnership
PDW	Percentage of delivered works by cost
PM	Project Manager
PMT	Project Management Team
PPC	Percent planned complete
PTM	Productivity – Time management
RCR	Recycling rate
RFI	Requests for Information
RFP	Request for Proposal
ROI	Return of Investment
RP	Re-planning
RUR	Re-using rate

SMEs	Small & Medium Enterprises
SPC	Statistical Process Control
SPE	Single Purpose Entity
SSL	Secure Sockets Layer
SWL	Site Work Logistics
TD	Task duration
Tde	Task delay
TO	Transportation optimization
TVD	Target Value Design
TWD	Total works duration
UK	United Kingdom
VDC	Virtual Design and Construction
WC	Water consumption
WD	Total delay
WP	Work Package
WSS	Work Site Sustainability

1. Executive Summary

In general terms, a **Deep Renovation project** basically consists on the implementation of a set of actions aimed to reduce the global energy consumption of an existing building, through the renovation of the heating, cooling, ventilation, hot water and lighting systems and the improvement of the energy passive features of the building envelope. It is usually a complex process which involves many stakeholders, goes through several stages, implements a wide and diverse range of technical solutions and must consider a set of technical, economic and human factors with common and ambitious objectives.

Renovation projects are usually approached not as an integral process according to the complexity required but as a service delivery indifferent to the difficulty and multiplicity of the interactions existing between the parties involved and developed activities. This approach may result in the achievement of a sub-optimal global solution, the non-compliance of the defined targets, the increase of the final costs for one or several parties or, in the worst case, the project failure.

The methodology outlined in this document offers a new way of conducting the management of deep renovation projects, defining the barriers and challenges that the building construction industry should address.

In order to optimize the whole building process while fulfilling the client's requests (building owner or real estate developer), deep renovation projects will be approached by **three main integrative systems**: **IPD (**Integrated Project Delivery) for collaborative work**, BIM (**Building Information Modelling**)** as an implementing tool and **LEAN** as a process optimization.

IPD provides the framework in terms of contract procedures and responsibilities of the stakeholders' involvement, promoting the early engagement of the partners and the transparency during the whole process.

Lean Construction is highly connected with IPD and BIM principles too. They facilitate Lean's final aim of process optimization and increases value for the client while reducing material costs at the project delivery level and improving the overall performance of the project.

BIM contributes by defining a collaborative approach supported by tools where the main actors involved can participate while all the information can be integrated. It also aims to avoid modifications and deviations during the construction phase. In 4RinEU the BIM strategy is conceived as the framework or conductive thread for the activities development.

These three systems will be integrated in a **management strategy** that will guide the client, as the first user, and all stakeholders during the whole process and will be **divided into 6 phases**:

- **Phase [0] Base case analysis (Baseline)**, where the existing building is analysed from the energy and indoor environmental quality perspective and the base case situation is established through an audit process.
- **Phase [1] Procurement.** Based on the baseline obtained from the previous phase, the owner defines the objectives and requirements for the project development, defining the tender process and selecting the teams to collaborate in the project.
- **Phase [2] Planning**. Main stakeholders involved in the process define altogether the relevant aspects for the project's development, especially regarding schedules, milestones and responsibilities.
- **Phase [3] Design.** The different packages for renovation are defined, in comparison with the baseline and according also to a cost-effective analysis.
- **Phase [4] Construction**. The selected renovation package is implemented according to the specifications defined during the design phase.
- **Phase [5] Operation & Maintenance**. In this phase the Measurement and Verification (M&V) protocol is applied to evaluate the achievements of the project's goals together with the ROI (Return on Investment) during the first years of operation.

Some of the phases are included in other tasks of the 4RinEU project and the related links are highlighted in the report.
The development of management protocol to implement deep renovation has also considered the feedbacks from the project demo-sites for its replication potential to different situations.

This document should be used as a **guideline to establish the rules of each project** and base approach from the very first moment while pursuing the achievement of the objectives in the following.

1. **Collaboration:** integrate all parties and teams participating collaboratively in the project from the first stages being coordinated properly.
2. **Coordination**: to successfully coordinate the changes in design and construction, controlling the impacts in costs and duration during the whole process, while providing a communication platform.

3. **Integration:** to clarify upfront project schedules, costs and objectives, to integrate all client requirements from the beginning of the project.
4. **Time control**: Control the development plan of the project, providing early identification and mitigation of the time deviations.
5. **Cost Control:** early identification and mitigation of the budget deviations, reducing and avoiding modified projects.
6. **Security:** assure and control complete definition and define level of detail and costs necessary for the project, minimizing risks.
7. **Results measurement:** Definition of a set of KPIs aimed to monitor the state of progress of the most relevant aspects in each phase of the project.
8. **Sustainability:** Decreasing the energy demand and the reduction of carbon emissions while attending the triple bottom line of environmental, economic and social benefits.

2. Introduction

Building construction is slow, costly and has misaligned processes in comparison to other industrial processes. Furthermore, these processes are usually established for new constructions and do not consider the issues of existing building renovations. The complexity of the construction industry, because of the large amount of materials, constructive elements and equipment, can make it difficult to check the quality throughout the whole process. In addition, there are many professionals involved, dealing with different areas and interests, who have their own partial vision of the project in spite of a wide perspective of the overall process. This framework increases the cost, works duration, risks and above all, it compromises the satisfaction of the client's objectives.
4RinEU aims to develop a methodology that ensures that the client´s objectives will be met, by:

(1) Managing the design through an integrated workflow that involves most of the stakeholders from the early stages using an Integrated Product Delivery (IPD) approach and Building Information Modeling (BIM) tools;
(2) Reducing time and costs during the implementation thanks to the use of BIM and LEAN methodologies;
(3) Providing a set of indicators that will be defined to assess the effectiveness of the whole process.

2.1 Scope

This methodology defines how we are managing deep renovation projects conducted presently and which are the barriers and challenges that the building construction industry should address from now on.
To fulfil the client requirements and to optimize the whole building process, deep renovation projects will be approached by three main integrative systems: **IPD** for collaborative work, **BIM** as an implementing tool and **LEAN** as a process optimization.
Based on these approaches, a management strategy that covers the whole project is presented to guide all stakeholders during the process. The strategy is divided into 6 phases:

- [0] Base case analysis
- [1] Procurement (strategy definition)
- [2] Planning
- [3] (detailing) Design
- [4] Construction (implementation)
- [5] Operation and in-use maintenance

Each phase defines inputs needed from the previous phase, outcomes for the next phase and KPIs to assess the overall phase objectives.

Some of the phases are deeply developed and defined in other tasks of 4RinEU project. Therefore, this document includes several references to other documents of the project (links are explained in Section 1.4).

2.2 Target Group

Being the first objective of this methodology the fulfilment of the client´s requirements, the first user of this methodology is the building owner or real estate developer **(the client)**. This document should be used as a guideline to establish the rules of the project from the very first moment. Therefore, all the stakeholders that are hired by the client must understand, accept and be able to develop the project following the processes defined here.

In addition to the client, stakeholders are directed as the processes defined in this document propose changes in their traditional workflows. Stakeholder interactions are explained in Section 3. Here are some examples: (1) End users will have the possibility to be a part of the team and explain their needs; (2) Designers will not be alone any more in the design stage because contractors and building managers will be involved in this process to reduce design changes in the next stages. (3) Contractors and building managers will have to set a maximum price before having a detailed design.

2.3 Objectives

4RInEU deep renovation management methodology is the tool to help building construction agents to overcome the barriers and challenges defined in Section 3. By the achievement of the following objectives within others:

- Integrate all parties and teams participating in the project from the first stages **(IPD)**.
- To clarify upfront project schedules, costs and objectives, to integrate all client requirements from the beginning of the project. **(IPD)**.
- Select and coordinate properly the necessary professional teams. **(IPD + LEAN)**.
- Assure complete definition and define level of detail necessary for the project, minimizing risks **(BIM)**.
- Control of the information workflow, Request for Information (RFIs), approvals, modifications, etc. **(IPD + BIM)**
- To successfully coordinate the changes in design and construction, controlling the impacts in costs and duration during the whole process. **(IPD + BIM)**.
- Control of the costs of the project, early identification and mitigation of the budget deviations. **(BIM + LEAN)**.
- Control the development plan of the project, providing early identification and mitigation of the time deviations. **(BIM + LEAN)**.
- Definition of a set of KPIs aimed to monitor the state of progress of the most relevant aspects in each phase of the construction. **(LEAN)**.

- Maximize the value of the materials and systems (Value Engineering) **(LEAN)**.
- Identification, monitoring and control of risks throughout all the project phases **(BIM)**.

In addition, as stated in the project proposal, the following specific objectives should be reached:

- Definition of design and general contractor procurement procedures adaptable to different contexts.
- Definition of strategies for the optimization of the construction site.
- Evaluation of possible coupling with potential co-benefit and safety renovation.
- Maintenance procedures to ensure deep renovation performances and quality for the building life time up to the next deep renovation (or demolition), investigating solutions to move the maintenance outside the apartment (flat) in particular for social housing.
- Facilitate the implementation of strategies to achieve the reduction of energy consumption of buildings, especially in the operation and maintenance phase.

2.4 Link to other activities in the project

The following table lists the related aspects that should be considered during the deployment of the strategy and that are the results from other 4RinEU tasks or activities in the project. As their development are not the objective of this D3.6, reference will be made to them in the phases developed in this document.

Table 1 Linked tasks

WP	Task	
WP2	D2.1	Geo-clusters building archetypes
	D2.5	Early design methodology for RES best use in renovation process
WP3	D3.1	Energy auditing protocol
	D3.2	Deep renovation collaborative design platform (CDP) and associated tools
	D3.3	Deep renovation packages and parametric models in different geo-clusters
	D3.5	Protocol for participative deep renovation design and user motivation
WP4	D4.1	Risk assessment
	D4.2	Cost-effectiveness rating system based on LCC and benefits approach for investor

	D4.5	Financing deep renovation
WP5	D5.3	Deep renovation design procurement

2.5 Guide to this document

This document is structured in three main parts. Being a long document, the following table shows how to use it.

Table 2 Guide to the document

Current overview of Deep Renovation projects	
This part of the document analyses how deep renovation projects are managed nowadays, the scope of the interventions and the remaining business opportunities. As a conclusion of the analysis, a set of barriers and challenges are presented. 4RinEU methodology will be a tool to manage those barriers and challenges.	
Section 2	Current overview of Deep Renovation.
Section 3	Barriers and challenges of Deep Renovation.

IPD, BIM and LEAN approaches	
Integrated Project Delivery (IPD), Building Information Modelling (BIM) and LEAN Construction are current trends in the Architecture-Engineering-Construction-Operations (AECO) sector for their potential with respect to the process optimization and project improvement. This section explains the main aspects of the three methodologies.	
Section 4.1	Integrated Project Delivery (IPD).
Section 4.2	Building Information Modelling/Management (BIM).
Section 4.3	Lean Construction.

4RinEU Strategy towards Deep Renovation	
This is the core section of the document. Here is where the 4RinEU methodology is developed to help construction industry agents to improve and optimize their processes in deep renovation projects.	
Section 5.1	Introduction.
Section 5.2	General aspects.
Section 5.3	Phase development.

3. Current overview of Deep Renovation

Current Deep Renovation practices in the residential building sector have some particularities which deserve to be studied previously to the development of the new approaches and solutions suggested in 4RinEU project. Some of them are related to the growing interest of this topic and its rapid expansion, which entails some uncertainty about its meaning, potential benefits, business opportunities and social urgency. Additionally, common practices in an emerging sector, related to an activity as traditional as construction, do not always contribute to its progress; on the contrary, they can be an obstacle to its development. All these issues have been studied and discussed in this chapter. As a result, some useful conclusions have been raised to facilitate compression of the 4RinEU project's targets and to focus the attention of the project's developers in its most important barriers and challenges, which are explained in the next chapter.

A large amount of information has been consulted and contrasted during this avant-garde study, in order to draw general and significant conclusions. The noted references must be understood as "main information/data source" used to develop the corresponding section. Not all the information contained in such sections under the reference mentioned has been taken from it; most of them, in fact, correspond to the general conclusions of the author of the section on the subject.

Finally note that, despite the differences between Retrofit and Renovation projects defined in the first section below, sources of information regarding both concepts have been used for carrying out this analysis due to the similar characteristics and problems they share. In the same way, information related to Deep Renovation or Retrofit projects addressed to other kind of buildings, different than residential, have been also considered.

3.1 Definition, potential benefits and development possibilities

In order to correctly assess the current overview of Deep Renovation in the residential building sector, it is necessary to have a global concept of what it consists of, why it should be addressed and what are currently the possibilities for development in the European Union (EU), considering both commercial opportunities and the social need to renew the stock of existing residential buildings.

3.1.1 Definition of a Deep Renovation project

First of all, a quick analysis of the concept "Deep Renovation Project" is advisable, as opposed to other similar concepts. There is no definition globally accepted all over the world related to these ideas. Diverse concepts or definitions are preferably adopted according to the region or are suggested by different expert bodies to join the criteria.

The most commonly used terms in this regard are "Deep Retrofit project", in the United States, and "Deep Renovation project" in the EU[1]:

- **Deep Retrofit projects**, as typically understood in the United States, are mainly focused on the equipment and installations responsible for the energy consumption of the buildings, including plug loads. The measures applied would seek to improve the energy performance of the building in the range of 30% -50%.
- **Deep Renovation projects**, as commonly defined in the EU, involve the adoption of more intensive and far-reaching measures than those implemented in deep retrofitting projects, which necessarily include important interventions in the building envelope, beyond improvements referrals of energy systems. All these measures are aimed to achieve a reduction from 50% up to 90% and more of the final energy consumption[2]. The relative improvement achieved, within the wide range mentioned, by a deep renovation project will depend not only on the established objectives but also on the effectiveness of the measures applied on site, which is mainly conditioned by the climate zone, the building typology and consumption loads. In this regard, the objective established in the 4RinEU project, which consists of a net decrease of primary energy between 60% and 70%, compared to the pre-renovation status, corresponds to the Deep Renovation concept currently contemplated in Europe.

  In general terms, a Deep Renovation project basically consists on the implementation of a set of actions aimed to **reduce the global energy consumption of the existing buildings**, through the **renovation of the heating, cooling, ventilation, hot water and lighting systems and the improvement of the energy passive features of the building envelope**. This kind of projects requires attention to certain key technical and management issues, essential for the project success. A more detailed description of what is commonly a deep renovation project is included in the following sections. The convenience and potential benefits of implementing deep renovation projects are also mentioned.

3.1.2 Potential benefits of Deep Renovation projects.

A sustainable development based on the decrease of the energy consumption can be boosted by Deep Renovation projects. The benefits of this kind of projects are **environmental, economic and social,** following the triple bottom line of all sustainability

1 "What is a Deep Renovation Definition?" GBPN Global Buildings Performance Network. Building Policies for a Better World. Authors: Sophie Shnapp (GBPN) / Rosa Sitjà (GBPN) / Jens Laustsen (GBPN). Technical Report. February 2013.

2 Improvement ranges proposed by different expert bodies, companies or authors: 75%, or more, compared to the status of the existing building/s before the renovation (GBPN, 2013); 60% - 90% (Renovate Europe, 2013); 50%, 75%, 84% or 90%, corresponding to factors 2, 4, 6 or 10 in the suggested scale (Eurima & Laustsen, 2011); 65% - 95% (Bowie, 2012). The International Energy Agency (IEA) defines Deep Renovation project as that which doesn't lock the savings potential (Saheb, 2012).

projects. The main potential benefits which might provide the extended implementation of Deep Renovation projects are the following[3]:

- **Energy security**: around 40% of the total primary energy demand are currently consumed by buildings in EU, more than the energy used by the industrial and transport sectors. The external energy dependence of the EU is very high, the decrease in energy demand in the building sector would improve the EU's energy balance. The energy market is highly volatile and unpredictable, measures to improve the resilient to market changes are needed.
- **Jobs and growth**: around 8% of direct employment and 10% of the EU Gross Domestic Product (GDP) are related to the building sector. The Deep Renovation of the building-stock would create about 2 millions of new direct jobs by 2020, most of them in Small & Medium Enterprises (SMEs). The increase of the activity would also have a positive impact in the industrial sector related to the building renovation sector.
- **Health:** implementation of deep renovation measures would contribute to improve the occupants' health and well-being; since they attend to all the variables of the comfort conditions.
- **Environment:** heating, cooling and hot water account for more than 60% of the buildings' consumption. Implementing renovation measures in heating consumption might reduce by 70%, at least. Improvement of the energy performance of the buildings would greatly decrease the CO_2 emissions in EU (around 36% of the total) through the reduction of the fossil fuels use, with an extra benefit for de citizens related to the improvement of the air quality.
- **Public Finances**: public inversion in Deep Renovation projects indirectly provides a good financial return, valuated around 5 € per 1 € invested.
- **Household economy of EU citizens**: reduction of the energy bill of those citizens which houses had been subjected to a Deep Renovation project would increase their quality of live; reducing cases of energy poverty.

3.1.3 Development opportunities of Deep Renovation projects

More than 40% of buildings in the EU were built before the 1960s, when no energy efficiency requirements existed in the national building codes. Buildings constructed today consume around half as much energy than those built in 1980s. Buildings considered energy efficient in the EU are just 10% of the total. It is estimated that at least

3 Renovate Europe. https://renovate-europe.eu (Renovate Europe is a political communications campaign with the ambition to reduce the energy demand of the EU building stock by 80% by 2050 compared to 2005 levels through legislation and ambitious renovation programmes. This will bring the energy performance of the entire building stock in the EU to an NZEB performance level).

two thirds of existing buildings will still exist in 2050, by which time the EU has proposed to achieve a reduction of emissions between 80% and 95%[4].

The current status of the building stock in the EU presents a greatly favorable scenario for developing business in the building deep renovation sector. As an example, looking at the data presented in figures 1,2,3,4 useful conclusions about the business possibilities of implementing deep renovation measures aimed to improve energy savings associated to the space heating of the EU residential buildings can be made:

- The EU country where these measures might be considered as a priority from a business point of view, after a first rapid assessment, is Belgium: having the second oldest residential building stock of the EU, Belgium presents one of the highest share of space heating consumption referenced to the total, the highest space heating consumption per dwelling, the most dependence rate on fossil fuels (gas and oil) and the worst thermal insulation of the buildings' walls compared to its neighbouring countries, with similar climate conditions.
- Another set of countries, such as UK, Netherlands, France and Slovakia, presents a similar situation than Belgium, although less pronounced. They might be also a preferred destination for investors involved in the deep renovation business.

[4] Energy efficiency of buildings. A nearly zero-energy future? EPRS. European Parliamentary Research Service. Author: Nikolina Šajn. Members' Research Service PE 582.022.

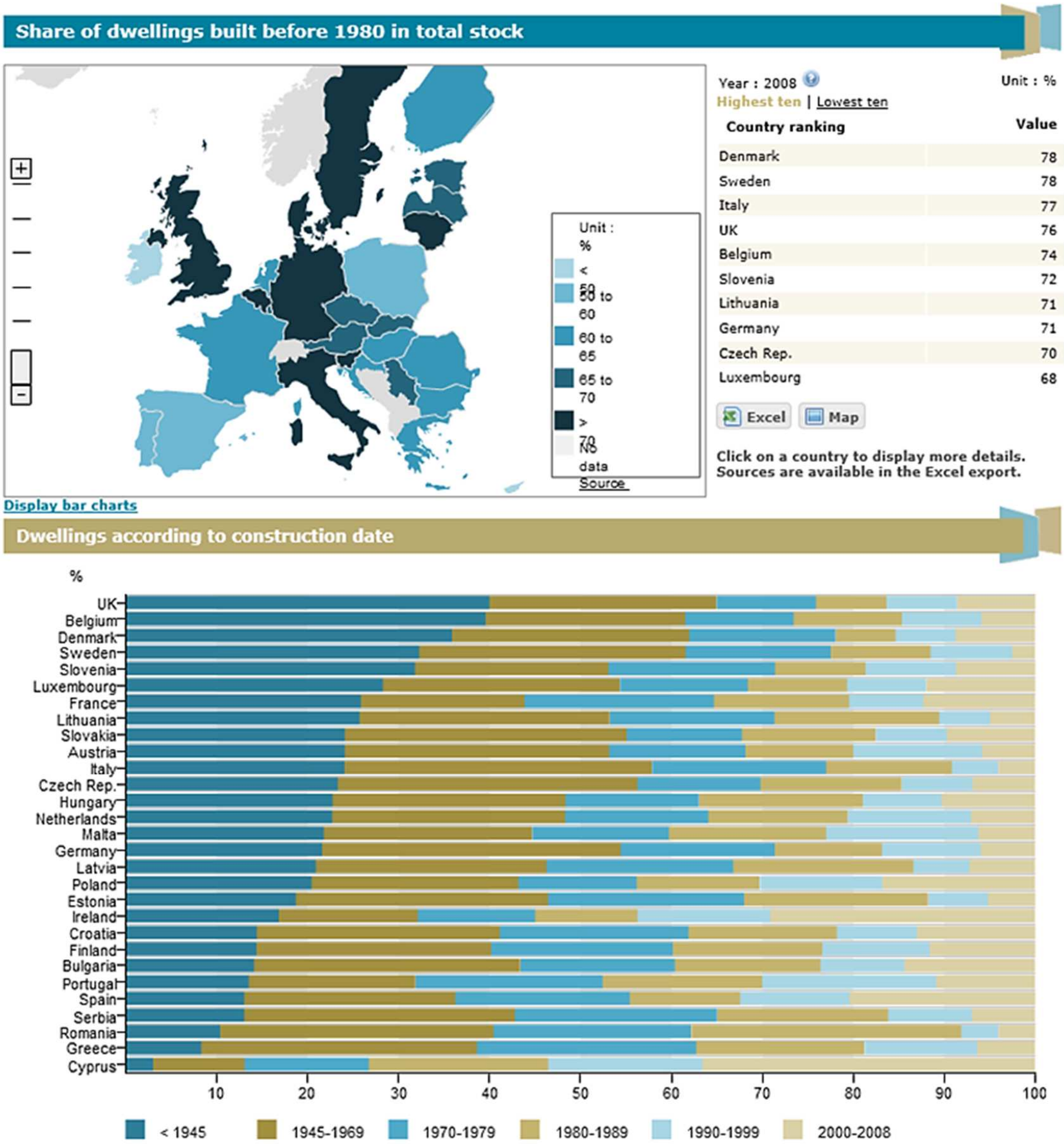


Figure 1 Share of dwellings according to construction date[5]*.*

5 Project ENTRANZE. www.entranze.eu/data-tool/interactive-data-tool

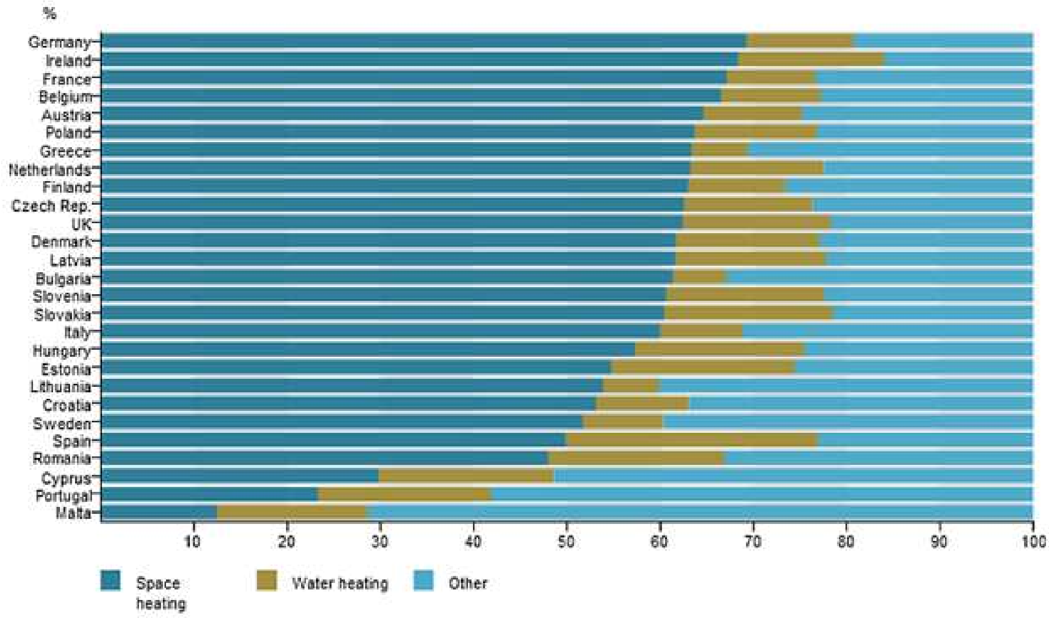


Figure 2 Share of space heating in total residential consumption[5]

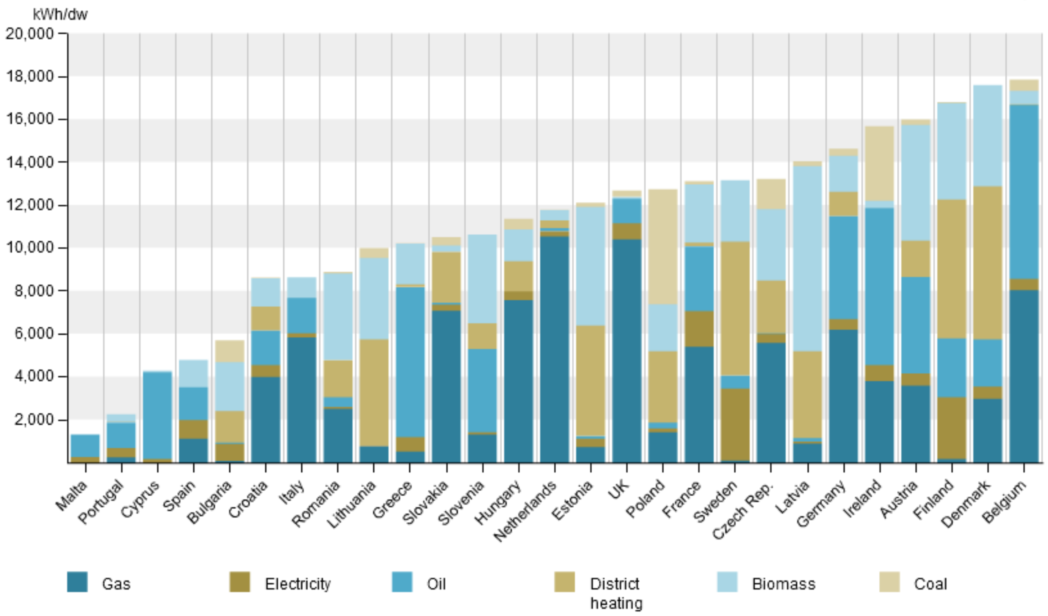


Figure 3 Space heating unit consumption per dwelling5.

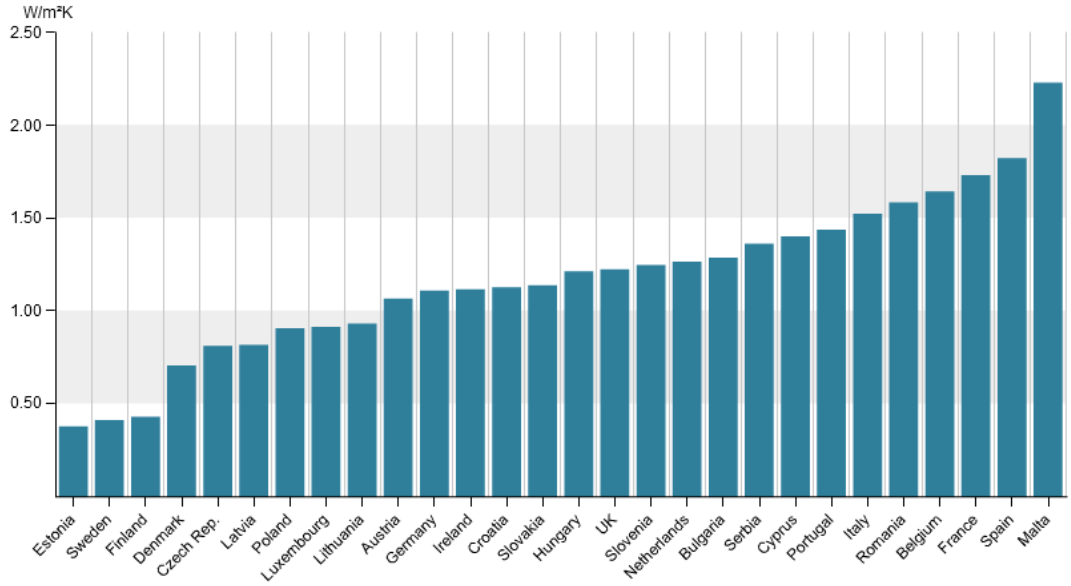


Figure 4 Average building walls U-values[5].

From the same analysis the EU countries where the governmental construction and energy policies, the owners and users implication and the industrial, business and financial sectors' interests have been more conducive to the instruction of energy saving and efficiency measures, such as renewable sources for energy supply or high thermal insulation of the building envelope. In this sense:

- **Denmark** appears as the most advanced EU country in the optimization of the energy efficiency in its residential building stock. It presents a moderate share of space heating consumption referenced to the total, despite it has the second highest space heating consumption per dwelling, mainly based on the use of district heating and biomass energy sources, and a moderate buildings' walls insulation average value, presumably due to the oldness of its residential building stock, the third oldest of the EU. All these circumstances suggests that the success of Denmark regarding the high performance of its dwellings is based on an investment effort on high efficiency energy systems, perhaps linked to the use of district heating and renewable energy sources.
- **Finland** is also an exemplary case in the same sense than Denmark, presenting both countries similar values and characteristics in almost the quantified variables. Although, in this case, success could be attributed not only to the high efficiency of its energy systems, but also to the great thermal insulation level of its buildings, higher than observed in Denmark. This fact could be attributed to its residential building stock, one of the youngest of Europe, and to the good practices in matters of construction and implementation of energy facilities.

Several European and national directives have been launched by the EU in order to seize the potential benefits and development opportunities of the Deep Renovation projects: the Effort Sharing Decision" of 2009, which established national targets aimed to enable Member States to collectively achieve a 10% Greenhouse Gas (GHG) reduction in sectors not covered by the Emissions Trading System (ETS); the EU's Energy Performance of Building Directive (EPBD) (Directive 2010/31/EU), which made nearly zero energy buildings (nZEB) the required norm for all new buildings in the EU from 2021 and established a minimum energy performance requirements for existing buildings; building units and building elements that are subject to major renovation; the "**Energy Efficiency Directive (EED) (2012/27/EU)" of 2012**, which **includes for the first time the concept of Deep** Renovation for existing buildings. And the directive 2018/844 which amends Directives 2010/31/EU on the energy performance of buildings and 2012/27/EU on energy efficiency, introducing building control and automation systems, promotes the deployment of the infrastructure for e-mobility and introduces an intelligence indicator to assess the technological readiness of the building.

3.2 Common practices in Deep Renovation projects

A **Deep Renovation Project** is, in general terms, a complex process which involves many stakeholders, goes through several stages, implements a wide and diverse range of technical solutions and must consider a set of **technical, economic and human factors** with common and ambitious objectives.

There are some crucial differences with new construction projects, due to the fact that some of those factors can constitute serious constraints which limit the intervention of the parties involved: buildings already exist and the technical solutions potentially suitable might not be practicable; in case of residential buildings, owners or occupants do not often have enough financial sources to approach the required reforms and private loans or public support is needed; payback periods are usually long because most of the expected benefits consist of energy savings, thus maintenance of equipment and installations and good energy practices concerning the operation of the energy systems are indispensable.

Nevertheless, renovation projects are usually no approached as an integral process according to the complexity required. On the contrary, they are conceived as a service delivery, indifferent to the difficulty and multiplicity of the interactions existing between the parties involved and developed activities. This approach may result in the achievement of a non-optimal global solution, the non-compliance of the targets defined, the increase of the final costs for one or several parties or, in the worst case, the project failure.

This section gathers the most **common practices to approach Deep Renovation projects** in the residential building sector, including a brief description of the different phases to pass through for carrying it out, the definition of the stakeholders' roles and the most usual actions undertaken.

3.2.1 Common key phases comprising a Deep Renovation project

The overall implementation process of a Deep Renovation project normally entails the execution of several key phases[6] that could be correlated to the ones mentioned in the introduction.

Phase I: Definition of the project's scope and targets → procurement:

- Main existing problems and aspects potentially unlikely concerning the energy performance and comfort conditions of the residential building must be previously detected. In this regard, not only the building property but also the occupants should be consulted by a survey process. These measures, together with the assessment of the financing options, allows drawing useful conclusions about the real scope and possibilities of executing an appropriate deep renovation project.
- Energy Service Companies (ESCO), Engineering Procurement Construction (EPC) and Engineering Procurement Construction Management (EPCM) companies are a good option to be contracted by the building owner for the planning, managing and implementing the renovation project. This company is responsible to gather the information from the building owner, occupants, users and the facility manages, if exists, related to the current energy performance of the building.

Phase II: Audit, assessment and diagnosis of the building energy performance → planning:

- The energy audit of the building performance comes to identify the reasons of the problems and shortcomings detected in the previous stage and to quantify its effects. The audit process is focused on analyzing energy waste, identifying energy demand peaks and recognizing possible improvements of energy-efficiency. In this phase, passive behavior of the building, consumption data and energy systems performance are empirically assessed and analyzed. Appropriate KPIs are defined and employed to evaluate the energy performance and comfort conditions of the building. As a result of the diagnostic, deep renovation packages, aimed to improve the thermal features of the building envelope and optimize the equipment efficiency and control schemes, can already be outlined.
- The project management company is the most appropriated to carry out these works. They usually take responsibility to prepare the preliminary documentation, with the technical requirements stablished from the results of the building diagnosis, and launch the tender to select the construction company; the one that presented the selected proposal.

Phase III: Generation and analysis of Deep Renovation package proposals → design:

- Deep renovation packages are designed and evaluated from different points of view. The most suitable deep renovation technologies, concerning building

[6] "Existing Building Retrofits: Methodology and State-of-the-Art". Zhenjun Ma*, Paul Cooper, Daniel Daly, Laia Ledo Sustainable Buildings Research Centre (SBRC), Faculty of Engineering, University of Wollongong, New South Wales (NSW), 2522, Australia.

envelope elements and heating, cooling, ventilation, hot water and lighting systems, are proposed in this stage. By means of suitable energy models, financial analysis tools and risk assessment methods, and with the KPIs and criteria stablished for each matter, the proposed options can be numerically evaluated and a final deep renovation package can be chosen. There are a wide and diverse range of selection methods, which try to find among the generated alternatives which maximize technical and economic benefits, minimizing all kind of risks.

- The Project Manager (PM) selects the best design among all the proposals presented by the companies participating in the tender and advises the building owner in the decision making process, considering not only the technical benefits but also the private financing and public supporting possibilities.

Phase IV: Project implementation and commissioning → construction:

- The chosen deep renovation project is implemented in the building and commissioned, which includes the correspondent optimal function testing of the measures applied. Since a deficient management of renovation works can significantly increase the economic risks, because of the non-compliance or the unneeded extension of deadlines to the detriment of the costs flow and the building occupants, it would be advisable to adopt effective strategies addressed to guarantee a success project implementation. In the same way, the commissioning of the renovated building should include the delivery of a set of guidelines elaborated to properly operate and maintain the elements, equipment and operating protocols introduced. In this regard, it could be advisable to use, in the assessment of alternatives described in the previous stage, a set of KPIs specifically defined to consider these factors: implementation works and Operation & Maintenance (O&M) actions after the commissioning; the last one, under the perspective of the criteria frequently applied for the Life Cycle Analysis (LCA) of the building materials and energy equipment.
- The chosen construction company is responsible for the implementation of the Project of Deep Renovation on site, with the help of all subcontracted technicians and the material and equipment supplied, respecting the deadlines and budget assigned.

Phase V: Project validation and verification → (towards O&M):

- The last stage is the validation and verification of the foreseen energy and economic saving after the implementation and commissioning of the deep renovation measures. In this phase, standard Measurement and Verification (M&V) procedures are used. Results should be verified, in turn, by the property and residents of the building throughout a new survey similar to the first phase, in order to assess the effectiveness of the measures applied and the satisfaction of the building owner and final users.
- The PM validates and verifies the final results achieved after the implementation and commissioning of the project and stablishes the guidelines needed to operate and maintain the implemented measures during the foreseen life-time and further.

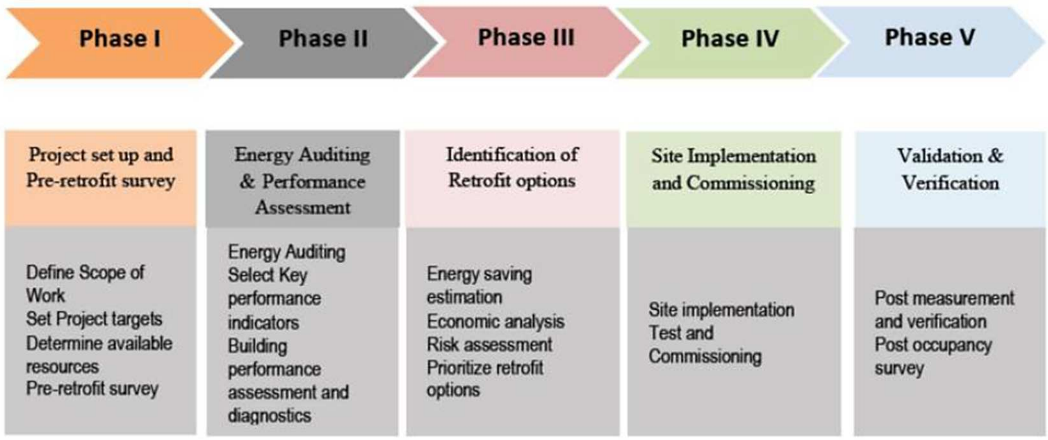


Figure 5 Key Phases in a Suitable Building Retrofit Programme (source: Ma et. al., 2012)[7].

3.2.2 Main stakeholders involved in a Deep renovation project

Stakeholders can be defined as people, companies or bodies directly or indirectly involved or interested in the Deep Renovation project. Main stakeholders and roles in a Deep Renovation Project of the public and private residential building sector are the following[8]:

<u>Building owner, occupants and users:</u>

The building owner is the promotor of the renovation project, moved by the deficiencies and problems and/or the potential energy savings detected. The building owners can be a legal person, a private institution or a public body, but not necessarily the occupants or user of the building. Public housings are often managed by local, regional and national authorities, which usually develop the energy renovation and retrofit activities in the framework of territorial energy plans. Building owner, occupants and users must transfer their complaints and comments about the deficiencies detected, the comfort conditions and their energy consumption habits.

[7] “Defining and developing an energy retrofitting approach”. Luther, MB and Rajagopalan, P 2014, Defining and developing an energy retrofitting approach, Journal of green building, vol. 9, no. 3, Summer, pp. 151-162.

[8] “Improving Management of Green Retrofits from a Stakeholder Perspective: A Case Study in China”. Xin Liang,1 Geoffrey Qiping Shen,1,* and Li Guo2. Derek Clements-Croome.

Project Manager and developer:

It is the agent contracted by the building property to manage and totally or partially carry out the Deep Renovation Project. Some of the most typical companies that can take up this role are the following:

- Engineering, Procurement and Construction companies (EPC): they offer a complete service, undertaking the design, procurement, construction, commissioning and maintenance works. Coordination of all the parties involved in the project, communication with sub-contractors and suppliers and control of timing and budget are essential issues to properly assume this role.
- Engineering, Procurement and Construction Management companies (EPCM): similar to the previous one, they limit their activity to coordinate design, procurement and construction works, but do not necessarily execute the construction because they are conceived just as service companies.
- Energy Service Companies (ESCO): they can provide specific and integrated energy solutions for buildings, based on thermal and power generation, storage systems, active energy saving measures, advantageous conditions for the energy supply contracts, calculated risks, adequate financing possibilities, etc. This kind of companies are mainly focused on systems and installations, they do not usually undertake deep interventions in the building envelope (passive solutions). Usually act through EPC (Energy Performance Contracting).

  ESCOs can undertake the audit, assessment and diagnosis of the building energy performance, previously to the project's implementation, and the validation and verification of the project's results after the commissioning. EPCM companies may also accept these roles and additionally provide a good service in the overall management of the project. EPC companies can carry out all these tasks and implement them, besides the construction works; interaction between different parties might be more fluid and intensive in this case. If the PM does not undertake the role of constructor, it uses to be in charge of launching a tender process, assessing the received proposals and advising the property about the final decision.

Architects and consulting engineers:

Architects and engineers form part of the companies mentioned above or sub-contracted by them. They deserve, in any case, a special attention considering that they are responsible for proposing the deep renovation measures according to the established technical and comfort requirements and the budget availability. Architects are involved in the construction measures. Engineers can participate in the energy systems' design. All of them, however, are usually focused on their respective tasks and use different methodologies and working platforms, in such a way that a deficient coordination between parties can entail unexpected delays and extra-costs.

Contractor:

Responsible for managing and developing of the project, construction services, and can also implement the deep renovation measures proposed. Otherwise, the building company chosen as a result of the tender process is sub-contracted by the property to

develop the project. The constructor must fulfil the deadlines and costs established by contract and follow the final design, thus rarely participate in the early diagnosis of the building and the generation of proposals; to which, perhaps, might provide important contributions.
Building material, equipment, construction machines, prevention measures, specialized workers, etc. are provided by the sub-contractors and suppliers chosen by the constructor. In the same way than this, they do not use to participate in any of the phases previous to the implementation on site.

Facility manager (FM):

It is the company or professionals responsible of the O&M works, an essential source of information, together with the occupants and users, for the assessment of the building energy performance. This figure does not always exist.

Private financial entities:

Banks provide loans and financial support to the project's promotor. Loan conditions are indispensable to calculate the economic viability of the project and must be taken into account in the KPIs definition.

Public support bodies:

European, national, regional and local governments establish policies and laws addressed to promote sustainable development and can launch energy efficiency plans in order to reduce low carbon emissions. Sometimes, these measures are part of renovation and retrofit plans boosted for the existing building stock. They can constitute important support for the Deep Renovation plans undertaken by the buildings' owners, and must also be considered in the analysis phase of the deep renovation package proposals.

Expertise bodies:

Research and industry institutions promote definition of technical standards and design guidelines. Although they usually do not directly participate in the Deep Renovation Projects, their consultation and assistance can contribute to achieve successful results.

3.2.3 Common procedures and actions adopted in Deep Renovation projects

There are several actions typically carried out in Deep Renovation projects which, however, take different forms depending of the preferences of the stakeholders involved. The first ones are the adoption of a traditional management scheme and a distribution of roles such as those exposed in the previous sections, the rest are mainly referred to the methodologies used in the analysis of the deep renovation package proposals and the renovation measures in themselves.
Regarding the analysis methodologies of Deep Renovation proposals, many methodologies have been used and suggested by designers and researches. Below are some of the most relevant methods or important aspects commonly considered to approach the generation, assessment and choice of Deep Renovation design proposals. With respect to the concrete technological measures and strategies intended to improve the energy efficiency of the residential buildings some common solutions are mentioned.

Deep renovation project management from a stakeholder perspective[6]:

The current literature usually defines the most important factors conditioning a Deep Renovation project as Critical Success Factors (CSFs). Although not every author base his studies in the same CSFs classification, the most common CSFs are gathered into the following categories: technology (technical and facility solutions), building status and environment (audit, diagnostic, environment impacts, etc.), economics (investment and O&M costs, financing, taxes, etc.), sociocultural (historical, culture, social and human factors), and policy and standards (legislations, regulations, energy renovation programs, etc.). Most studies identify and prioritize CSFs independently of stakeholders for the assessment and choice of the proposed Deep Renovation packages. This approach is poor and it is retreated from reality, since both (CSFs and stakeholders) are strongly interrelated and should not be separately considered. Some of the source consulted, throughout the state of the art studied, suggest a Social Network Analysis (SNA) to reveal the relationship between CSFs and stakeholders and propose methodologies to develop Deep Renovation projects on the bases on an integrated project concept.

Multivariant design and multi-criteria analysis[9]:

A methodology based on this idea uses quantitative and qualitative design and evaluation criteria, expressed by means of a system of values and weights, in order to generate a wide range of alternative among the most suitable and convenient, is selected. Those criteria expressed in a quantitative form are related to the measurable renovation aspects; such as, thermal insulation of the building envelope, comfort requirements, average daily power demand for air conditioning, investment costs, etc. Qualitative criteria usually regard to comfort appreciation, aesthetical aspects, social impact, innovation level of the applied solutions, etc. Since every energy system or building components which take part in the energy building performance are in continuous interaction each other, the calculation problem for the multi-criteria analysis can become really complex. Many decision-making models have been suggested in this regard based on: cost-benefit analysis, lattice methods for global optimization, prediction of the building's habitability index, energy rating system for existing houses, among others. This kind of analysis results in a decision-making matrix where each assessed alternative is characterized by a certain quantitative and qualitative value.

---

[9] "Multivariant design and multiple criteria analysis of building refurbishments". Arturas Kaklauskas, Edmundas Kazimieras Zavadskas, Saulius Raslanas, Faculty of Civil Engineering, Vilnius Gediminas Technical University, Sauletekio al. 11, LT-2040 Vilnius, Lithuania.

Multi-objective optimization model based on a Life Cycle Cost Analysis (LCC)[10]:

Currently, the multi-objective optimization models are being extensively used in the building renovation sector. Through these models are set multiple technical and financial alternatives, based on specific requirements, generated and assessed in order to meet a double objective: maximize the energy savings and minimize the payback period of the initial investment. In this way, the project designer can advise the building property for the decision making. Critical Success Factors (CSFs), related to energy, economic, social and others, should also be taken into account by the property and the rest of stakeholders, including the building occupants and users, for a right final decision. As a variant of the conventional multi-objective optimization models, some authors suggest to introduce a technical and economic analysis based on the life-cycle cost, in order to meet the mentioned two objectives during the life time of the energy systems and building solutions implemented.

Large-scale deep renovation building projects[11]:

Some experts introduce a new dimension to the concept of Deep Renovation projects related to the size of the implementation. This may include district, municipal or regional energy efficiency projects; probably, partially financed or supported by the public authorities. Therefore, management and implementation strategies for large-scale renovation projects have been studied on the basis of a dynamically optimizing control approach aimed to maximize the energy savings and minimize payback periods throughout the whole project. During the timeframe of the project, partial objectives, stakeholders' needs or requirements and old and emerging technologies might experiment changes, forcing the PM in turn to change partial objectives and continuously adapt the global ones throughout the time. It is worth mentioning that public building renovation and retrofit projects are usually especially focused on the residential sector.

Common Deep Renovation measures to improve the building energy performance[4]:

Specific technologies and actions undertaken to improve, through Deep Renovation projects, the energy performance of residential buildings are common to all the studies and they used to be categorized into three groups:

- Energy supply management: it includes renovation of power and thermal networks of the building and introduction of renewable generation systems, such as photovoltaics, solar thermal, wind turbines and geothermal heat pumps. Some of them can become part of the building as integrated elements, assuming energy and construction functionalities.
- Energy demand management: consist of the reduction of the heating and cooling demand by improving the passive features of the building envelope.

---

10 "A multi-objective optimization model for the life-cycle cost analysis and retrofitting planning of buildings". Wang, B., Xia, X., & Zhang, J. (July 2014). Energy and Buildings, Volume 77, pp. 227-235.

11 "Large-scale building energy efficiency retrofit: Concept, model and control". ZhouWua, Bo Wangb, Xiaohua Xiab. School of Automation, Chongqing University, Chongqing, China.

- Energy consumption patterns: optimized consumption habits, advanced control schemes, natural or mechanical ventilation, heat recovery and thermal storage systems are some of the typical measures applied to improve the energy efficiency of the buildings.

Key Performance Indicators (KPIs).

One of the most common concepts used for the management of Deep Renovation projects are the Key Performance Indicators (KPIs), which quantify the implementation success of a certain measure. Its use is extended in every kind of multi-criteria analysis or multi-objective optimization models of different sectors to find the optimal solution among the different available options. The right definition of the most suitable set of KPIs is essential for the project success and it is aligned to some mentioned above concepts such as the Critical Success Factors (CSFs), the specific Deep Renovation measures and other useful indicators commonly used in the making-decision process.

Part of the common practices summarized in this section, a wide range of bibliographic references can be found in the specialized literature. The study “Existing Building Retrofits: Methodology and State-of-the-Art” (by Zhenjun Ma, Paul Cooper, Daniel Daly and Laia Ledo, from the University of Wollongong, Australia) offers an overview about the recent researches and developments in the field of the retrofit technologies addressed to existing buildings. All the aspects treated can be also applied to the Deep Renovation projects of the residential sector.

4. Barriers and challenges of Deep Renovation

This section summarises the main findings from the assessment of the state of the art and common practices prevailing on the managing and implementation of the deep renovation projects in the residential sector. In this regard, several key aspects are investigated and some possible solutions outlined.

Figure 6 shows the main improvement possibilities detected in a deep renovation projects' classic management scheme, as a result of the analysis of the state of the art carried out. The overall management scheme, the interaction between stakeholders and the methodologies and tools introduced through the development of 4RinEU project should result in a more integral approach of the project as a whole.

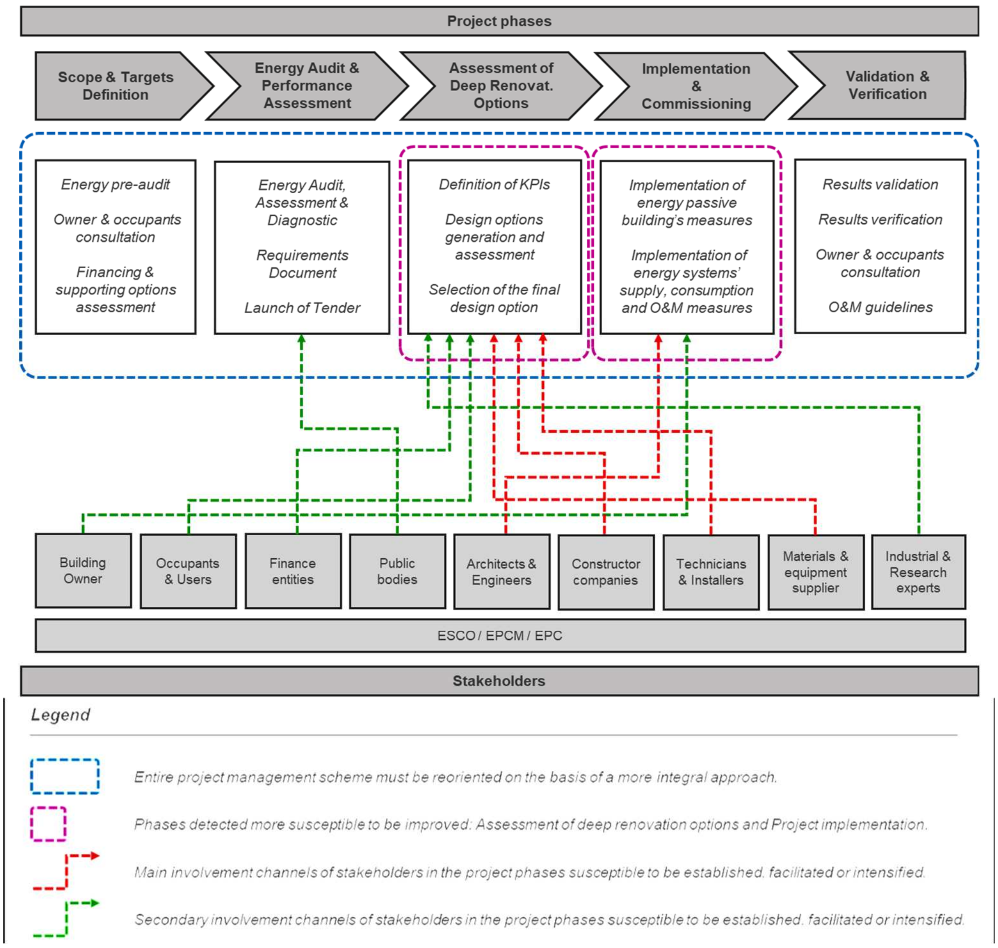


Figure 6 Main potential improvements detected in the classic Deep Renovation projects' management scheme.

The main barriers and challenges identified for the improvement of the deep renovation projects implementation are outlined below.

4.1 Deficient definition of objectives

Traditionally, Deep Renovation projects are **poorly targeted from the beginning**. This is evident by the conclusions extracted from the searching and study process of the state of the art in itself: almost all the specialised publications are focused just on the phase of renovation proposals analysis and selection; it is difficult to find references to the overall conception and management of the project as a whole, considering the project as an integral set of activities undertaken by a wide number of stakeholders and with complex and multiple interactions between tasks and participants. The principal objective usually declared is to find the optimal package of renovation measures among a wide range of possibilities, by means of complex calculation methodologies, mainly based on the quantification of the existing and expected comfort conditions and the associated economic costs, and the establishment of a set of priority criteria useful for the choice of the best option. Opportunities to implement improvements in the project management scheme and the working strategies and tools between the parties involved are not commonly explored; not being generally included and quantified in the same way than the mentioned technical and economic issues. In this sense, it can be admitted that definition of objectives is limited and not very ambitious, being reduced to a set of partial targets accepted for each participant. The way it usually operates the management schemes comes to confirm this conclusion.

4.2 Obsolete management scheme and poor interaction between stakeholders

The commonly adopted project management scheme is clearly linear. The phases which through a deep renovation project happen one after another. Competencies of each party are developed alone, as worked on commission, with low or null participation of the other stakeholders. Interactions between participants are quite limited and debates and feedbacks are not a common practice. There are many possible interactions that might enrich the project, towards a well stablished common objective, not sufficiently appreciated and experimented.

As a conclusion, **a more sophisticated management scheme is needed** to respond more effectively to the complexity of a Deep Renovation project. Interactions among stakeholders must be increased and intensified in order to improve the efficiency of the project global management and translate associated benefits into a more success result. This would place the project team in an advantageous position with regard to its competitors. Some of the studies analyzed in this state of the art is aimed in this direction, as presented as “Deep renovation project management from a stakeholder perspective” in the previous chapter.

4.3 Design based on poor schedule and budget criteria

As commented above, on the basis of a traditional management scheme, each stakeholder carries out its works separately with respect to the others. This fact has a direct negative consequence on the solutions package finally implemented by the contractor. Since the contractor does not participate in the preliminary conception of the proposed renovation measures' packages, the assessment of these proposals and the choice of a final package, it cannot contribute to the adoption of the most suitable solution. Considering that the contractor is the most qualified stakeholder for the assessment of the contingencies regarding deadlines and budgets, an essential information resource, in the early development phases, is being wasting for the project success. Therefore, the traditional working scheme directly conducts to a final solution design based on a poor assessment of schedule and budget beyond the contractors' criteria, which is obliged to meet time and technical milestones not always according to the real status of the building and the needs of the measures implemented. This circumstance may result in delays, extra costs or deficient implementation of the foreseen measures.

On the other hand, the traditional way of working in the building sector does not specially promote the streamlining of the project. **Most efficient processes**, inspired in the industrial sector, **are needed in order to reduce unforeseen contingencies,** control the production quality and reduce costs during the implementation phase.

4.4 Non-integrated systems and components design

One of the most relevant deficiencies, detected from the state of the art study, is the lack of an integral plan and a methodology for integrating the different building components and energy systems, which constitute the renovation measures' package during the implementation phase. The wide range of professionals (architects, engineers, construction, electric and hydraulic technicians, etc.) taking part in a deep renovation project do not have a common ground and a suitable working platform where cross incompatibilities may be early detected.

In this regard, the use of advances technologies, aimed to facilitate communication between the professionals involved and help to the integral management of the implementation project is discovered as essential (such as **BIM**). The chosen technology should enable the entire characterization of every component and system, not just restricted to their physical features but extended to their historical tracking from the purchase to the installation, in the framework of an **integral project concept**. A well-conceived methodology would permit increasing the effectiveness of the implementation works and achieve a consensual final result where no detail has been left to chance.

4.5 Project financing problem in the residential sector

One of the main barriers and challenge to overcome regarding deep renovation in the residential building sector is finance. The building owners cannot often alone undertake the high implementation costs of a deep renovation project, even more considering that most of proprietaries are private. Besides, many of the residential buildings are of shared ownership, which constitutes an extra problem because of the **difficulties to achieve consensus about the object and scope of the project and the sharing of investment and**

O&M costs. On the other hand, public supports are not usually easy to achieve due to legal, administrative and fiscal issues. The European Parliament, aware of these barriers is continuously trying to boost deep renovation projects and being ambitious in its targets concerning the renovation of the building stock, specially focused on the improvement of the buildings energy performance.

Project financing problems might be reduced through a **more fluid and intense implication of the private finance entities and public authorities**, in the framework of a better conceived project management scheme.

5 IPD, BIM and Lean approaches

Integrated Project Delivery (IPD), Building Information Modelling (BIM) and Lean Construction are current trends in the AEC sector for their potential to the process optimization and project improvement.
The following subsections outline the main aspects of the three methodologies that are taken into account in the 4RinEU strategy definition in section 5.4.2.

5.1 Integrated Project Delivery (IPD)

Several fundamental project considerations are directly impacted by the delivery method selected: the need to adhere to a realistic budget, a schedule that accurately presents the performance period, a responsive and efficient design process that leads to a quality set of documents, a thorough risk assessment followed by the proper allocation of risk by the owner, and a recognition of the level of expertise within the owner's organization.
According to the guide from the American Institute of Architects (AIA), a project delivery method defines '*how the project will be designed and constructed*'[12]. Integrated Project Delivery (IPD) is a project delivery approach '*that integrates people, 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*'[13].
The principles of IPD projects compared to the traditional process that add value to the project are (AIA 2007) listed below.

- Mutual respect and trust.
- Mutual benefit and reward.
- Collaborative innovation and decision making.
- Early involvement of key participants.
- Early goal definition.
- Intensified planning.
- Open communication.
- Appropriate technology.
- Organization and leadership.

[12] AIA. (2007). *Integrated Project Delivery: A Guide*.

[13] Idem

The following schemes shows the relationship between main actors in the three main project typologies:

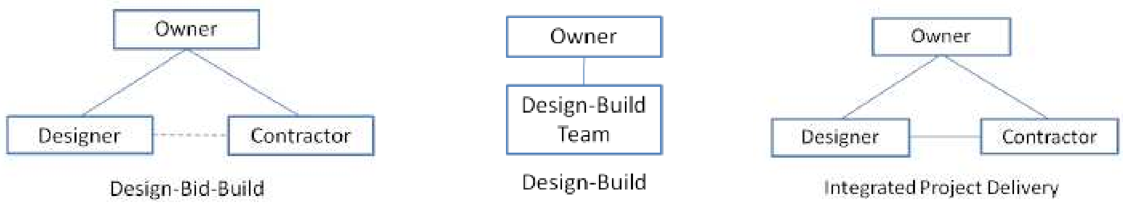


Figure 7. Integrated project delivery compared to traditional Design-Bid-Build or Design-Build (CMAA 2012)

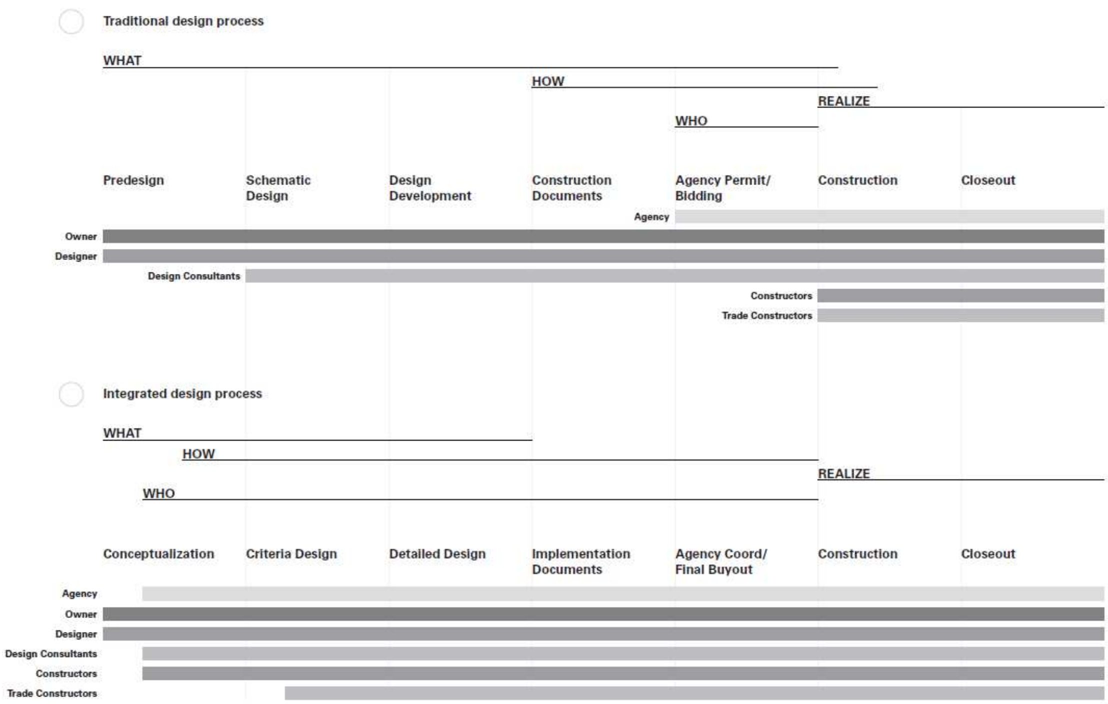


Figure 8 Traditional vs integrated design process (AIA 2007)

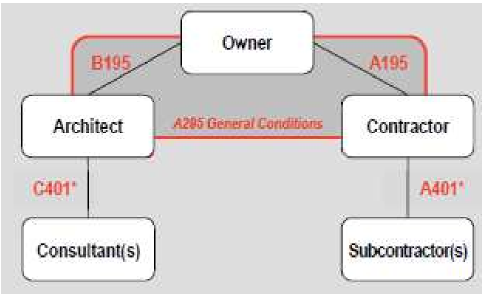
IPD leverages early contributions of knowledge and expertise through the use of new technologies, allowing all team members to better realize their work and achieve the highest optimization of the project's resources. These early contributions of expertise are guided by the principles of trust, transparent processes, effective collaboration, open information sharing, team success tied to project success, shared risk and reward, utilization of full technological capabilities and support, amongst others.

As can be seen in previous Figure 8, IPD introduces a change in the traditional process by anticipating the 'how' and 'who'. The share of vision and increase use of resources during the early stages to achieve this scheme implies the optimization of the construction phase, saving more resources than those that are spent at the beginning.

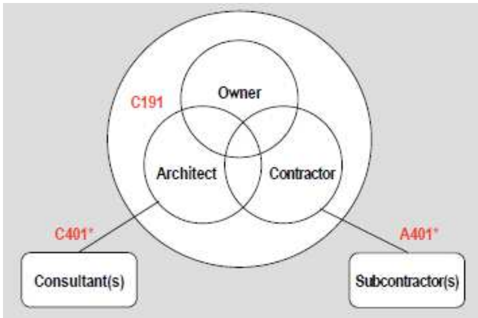
IPD is supported by special agreements in which the main stakeholders show their responsibilities and share risks and rewards. At least, the owner/promoter, the designer and the contractor are included in these agreements with the aim of achieving an early involvement of the main stakeholders.

The use of a qualified Construction Manager can greatly help in developing a project and in making the decision on project delivery methods, regardless of whether this expertise comes from internal staff or from a third-party provider.

There are different formats of IPD agreements, the AIA allocates the Single Purpose Entity (SPE) – AIA C195 that creates a limited liability company for the project development through several contracts with the entities participating; Multi-party Agreements (MPA) – AIA C191; or the Transitional Documents in which IPD is not fully deployed but the collaborative project delivery is present. There are more examples of contracts proposed by different organizations as, i.e., ConsensusDocs 300[14], among others.



Transitional Documents



Multi-Party Agreement

Single Purpose Entity (SPE)

Figure 9 AIA's documents for different IPD agreements (AIA 2015)

The implementation of IPD provides benefits to the project but, as all innovative approaches, also implies a number of barriers. In the first place there is skepticism on the companies' side due to their unwillingness to transform their traditional procedures. This is known as resistance to change. The increase of effort during the strategy definition stage of the project that IPD requires or the uncertainties provoked during tendering

[14] https://www.consensusdocs.org/

process are not well accepted. Also, IPD requires a mutual trust and share of objectives between the organizations that is not always easy to achieve.

Therefore, different cultural, legal and financial barriers related to the implementation of IPD approach (Ghassemi, 2011) were identified, and are listed below.

- Integrating project personnel as early as possible in contrast with traditional process.
- IPD requires training for a correct application of all the parties involved.
- Difficulties in trust-building activities and tools among the stakeholders, as well as sharing cost savings and overruns.
- The compensation structure is different to the traditional contract structure that provides incentives to each individual firm.
- Legal limitations and implications for the new contracting.
- The legal framework for public procurement usually does not allow the multi-party agreements or the best value selection.
- The need of tools for supporting the collaborative approach.

In order to overcome these barriers, organizations need to clearly understand the benefits that will be obtained in later stages of the process.

5.2 Building Information Modelling/Management (BIM)

The BIM Project Execution (BEP) Guide from The Computer Integrated Construction (CIC) Research Group of The Pennsylvania State University (CIC 2010) is one of the most remarkable guides of BIM. It includes the BIM definition from the National Building Information Modeling Standards (NBIMS) Committee. This committee defines Building Information Modelling as *'a digital representation of physical and functional characteristics of a facility. A* ***BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle****; defined as existing from earliest conception to demolition. A basic premise of BIM is a* ***collaboration by different stakeholders at different phases*** *of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder"*[15].

BIM is not only an information model but also a **working methodology that integrates digital models, information systems and processes to achieve the project delivery**

[15] MBIMS. (2007). Available at http://www.wbdg.org/pdfs/NBIMSv1_p1.pdf

optimizing the design and construction process. Its basis for tools and procedures definition could be summarize as collaboration.

Main goals and **benefits** of BIM methodology application in a project are:

- **Improved communication** between stakeholders (data exchange).
- **Collaboration** between the stakeholders (action on data).
- **Advanced models simulation** (use data for prediction).
- **Organized and efficient Planning** (use data for planning activities).
- **Optimization** related to the feedback **to improve the design, execution and management**, as well as **clash detection** (check data).

The application of BIM could entail more efforts or time spent during design phase compared to traditional processes, as well as IPD does. However, there are remarkable benefits during the later phases of the project that compensate it, as for example **avoiding design modifications during construction phase** – which normally implies higher costs - or deviations with respect to the initial budget estimation, among many others.

In order to implement successfully BIM in a project, it is recommended to begin with the end in mind, considering in first place the BIM goals that are intended to be achieved during the project. Afterwards, they could be linked to the related BIM uses (CIC 2010). These are the common uses of the BIM models along the project phases:

- **Design Phase**. Models developed by the design team with the required level of detail to generate the current construction documentation.
- **Construction Phase**. Models with higher level of detail, used before and during the construction phase to reduce risks, improve safety and eliminate errors and conflicts. The as-built model, updated with all changes, contains useful information on installed assets and systems.
- **O&M**. Models derived from the as-built model erasing construction details and other superfluous information. It links to O&M systems.

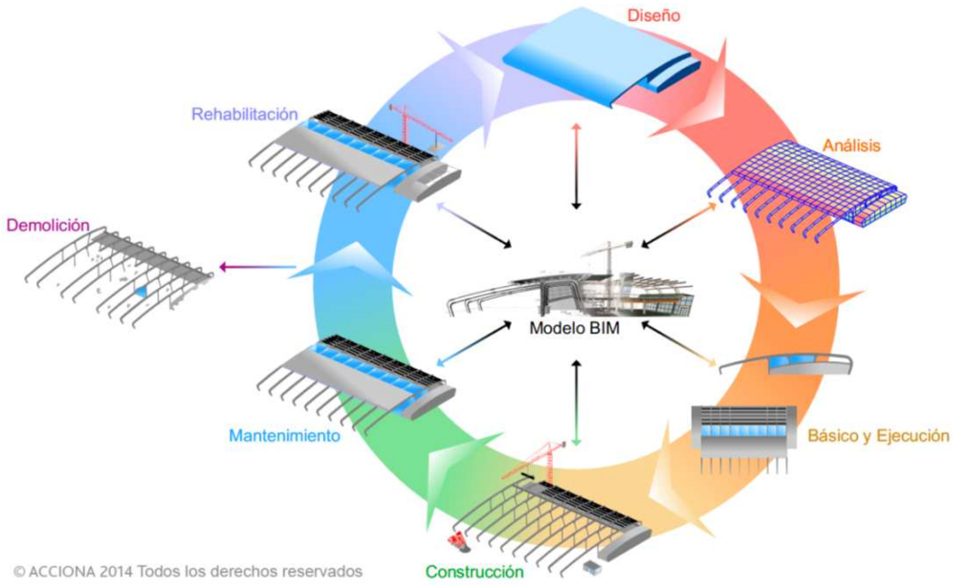


Figure 10 BIM main concepts illustration

As in the case of the IPD process, the main barrier for its implementation is the resistance to change, organizations normally don't want to modify their regular processes. Another relevant barrier is the erroneous perception of **BIM as a tool instead of a collaborative methodology**. In addition, the implementation of the BIM's methodology in an organization requires associated costs to IT and training.

There are tools that allow to calculate the Return of Investment (ROI) to evaluate the initial investment compared to the future profits which is a relevant argument to overcome BIM implementation barriers.

The management of multidisciplinary models integrated in design and construction projects is called **Virtual Design and Construction (VDC).**

This management includes from the product (materials, facilities...) to the work processes and organizational flows of the different operating teams.

The Virtual Design and Construction (VDC) methodology[16], developed at Stanford University, should be used together with the BIM **to improve processes in the sector** not only at the level of 3D visualization and interference detection and collision, but also to generate an external instrument for the industrialization of the sector.

It is important to highlight that the basic design developed from BIM models will always need a constructive validation that will only occur with the inclusion of the builder, subcontractors, manufacturers and suppliers.

---

16 Stanford University Center for Integrated Facility Engineering (CIFE) research

VDC together with BIM and LEAN and automation are needed to achieve detailed product definition and industrialize construction, in order to obtain notable savings.

Basis of Virtual Design Construction:

- **Engineering modeling methods** covering the product definition, organization and involved process.
- **Analysis methods:** a model-based design that includes quantities, schedule, cost, 4D interactions and process risks, which are called construction information modeling tools (BIM).
- **Display methods.**
- **Business metrics -** within business analysis - with a focus on strategic management.
- **Analysis of economic impact,** that is, models of both the coefficient and the value of capital investments.

Among the main **benefits** of having the entire construction process in virtual format is the notable improvement of **collaborative work** between the different agents involved in the project, the **reduction of time and costs** to react in more detail to unforeseen events and have a **much more agile decision making.**

Consequently, working with Virtual Design and Construction models allows **to improve planning and create safer and more efficient work environments.**

5.3 Lean Construction

Lean Construction is based on the **Lean Manufacturing principles** developed by Toyota after the Second World War, promoted by the **optimization of the production system** pursued by the engineer Ohno. It '*aimed to optimize performance of the production system against a standard of perfection to meet unique customer requirements*'[17]. More than a methodology, it is considered a **work philosophy.**

In contrast with the engineering sector, there was a need in the construction industry of new strategies to improve the productivity, especially considering the global competitiveness from the last decade and less progress made in the construction process. Therefore, the concepts from Lean Manufacturing were transferred to the construction sector. Howell explains that this could be achieved if instead of controlling the schedule of each task individually, we are able **to manage the combination of *dependence* (the links) between the tasks and their *variation* (their progress).** When one task varies with respect to the schedule, other tasks are affected due to the dependence between them which alters the overall timing of the project producing waste.

[17] Howell, Gregory A. (1999). *What is Lean Construction*. 26-28 July 1999, University of California, Berkeley, CA, USA.

Basically, the idea is to **optimize reducing waste and introducing improvement from the tasks** in which every project can be broken down, having to main goals (Bhargav 2013): minimize physical and process waste; and improve the value generation to the client.

There are **five main principles** of Lean Construction (Womack 1996):

- **Create value** for the client.
- Identify the **value chain.**
- **Eliminate waste** to guarantee the work flow. Waste can be classified according to these categories (Pons 2014):
    - Overproduction
    - Time waste/ inactivity periods
    - Unnecessary transport
    - Over processing
    - Inventory excess
    - Unnecessary movements
    - Quality defects
    - Talent
- **Pull system** instead of push in order to eliminate inventory excess and overproduction.
- **Perfection**, as a process that only provides value without waste.

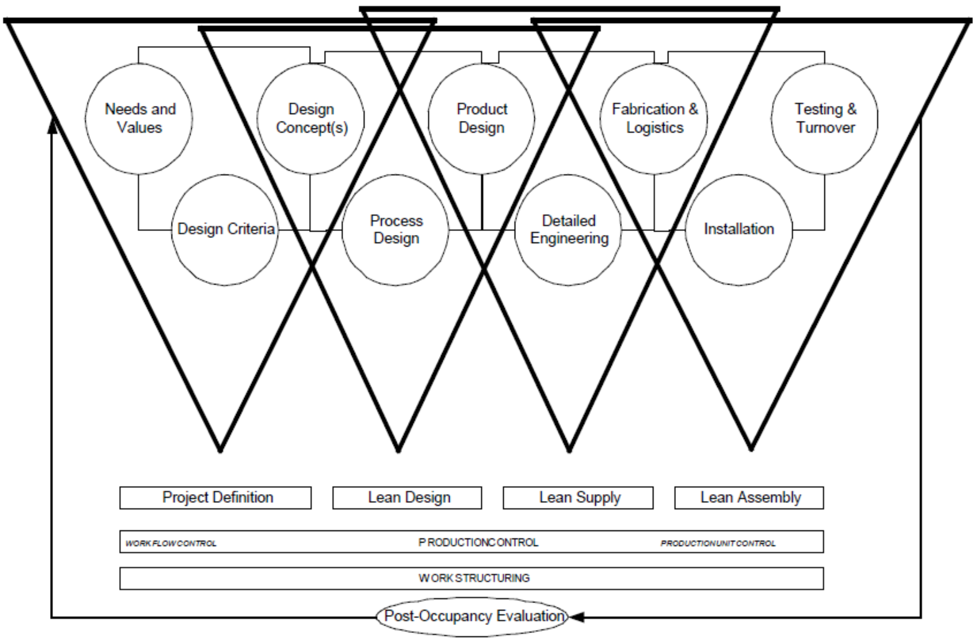


Figure 11 Lean Project Delivery System (Ballard 2000)

According to Howell, the differences between common practice and managing a project construction under Lean are:

- It has **a clear set of objectives** for the delivery process.
- It is aimed at **maximizing performance** for the customer at the project level.

- It designs concurrently **product and process.**
- It applies **production control** throughout the life of the project.

As in the case of the other methodologies explained, reluctance to change is the main barrier for the implementation of Lean, together with the lack of training or of confidence on the benefits to be obtained compared to the effort required.

6 4RinEU Strategy towards Deep Renovation

6.1 Introduction

6.1.1 Strategy application

4RinEU strategy for deep renovation aims to **define the retrofitting process from the early stages of the project to the Operation and Maintenance (O&M) phase, introducing IPD, BIM and Lean Construction principles in order to optimize the process and enhance the collaborative work**. In addition, the methodology herein proposed is aligned with other protocols, procedures and indicators defined in other tasks of the 4RinEU project, including the feedback as well, from the project demo sites for its replication potential to different situations.

The strategy is expected to be useful and to provide guidance to all the stakeholders involved in the deep renovation value chain, i.e., municipalities, building owners, contractors, technology providers, final users, etc. The procedure proposed is conceived to be applied in the existing residential building stock, in alignment with the 4RinEU project's scope. However, as a guide, it has to be applied to each particular case, considering the current limitations and local background. It is designed flexible enough for guaranteeing the replication potential and for being applied in projects under different conditions or boundaries.

With respect to the target market, it could be applied in both residential and private sector. In spite of this, it should be considered that it was selected the most limiting case of these both for the process definition and phasing which, in this case, turns out to be the public sector. Therefore, it should be considered that there are some aspects that could be modified in case of application in the private sector.

6.1.2 Integration of IPD, BIM and Lean Construction

As explained in section 4, IPD, BIM and Lean Construction are current trends in the AEC sector and are the three pillars of the strategy proposed. They are connected through their proposal on the **collaborative work between the different stakeholders** and the **aim of creating a high value product thus optimizing the design and construction processes.**

Figure 12. The three pillars of 4RinEU deep renovation strategy

These are the different synergies identified between the three approaches and from which the 4RinEU strategy takes advantage:

- **IPD** provides the framework in terms of contract procedures and responsibilities of the stakeholders' involvement, promoting the early engagement of the partners and the transparency during the whole process. This methodology is related to the other two methodologies by the following principles:
    - **Initial agreement** between all parties of the project. (IPD, BIM)
    - **Early incorporation** of all parties. (BIM, Lean, IPD)
    - **Shared risks and rewards**, higher confidence. (BIM, IPD)
- **Lean Construction** is highly connected with IPD and BIM principles too. They facilitate Lean's final aim of process optimization and increases value for the client:
    - **Maximize value and reduce material costs** at the project delivery level. (IPD, BIM)
    - **Improve the overall performance** of the project. (BIM, IPD)
    - **Full integration between project time, costs and quality.** (BIM)
- **BIM** contributes by defining a collaborative approach supported by **tools** where the main actors involved can participate while all the information can be integrated. It also aims to **avoid modifications** and deviations during the construction phase. In 4RinEU the **BIM strategy is conceived as the framework or conductive thread for the activities development.**
  There are four major mechanisms for **how BIM and Lean interact** (Bhargay 2013):
    - BIM contributes directly to Lean goals of **reducing waste and increase value**.
    - BIM enables Lean processes and **contributes** indirectly **to Lean goals**.
    - **Auxiliary information systems**, enabled by BIM, contribute directly and indirectly to Lean goals.
    - Lean processes facilitate the introduction of BIM.

  And also others identified between **IPD and BIM**:

- BIM allows the **simultaneous interaction between the stakeholders**.
- BIM tools support the **collaborative workflow**.
- BIM methodology promotes the **clear definition of roles and responsibilities.**

It could be summarized that IPD and BIM pursue directly the same objective, though IPD should be considered as a process methodology and BIM as a tool. This shared target is shown in MacLeamy curve (Figure 13). In this chart there are two curves in white, the first one (1) presents the ability to impact in cost and functional capabilities that decreases with the project progress. The second one (2) is the cost of design changes, which in this case increases as closer the end of the project arrives. The objective of IPD and BIM is to change the traditional design process (3) by moving the increase of works and efforts to the early phases, from construction to design phase, when it is easier to react to any situation and when the costs of modifications are lower. Through this way, the fourth path (4) is achieved, saving time, cost and resources.

Finally, also Lean Construction is completely aligned with this objective thanks to its philosophy of avoiding waste, which can be also defined in the same terms of saving time and resources while creating value in terms of "best value".

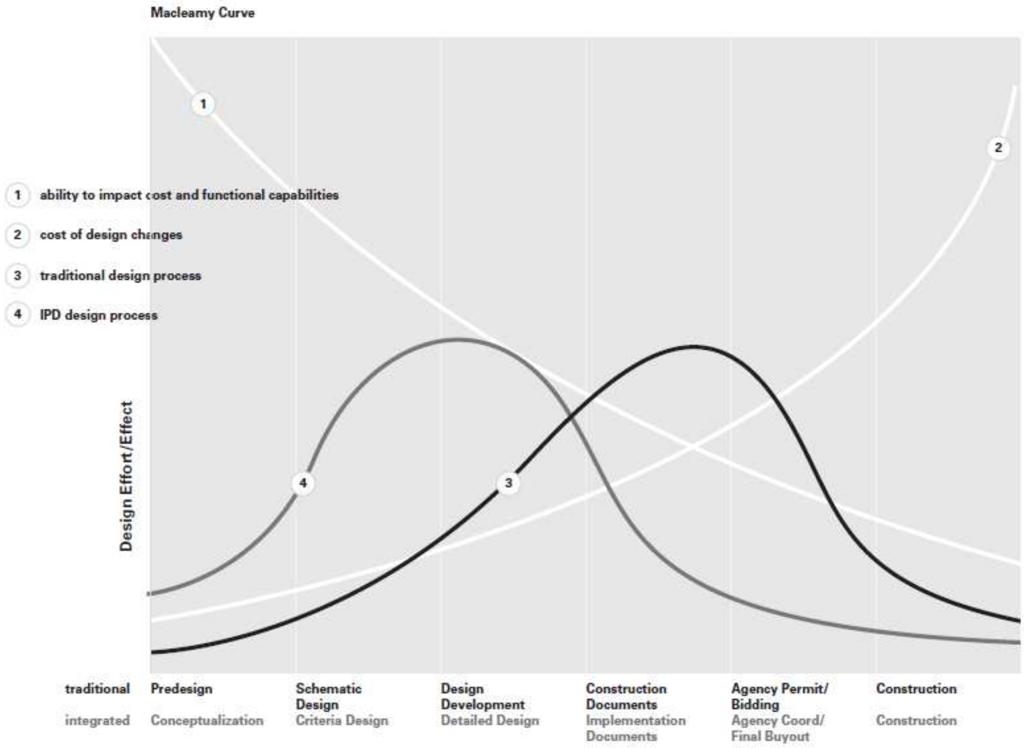


Figure 13. MacLeamy curve (AIA 2007)

Despite the potential shown, it was identified that there is a lack of strategies able to merge the three concepts and particularly conceived to be applied in construction renovation. The 4RinEU methodology aims to solve this gap by introducing the possibilities that the combination of these three approaches offer in the retrofitting process.

6.2 General aspects

6.2.1 Phases of the process

How the project will be designed and constructed, or the "project delivery method", is one of the most important decisions made on a construction project.
Most delivery methods used today are variations of three main methods: Design-Bid-Build, Construction Management at Risk and Design-Build.

- **Design-Bid-Build (DBB) –**which typically involves three sequential project phases: The design phase, which requires the services of a designer who will design the project; the bid phase, when a contractor is procured; and a build or construction phase, when the project is built by the contractor. This sequence usually leads to the sealed bid, fixed price contract.
- **Construction Management At Risk (CMR)–** a delivery method that entails a commitment by the CMR (Construction Manager at Risk), as consultant to the owner, for construction performance to deliver the project within a defined schedule and price, either fixed or a Guaranteed Maximum Price (GMP).
- **Design-Build (DB)** –which combines architectural and engineering design services with construction performance under one sole contract. Variations include:
    - *Bridging* – A designer is retained by the owner to develop the design documents to a specific point (usually schematic level) prior to engaging the Design-Build contractor, who then finishes the design and constructs the project.
    - *Public Private Partnership (PPP)* – A private entity or consortium of investors provides some or all of the required capital with a commitment to deliver a completed project for a public sector owner in exchange for revenue that the completed facility is anticipated to generate. In the most typical of these variations, the private entity will be comprised of a design-build team, a maintenance firm, and a lending firm. This entity will design, build, finance, maintain and/or operate the facility for a set number of years, agreeing to meet specified performance criteria in exchange for lease payments or some other compensation. At the end of the specified period, the facility is returned to the public entity.

Alongside these three traditional processes a fourth would appear, the already mentioned and explained **IPD** – A project delivery method that attempts to spread the risk, responsibility and liability for project delivery equally among the primary parties—the owner, the designer, and the builder, whether through partnership agreements or multi-party contracts.

The **4RinEU strategy** has been developed in **six different phases**, from the base case analysis to the O&M stage. It is important to highlight that the order of the phases in the process proposed is the one identified as the most adaptable to different situations, i.e., public and private ownership, etc. These phases are developed in section 6.
It is important to mention that these six phases will be adapted to each demo site, according to the current situation and local constraints.

- **Phase [0] Base case analysis (Baseline)**. In this inception phase, the existing building is analysed from the energy perspective and the base case situation is established.
- **Phase [1] Procurement.** According to these results, the owner defines the objectives and requirements for the project development. With these requirements the tender process starts in order to select the teams to collaborate in the project.
- **Phase [2] Planning**. Main stakeholders involved in the process define altogether the relevant aspects for the project's development, especially regarding planning issues. Schedules, milestones and responsibilities are defined in this phase.
- **Phase [3] Design.** In this stage, the different packages for renovation are evaluated and compared to the baseline. The decision-making selection on the renovation package to be implemented is defined according also to a cost-effective analysis.
- **Phase [4] Construction**. The selected renovation package is implemented according to the specifications defined during the design phase.
- **Phase [5] Operation & Maintenance**. In this phase the Measurement and Verification (M&V) protocol is applied to evaluate the achievements of the project's goals together with the ROI (Return on Investment) during the first years of operation.

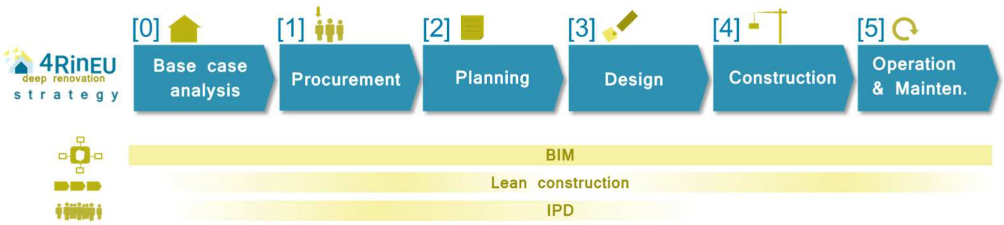


Figure 14. Phases of the 4RinEU strategy for deep renovation

The phasing proposed for the 4RinEU's methodology is partially based on the UK regulation for BIM project management PAS1192-2. However, during the methodology developed there will be found differences that corresponds to IPD and Lean principles integration.

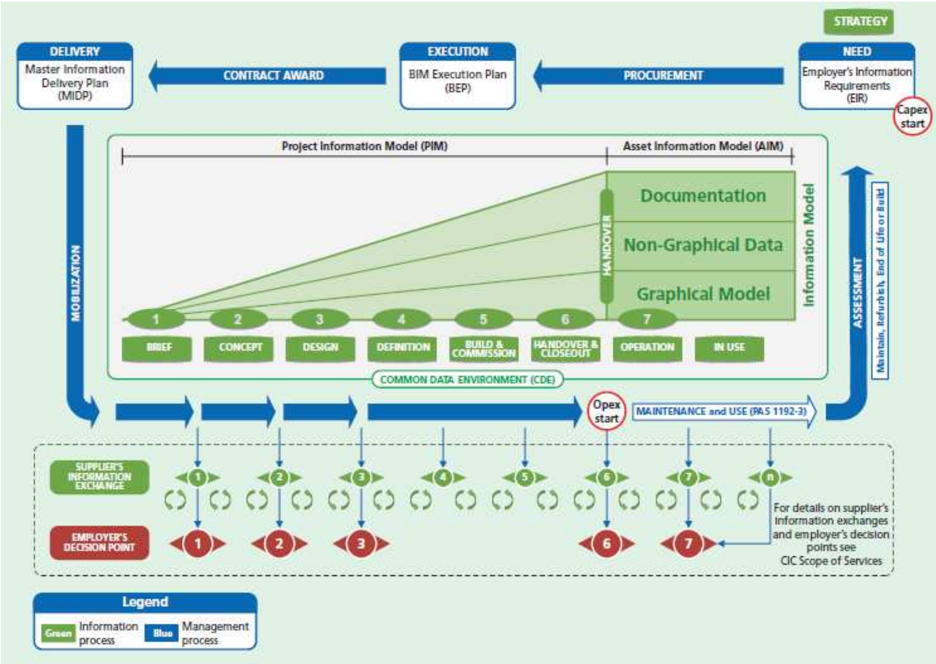


Figure 15. PAS1192-2 project delivery procedure[18]

6.2.2 Holistic approach: link to other activities in the project

In order to achieve a high replication potential, the strategy defined here takes as reference the renovation and research activities that are developed in the scope of the 4RinEU's project. In this sense, the strategy collects different procedures, protocols, indicators and other activities that could be considered during the methodology's deployment.

[18] PAS1192-2:2013. *Specification for information management for the capital/delivery phase of construction projects using building information modelling.* The British Standards Institution (BSI).

Table 3. Tasks from 4RinEU strategy related to the deep renovation strategy

Phase	WP	Task		Input
[0] Base case analysis	WP2	D2.1	Geo-clusters building archetypes	• Determination of the building archetype
	WP3	D3.1	Energy auditing protocol	• Base case analysis
		D3.5	Protocol for participative deep renovation design and user motivation	• End user participation during the procedure
[1] Tender process	WP5	D5.3	Deep renovation design procurement	• Procurement aspects compatible with IPD
[2] Strategic definition	WP2	D2.1	Geo-clusters building archetypes	• Deep renovation definition
	WP3	D3.1	Energy auditing protocol	• Cost effective analysis
		T3.2	Deep renovation collaborative design platform (CDP) and associated tools	• Collaborative design Platform (CDP)
		T3.3	Deep renovation packages and parametric models in different geo-clusters	• Renovation packages
	WP4	T4.1	Risk assessment	• Risk assessment guidance
		T4.5	Financing deep renovation	• Financial mechanisms for deep renovation
[3] Design	WP2	T2.1	Geo-clusters building archetypes	• Design KPIs
		T2.5	Early design methodology for RES best use in renovation process	• Recommendations for design integration of RES. RENo tool
	WP3	T3.2	Deep renovation collaborative design platform (CDP) and associated tools	• Collaborative design Platform (CDP)
		T3.5	Protocol for participative deep renovation design and user motivation	• End user participation during decision making
	WP4	T4.2	Cost-effectiveness rating system based on LCC and benefits approach for investor	• Rating tool
[4] Construction	WP5	T5.4	Deep renovation construction work procurement and implementation	• Guidelines on management for the implementation compatible with BIM and LEAN. Construction KPIs.
[5] Operation & Maintenance	WP3	T3.1	Energy auditing protocol	• M&V protocol
		T3.5	Protocol for participative deep renovation design and use motivation	• End user participation during the procedure

6.2.3 Main stakeholders

According to the IPD approach there are three main roles or teams that could be identified in renovation projects:

- The Owner (with or without other consultants or represented by a PM);
- The Design team; and
- The Construction team.

However, in the value chain identified in the renovation construction sector, there is a higher number of stakeholders participating and their roles depend on each specific project. This increases the complexity of the collaborative process, while the final goals will remain the same. The following table shows the main stakeholders and the common roles they could play in deep renovation projects, as well as their possible responsibilities.

Table 4. Main stakeholders involved in deep renovation

Stakeholder		Involvement	Phases					
			Base case	Tender process	Strategic definition	Design	Construction	O&M
Promoter	Municipality, building owner, public-private organization, financial entity, banks.	Project investment.	X	X	X	X		X
Owner	Public entities, private owners.	Client. Definition of the project objectives and requirements.	X	X	X	X		X
Project Manager (optional)	Design or Project Manager Consultant.	Representing owner's interests.	X	X	X	X	X	X
End user	Citizens, private owners, tenants, public entities.	Participation in the decision-making process. Definition of the base case.	X		X	X		X
Design team	Architecture firms, Eng. companies, Consultancies, Energy Service Companies (ESCOs).	Design and engineering of the project according to the strategic definition and requirements.	X	X	X	X	X	

Construct. team	Construction / Building companies.	Execution of passive measures. Monitoring. Participation in decision making and strategic definition.		X	X	X	X	
Implement. team	ESCOs, Eng. companies.	Implementation of active measures. Participation in decision making and strategic definition.		X	X	X	X	
Facility Managers	ESCOs, Energy Supply / Eng. companies.	Participation in strategic definition. Operation & Maintenance activities.		X	X			X
Others	Energy consultancies, Product developers, Suppliers, etc.	Supporting activities.	X	X	X	X	X	X

IPD principles recommend to define two committees formed by previous stakeholders that could be defined in the initial agreement (ConsensusDocs 300):

- **Collaborative Project Delivery Team (CPD)**. The team is in charge of facilitating design, construction and commissioning in daily decisions. Initially, the partners in this team include the Owner, Design team and Construction team, but can include experts from every team. Joining agreements based on IPD are expected to be shared between these stakeholders as Single Purpose Entity (SPE) or Multi-Party agreements.
- **Project Management Team (PMT)**. The delivery of the project is managed by this team, as the main decision-making body. This committee should guarantee the collaborative work and the implementation of the methodological approach. This group is formed by one representative of each of the teams that form part of the CPD, but different configurations could be achieved according to the Owner requirements.

In parallel, the BIM methodology explains that all involved professionals in the process should have a minimum training on BIM (BIM technicians), but also there should be some leaders related to BIM activities. It is necessary to remark that there is no common standard on BIM position names, therefore it is really important to define the responsibilities for each role and not the name itself in the agreement documents:

- **BIM Coordinator**. This role is the responsible of the coordination of the BIM activities of the overall project. It is recommended to be part of the Management Group and the Collaborative Project Delivery Team. Usually this role is covered by the PM, an external consultant or one representative of the Design team.
- **BIM Manager**. In this case, this role coordinates the BIM activities that are carried out in their organization. They collaborate with the BIM Managers

from other companies, as well as with the BIM Coordinator. They could belong to the Collaborative Project Delivery Team.

In order to integrate the BIM approach on the project management proposed by IPD, the following responsibility matrix is proposed to be defined during the strategy definition in the BIM Execution Plan, as it will be explained in the following chapters. In this matrix, the contact details of each professional are allocated, as well as their role related to BIM and IPD structures.

Table 5. Example of contact information matrix

Name	Organization	Role	Contact details	
			Phone	Email
Jane XXXX	XXXXX	Owner	+34 XXX XXX XXX	jane@xxxxx.com
John XXXX	XXXXX	Design leader	+34 XXX XXX XXX	john@xxxxx.com

Table 6. Example of responsibility matrix

Name	Organization / Role	Responsibility	BIM role			IPD role	
			Coord.	Man.	Tech.	PMT	CPD
Jane XXXX	XXXXX	Owner	-	-	-	X	-
John XXXXX	XXXXX	Design leader	X	-	-	-	X

6.2.4 Key Performance Indicators (KPIs)

In order to provide guidance and assessment during the strategy deployment, two set of KPIs were defined in the project.

Table 7 KPIs from the 4RinEU project supporting the deep renovation strategy

Set of KPIs	Task develop.	Reported in	Strategy phase of application	Comments
Design KPIs	T2.1	D2.1	[0] Base case analysis [3] Design [5] O&M	In case of expected to be applied, it is also recommended to include them as a requirement in the strategy definition and tender process (Phases [1] and [2])
Construction KPIs	T3.6	D3.6, Annex	[4] Construction	

6.2.4.1 Design KPIs

Design KPIs have been developed is task T2.1, and can be seen in the associated deliverable D2.1. They are used to evaluate the performance of the 4RinEU deep renovation packages according to five different areas:

- **Energy**
  - Energy demand for heating [kWh] - [kWh/m2] [kWh/(m^2 HDD)]
  - Energy demand for DHW production [kWh] - [kWh/m^2]

  - Energy demand for ventilation [kWh] - [kWh/m^2]
  - PV system energy produced [kWh] - [kWh/m^2] - [kWh/m^{2}PV surface]
  - Energy demand for lighting and appliances [kWh] - [kWh/m^2]
  - Electricity self-consumed [kWh] - [kWh/m^2]
  - ST system energy produced [kWh] - [kWh/m^2] - [kWh/m^{2}ST surface]
  - ST energy balance [%]

- **Comfort and Indoor Air Quality**
  - Number of hours category IV cold [h]
  - Number of hours category IV hot [h]
  - Over-heating Degree Hours [°C]
  - Indoor Air Quality

- **Environment**
  - CO_2 emission of the building [kg/year]

- **Economy**
  - Investment cost [€] – [€/m2]
  - Net Present Value [€]
- Energy cost before and after renovation [€]

- **Building site management (Construction KPIs)**

6.2.4.2 Construction KPIs

These KPIs are defined to support the supervision of works during the Construction Phase, with the aim, among others, of avoiding “waste” during the process in alignment with Lean Construction principles. They have been developed in task T3.6 (D3.6) of the project according to research and authors background, and have been validated by the demo sites of the project, as well as other partners from WP5 and WP3.

The 25 KPIs are sorted in five different areas according to their field, and by their application (construction site and/or workshop site). They are shown in section Annex 1. Construction KPIs and summarized in the following list:

- **Health and Safety (HS)**
  - HS – AR – CS/WS Accidents rate [-]
  - HS – AF – CS/WS Accidents frequency [No./h]
  - HS – AC – CS/WS Accidents cost [€/h]
  - HS – IR – CS/WS Incidents rate [-]
  - HS – IF – CS/WS Incidents frequency [No-/h]

- **Site Work Logistics (SWL)**
  - SWL – TO – CS/WS Transportation optimization [%]
  - SWL – IE – CS/WS Inventory excess [%]
  - SWL – DDI – CS/WS Delay due to inventory [%]

- **Budget (B)**
  - B – NPM – CS/WS Net profit margin [%]
  - B – CCF – CS/WS Change cost factor [%]

- B – IRe – CS/WS Impacts of repairs (internal) [%]
- B – IRi – CS/WS Impact of repairs (internal) [%]

- **Productivity – Time management (PTM)**
  - PTM – TWD – CS/WS Total works duration [days]
  - PTM – TD – CS/WS Task duration [days], [h]
  - PTM – PDW – CS/WS Percentage of delivered works by cost [%]
  - PTM – TD – CS/WS Task Delay [%]
  - PTM – WD – CS/WS Total delay [%]
  - PTM – IR – CS/WS Tome impact of repairs [%]
  - PTM – RP – CS/WS Re-planning [No. / months]

- **Work Site Sustainability (WSS)**
  - WSS – EC – CS/WS Electricity consumption [kWh/m^2]
  - WSS – OC – CS/WS Oil consumption [liters / m^2]
  - WSS – WC – CS/WS Water Consumption [m^3 / m^2]
  - WSS – LR – CS/WS Landfill rate [Tn / m^2]
  - WSS – RCR – CS/WS Recycling rate [Tn / m^2]
  - WSS – RUR – CS/WS Re-using rate [Tn / m^2]

There are some recommendations that are suggested to consider when applying these indicators. First of all, the periodicity of calculation during the Construction Phase should be defined by the stakeholders involved in supervision of works, according to the works duration and available resources. Also, to maximize their potential, it has to be taken into account that the calculation of these KPIs should be foreseen in the first stages of the process, because most of them compare the values achieved with respect to those planned.

Finally, some of the indicators are calculated with sensitive data from the construction company, so the decision of sharing them would depend on the specifications of the selected IPD contract and its transparency requirements.

6.2.5 Collaborative Design Platform (CDP)

Within Task 3.2, the 4RinEu project comprises the development of a **collaborative design platform (CDP**). The CDP has been designed with an **integrated and holistic approach**, including some of the main concepts covered by the IPD philosophy.

Some of the **main features of the CDP** are aligned with the main principles of the **IPD, Lean and BIM methodologies**, in particular:

- **Integrated Project Delivery:** The underlining structure of the CDP is a web-based project management platform, with different user roles and permissions. It allows holistic project where all member are involved in the process.

- **Flexibility based on a participative and collaborative approach:** Document upload and download, to take outputs from 3rd party tools and store them centrally within the CDP. This allows continuous follow up of the project and keeping the information centralized and up to date.

- **Pervasive communication system**: Communication is key for any project to succeed. The CDP reports project progress/updates within a rolling feed, and users can discuss in projects and tasks.

- **Inclusion of 4RinEU methodologies and workflows:** The CDP allows to include guidance within portals, projects or tasks to share methodologies and process decisions. This can be used to provide information to specific users within project tasks and ensure clarity on the process. This can be 4RinEU methodologies or specific workflows agreed for each project

7 Phase development

In this section 4RinEU strategy phases are shown. Firstly, Objectives and Outcomes are clarified while the core of the development are the recommendations outlined to guide the project.

4RinEU strategy is divided into **six different phases**, as it is shown in the following Figure . They are developed in later subsections and supported by two sets of KPIs developed in the project. Each subsection is divided in the following chapters:

- **Objectives**. This chapter explains the main objectives to be achieved by each phase, as well as the inputs required from previous phases and the expected outputs for next ones. This links all phases and establishes continuity between them to increase the process understanding, by promoting their interaction and created a holistic process.
- **Stakeholders involvement**. In this section the main responsibilities of the stakeholders involved on each phase according to their role are defined.
- **Recommendations for phase development**. As step by step process, the different aspects or actions to be taken into account for the phase deployment are explained. Also the relations with other activities of the project and different tools together with the proposed KPIs, in order to facilitate the measurement of the final outputs.

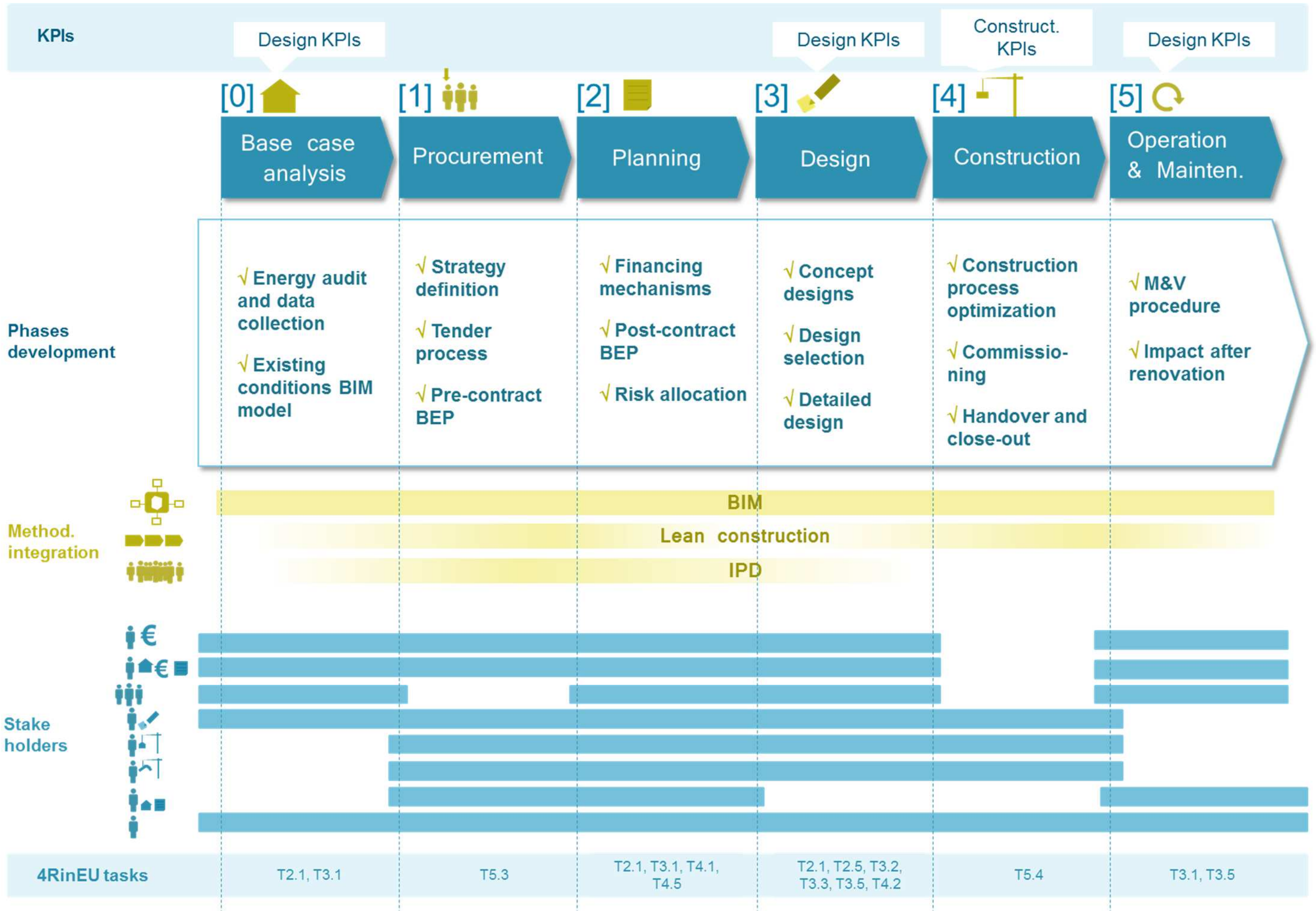


Figure 16. Main aspects of the 4RinEU strategy for deep renovation

7.1 Phase [0] Base case analysis

Objectives

The objective of this phase is to analyse the energy performance of the existing building in order to **establish the baseline**. Also to collect the necessary data and define the boundaries conditions. This study is carried out supported by different procedures, as the energy audit proposed in D3.1 or the Design KPIs.

- Outputs for next phases
  - Data collection and boundaries.
  - Performance of the existing building (base case).
  - Results of Design KPIs calculations in the base case.
  - Barriers and drivers identified.

Stakeholders involvement

In this Phase [0] the analysis of the current situation is carried out to determine the need of a deep renovation. In this sense, these works can be done by a team that could be the same or different from the one that will carry out the design and construction in the next phases of the methodology, especially depending in the case of public ownership. Therefore, there are two options:

a) The team in Phase [0] is different from the team in charge of the development of the following phases.
b) The team in Phase [0] is the same to cover the following phases, mainly the design, construction and operation.

Our recommendation is to have the same team from the inception phase of the project in order to be able to address existing problems and barriers more effectively from the beginning and throughout the process, also favouring communications and the creation of an integrating team.
The main stakeholder in this phase is the Owner/Promoter, who promotes the analysis study in order to determine the needs of each deep renovation project. Also feedback from other stakeholders, as tenants or citizens in the case of public buildings, should be addressed.

Table 8. Main stakeholders involved in Base case analysis

Stakeholder	Involvement	Proposed LEAN-BIM and IPD roles				
		LEAN-BIM			IPD	
		Coord	Man.	Tech.	PMT	CPD
Building owner/ Promoter/PM	Define the scope of the analysis and involve the rest of the team. Data collection.	-	-	-	X	X
End users (Tenants, Citizens)	Feedback on the base case	-	-	-	-	-
Design team (Architects, Engineers, Energy experts, etc.)	Technical work related to the energy audit, boundaries and data collection. Creation of BIM models of the base case. Energy analysis.	X	X	X	X	X
Others (Energy Consultancy, etc.)	Technical work related to the energy audit, boundaries and data collection. Creation of BIM models of the base case. Energy analysis.	X	X	X	X	X

- not proposed | X proposed | ? depends on responsibilities

Recommendations for phase development

The 4RinEU strategy proposed considers this Phase [0] Base case analysis before the tendering process proposed in Phase [1], following the criteria of defining the procedure according to the most restrictive situation. The reasons are:

- The base case analysis of an existing building can be carried out with the purpose of determining the need of a deep renovation. The results of decision making could vary depending on the diagnosis of the situation in terms of implications. For instance, it could be needed a light upgradation but not deep renovation.
- The urgency determined in this diagnosis could distance the moment of the base case analysis and the renovation itself, if the building stock to be analysed is large, as if for example the renovation is promoted by the municipality. Therefore, it is possible to have different stakeholders or teams involved in the base case analysis and later in design and construction activities.
- In case of public ownership of the building, it is possible that the municipality has the technical capacity to carry out all or part of the activities (in house).

In conclusion, if both activities are not expected to be done in the same time frame or the public building owner has the capacity to assume the activities, the order of phases [0] and [1] can be followed as proposed. However, if both activities are expected to be carried out in the same period, it is recommended to do the tender process proposed in Phase [1] before this Phase [0] and include the activities from the last one in the tender process. Procurement steps in any case should depend on the ownership of the building.

The actions to be done in the scope of the base case analysis are divided in two. In the first place, it is necessary to carry out an energy audit and collect all the necessary information. In parallel, the BIM model of the existing conditions and that will be used in the later phases of the methodology has to be created, in order to understand the base case as well as to establish the energy performance through energy simulations based on real existing measurements.

Finally, the base case performance of the building is determined by the results obtained in the energy audit and the calculation of the Design KPIs indicators with inputs from both the energy audit and the energy simulations.

- **Energy audit and data collection**

An energy audit is the first step toward reducing energy use and improving the performance of facilities in a renovation project.

Obtaining reliable data is directly related to the planning of energy efficiency investment in renovation buildings. Accurate data collection is paramount not only to analyze energy consumption, but also to evaluate the effectiveness of proposed changes suggested in an energy audit report.

In this first phase of the Consultancy, an analysis of the climate zone and the most relevant climatological data will be collected, considering the hygrothermal variables of temperature, humidity, solar radiation, speed and direction of the prevailing winds and rainfall that affects each project, so that from the first moment data are available on which they can be, a priori, the variables to be protected, and those that have a potential for energy use.

In parallel, a site visit should be performed to the selected buildings in order to compile the existing design parameters. The number of floors, the total built surface and the gross surface of the plot will need to be considered. Data on the number of users and visitors should also be collected.
The main materials and construction systems of the building, and specially the façade, will be studied. Also the current facilities including heating, cooling and lighting installations.
Local regulations will be also reviewed and analysed.

Once compiled all relevant existing data, an energy audit will be developed in accordance to task D3.1 protocol and task D2.1 building archetype identification. The purpose of an energy audit is to determine where, when, why and how energy is used in a facility, and to identify opportunities to improve efficiency.

Energy audits typically take a whole building approach by examining the building envelope, building systems, operations and maintenance procedures, and building schedules. The energy audit will serve to examine the current energy consumption of the renovation buildings and will enable to propose alternative ways to cut down energy consumption or costs. Many of these recommendations would be easily implemented during the operation and maintenance phase, providing tentative energy savings from the very first moment of the analysis.

Therefore, nowadays capital improvement and operation and maintenance budgets are key funding sources for energy audits. In some cases the cost of an energy audit can be seen as a temporary investment rather than a cost, due to the payback from implementing no-cost or low-cost energy savings measures recommended during the energy audit.

It is important to consider further potential funding sources for the Energy Audits by: ESCOs who will finance and manage the energy efficiency improvement projects and share the energy savings; and Utilities may offer incentives or partial funding for energy audits. Funds may also be available for installation of financially-viable energy efficiency measures.

The Energy Audit will be mainly developed in four phases:

1) Preliminary Review of energy use, including utility data and EE potential, in comparison to similar facilities.
2) Site assessment including the data collection and local interviews.
3) Energy and cost analysis, considering savings and developing recommended measures.
4) Completion of audit Report, where findings will be summarised and recommendations presented.

The Energy Audit will outline the recommended **Energy Efficiency Measures (EEM)** considering:

- Existing conditions and recommended changes, including equipment specs and specific locations of installations.
- How the measure will save energy and how much energy it will save.
- Financial analysis results including costs of recommended measures.
- Effects on maintenance and comfort.

This EEM will enhance to **define the Design KPIs in order to establish the base line** situation in later phases with the different design proposals and the results obtained from monitoring the current facilities.

- **BIM model of the current situation**

As already mentioned, BIM would be **more effective** if it could be **used in the initial stages** in renovation projects. Due to the complex nature of these existing buildings and, as there are many different individuals involved in them, strong collaboration is needed for better outcomes. BIM increases collaboration between all the participants and enables them to speak a common project language.

Furthermore, there are many misunderstandings because of the faulty drawings, lack of visual support, and improper material handling in renovation projects. Such misunderstandings would be avoided with the creation of the BIM model of the current situation from the very beginning. The **main parameters** of the BIM process **will be defined at this stage**, ideally by the Owner/Promoter/Project Manager, so that the following implementing teams will be able to continue working on it, providing an alive model, fed during the following phases. This model will also **facilitate the energy simulations** and further analysis.

Moreover, waste generation is a problem in most renovation projects, as the LEAN philosophy also outlines. For this reason, proper and effective waste handling is needed in order to prevent and manage whatever waste that is generated. BIM would be **helpful in managing waste** on the renovation site as support for organizing logistics, separating waste types and structuring material handling for the following project phases, mainly the Design and Construction ones. In order to optimize the channel throughout the project's lifecycle, it is highly desirable **to include all main constraints and design parameters** in the first BIM model based on the current situation. Therefore, it is important **to begin with the End in Mind.**

The **four main steps** to be considered when drafting the BIM model at this stage are:

1- Identify **high value BIM uses** during project planning, design, construction and operational phases.
2- Design the **BIM execution process (including the BEP,** i.e. BIM Execution Plan**)** by creating process maps.
3- Define the **BIM deliverables** in the form of information exchanges.
4- Develop the **infrastructure** in the form of contracts, communication procedures, technology and quality control to support the implementation.

The goal for developing this structured procedure is to **stimulate planning and direct communication** by the project team during the early phases of each renovation project. The team leading the planning process should include members from all the organizations with a significant role in the project. Since there is no single best method for BIM implementation on every project, each team must effectively design a tailored execution strategy by understanding the project goals, the project characteristics, and the capabilities of the team members.

By developing a BIM Plan, the renovation project and project team members can achieve the following value:

1) All parties will clearly **understand and communicate the strategic goals** for implementing BIM on the project.
2) Organizations will understand their **roles and responsibilities** in the implementation.
3) The team will be able to **design an execution process** which is well suited for each team member's business practices and typical organizational workflows.
4) The plan will outline **additional resources, training**, or other competencies necessary to successfully implement BIM for the intended uses.
5) The plan will provide a **benchmark** for describing the process to future participants who join the project.
6) The purchasing divisions will be able to define **contract language** to ensure that all project participants fulfil their obligations.

7) The **baseline plan** defined in the BIM model of the current situation will provide a goal for measuring progress throughout the following project's phases.

In order to define properly the BIM project Execution Plan it is important to identify the project goals, given each renovation project characteristics, participants' goals and capabilities and the direct risk allocation.

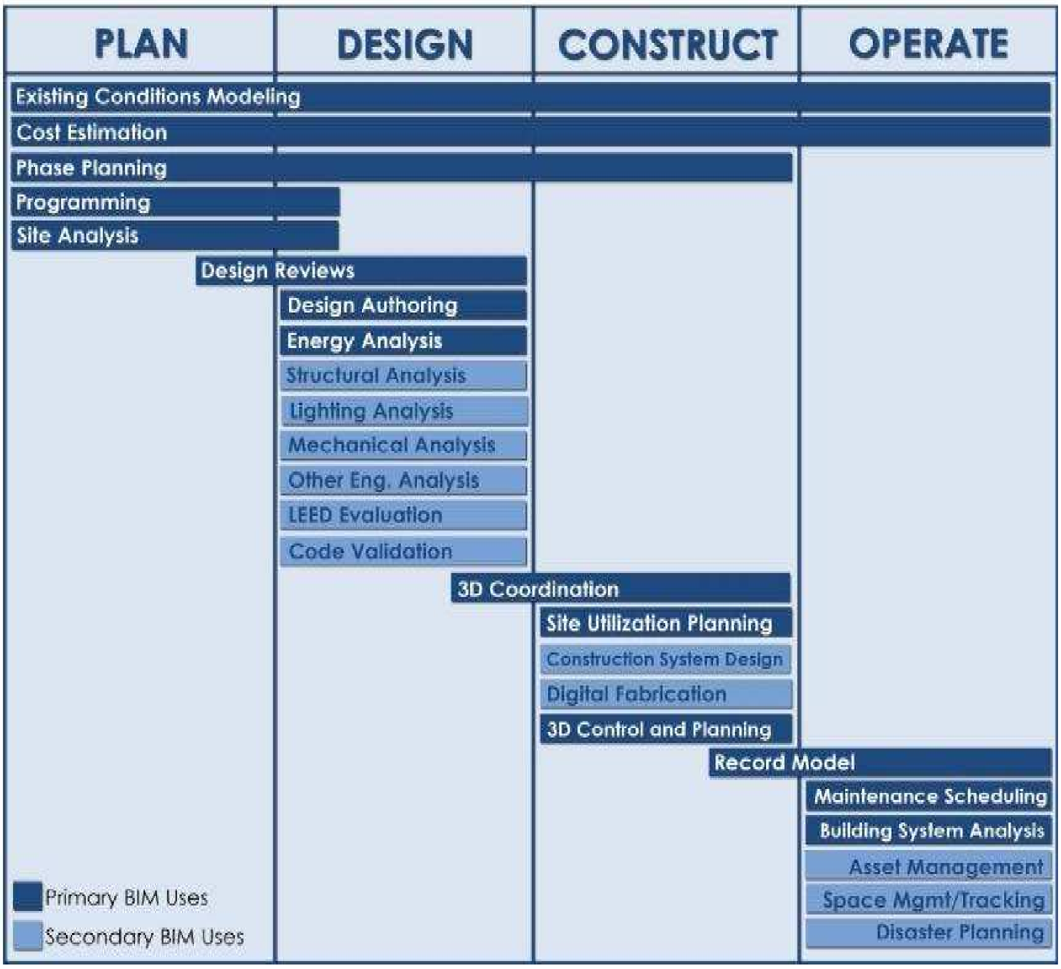


Figure 17. BIM Uses throughout a Building Lifecycle
(organized in chronological order from planning to operation).

One of the main goals considered in the **4Rineu** strategy is be the **development of a more energy efficient design** through the rapid iteration of energy modeling.

7.2 Phase [1] Procurement

Objectives

The objective of this phase is to select the teams needed for the project development, according to the Owner/Promoter requirements. This corresponds to the tender/bidding process and different considerations have to be taken into account depending on the ownership and also for the integration of IPD principles.

- Inputs from previous Phase [0]:
    - Performance of existing building and data collection.
    - Results of Design KPIs calculations (base case).
    - BIM model of existing conditions.
- Outputs for next phases:
    - Employers Information Requirements (EIRs).
    - Project teams' selection.
    - Selected Pre-contract BIM Execution Plan (BEP).
    - Request for Proposals (RFP) / BID documents / Contract.

Stakeholders involvement

The Owner/Promoter is the key partner in this phase, who will be in charge of the procurement process. The rest of the stakeholders that would be part of the team will participate in the tender process as bidders.

Table 9. Main stakeholders involved in Tender process

Stakeholder		Involvement	Proposed LEAN-BIM and IPD roles				
			BIM			IPD	
			Coord.	Man.	Tech.	PMT	CPD
	Owner/Promoter (optional Project Manager)	Publishing of the Request for Proposal, including the EIRs and target cost. Best value criteria definition for tender award.	?	-	-	X	-
	Design team (s)	Bidder. Pre-contract BEP (Design aspects).	-	-	-	-	-
	Construction team (s)	Bidder. Pre-contract BEP (Construction aspects).	-	-	-	-	-
	Implementation team (s)	Bidder. Pre-contract BEP (Implementation aspects).	-	-	-	-	-
	Facility Manager (s)	Bidder. Pre-contract BEP (Maintenance aspects).	-	-	-	-	-
	Others (consultancy, etc.)	-	-	-	-	-	-

- not proposed | X proposed | ? depends on responsibilities

Recommendations for phase development

According to IPD, LEAN and BIM principles, **stakeholders have to be involved as early as possible** in order to guarantee an **effective collaborative work**. The procedure proposed to fulfil with this principle is one of the less traditional aspects of the strategy. It is important also to notice that although Design-Build project delivery methods could appear in these renovations, the scope here is similar to the IPD structure, which means that there is more than one entity in charge of the design and construction/implementation's phase.

In order to follow **LEAN, IPD and BIM recommendations to maximize the collaborative potential** and to **optimize the process**, the **stakeholders are selected even before planning** the project or design process in Phases [2] or [3]. This could be done thanks to the preliminary information and goals definition from Phase [0] together with the requirements and expectations provided by the Owner/Promoter, as well as other supporting strategies as included in IPD contracts or target costing, among others. Also, in these tender processes the **qualitative** aspects of the companies and their previous experience have a higher relevance compared to other processes.

In this case, the Owner/Promoter defines the **Employers Information Requirements (EIRs**). This document is related to BIM activities and they normally include (espacioBIM 2017):

- **Technical requirements**. Software, data exchange, Level of Development (LOD), etc.
- **Management requirements**. Stakeholders' responsibilities, collaborative workflow, etc.
- **Commercial requirements**.

Furthermore, administrative and technical requirements should be included in the **Request for Proposal (RFP)** apart from the EIRs related to the procedure expected to be carried out during the project depending on the objectives, as for example:

- Information about the base case.
- Objectives to be achieved with the renovation or preliminary ideas (energy certification, performance objective, etc.).
- Requirement of integrating IPD principles. IPD contract form. Risk and benefits sharing proposed.
- Requirement of integrating Lean Construction philosophy.
- Requirement of Design and Construction KPIs calculation.
- Monitoring period required and main activities to be considered.
- Definition of commissioning procedures.
- Measurement & Verification (M&V) protocol to be applied.
- Others.

It is possible to integrate the **Green or Sustainable Procurement** concept by introducing objectives to be achieved in the project in terms of energy savings, energy consumption or energy performance, as, i.e., energy goal, net-zero energy, percent savings, energy use intensity or sustainability rating certification as LEED or BREEAM (U.S. Department of Energy 2012). In this case, it is really important to define how and when it is expected to certify that these goals have been achieved, i.e., at the finalization of construction, after one year of monitoring, etc. In response, the bidders should present their economic, technical and administrative response, as well as a **Pre-contract BIM Execution Plan (BEP)**. It should contain the following information:

- Project scope.
- Objectives and BIM uses.
- Information and data segregation.
- General Planning.
- Tender process criteria.

As mentioned before, the award criteria would be related to the technical capacity of the company, previous experience and their response to the Owner/Promoter requirements. For the economic proposal, **Lean Construction principles proposes target costing** (Pons 2014) approach. In this case, the client fixes the maximum according to its expectancies and the expected value of the product, while bidders as a response propose a target cost lower than the maximum according to their estimations.

- **Strategy definition**

The procurement stage should incorporate the **LEAN and IPD principles**. The most common contracting method in an IPD approach is a joint agreement that includes the design firm, the construction firm, and the owner. The typical contract is a cost-plus-incentive-based contract built around target costs for all elements of the project and on the achievement of non-cost-related project goals.

During the procurement phase, the main goals, objectives and scope of the project will be defined and compiled in the tender documents, together with the **design criteria** outlined in the **owner's bases of design (BOD).** It reflects the owner needs and wants that must be satisfied by the design of the project, such as the use of spaces, size, proximities/adjacencies, finishes, and energy efficiency requirements. They will also include a **transcription of the EIR's** already outlined by the Owner /Promoter of the previous phase. The EIR will require editing to confirm project-specific requirements for each of the sections.

In accordance with PAS 1192-2, the Design Team and Constructor should each include an **outline BIM Execution Plan (BEP)** in their proposal. A compliant BEP will demonstrate how the requirements outlined in the EIRs will be met.

Tender documents will also refer to **project standards and protocols** to be considered **attending local regulations and desired KPIs** in order to acknowledge final measurements and savings.

During the tender process it is desirable to outline an overall price estimation, following the **target costing procedure as described in LEAN**. The **Target Value Design (TVD) process** assumed in LEAN's philosophy intends to have a project designed within the desired budget in accordance with a detail estimate. It accomplishes that end by establishing **value, cost, schedule and constructability** as basic **components of the design criteria.**

Target costing should be considered as an approach to determine the **renovation's life-cycle cost** of each building which should be sufficient to develop specified functionality and quality, while ensuring its desired profit (EE savings). The target cost would be the **maximum amount of cost** that could be **incurred on the renovation project**, however, the Consultant could still earn the required profit margin from that renovation offering a particular selling price.

Target costing consists of cost planning in the design phase of the project, as well as cost control throughout the following phases, until operation and maintenance. The cardinal rule of target costing is to never exceed the target cost. However, the focus of target costing is not to minimize costs, but to achieve a desired level of cost reduction determined by the target costing process.

As the **4RINeu** strategy mainly addresses the main goal of reducing the energy consumption, CO2 emissions, renovation time and costs, while increasing IEQ in residential buildings, the procurement phase should include **responsible sustainability practices** in order to achieve those objectives. The design must be based on reducing the carbon footprint, including lower energy usage and less utilization of potable water, by improving the building's envelope reducing current energy losses. The adoption of Green Building standards may significantly influence the renovation design criteria and the OPR (Owner Project Requirements)). It may also increase the number of decision makers involved in the design and construction process, for beneficial reasons. These standards require decisions and support structures as early as the project definition and preliminary design phases.

All these "green" measures could be incorporated in a **Sustainable Procurement** as an option of the process to be considered. Sustainable procurement is the adoption and integration of **Corporate Social Responsibility (CSR)** principles into the whole procurement process and decisions while also ensuring, they meet the requirements of the owner/promoter and final users.

Sustainable Procurement integrates requirements, specifications and criteria that are compatible with the protection of the environment and the society. Policies and strategies for sustainable procurement are based on the need to obtain scarcity in supply and ability to cope with the demand of emerging markets, pressures brought upon by cost and ability to reduce this through reductions in energy consumption and waste reduction.

The main **drivers for Sustainable Procurement** are:

- **Cost Reduction**: Reduction in total cost of ownership linked to reduced energy costs, reduced over specification, reduced consumption and reduced social and environmental compliance costs.
- **Risk Reduction:** Financial impact on brand value from bad supplier practices (e.g., child labour, local pollution); economic cost of Sustainable procurement disruptions (e.g., noncompliance with environmental regulations).
- **Revenue Growth:** Additional revenue through innovation of eco-friendly products/services, price premium or income from recycling programmes.

- **Tender process**

IPD is an attempt to properly reflect, in contract, the working relationships and efforts that are possible when a team is working in an integrated fashion to complete a design and construction project.

Compensation for parties in the IPD delivery method is typically comprised of three components: Cost reimbursement to cover costs, incentive for achieving or bettering agreed project cost targets, and rewards for accomplishing set project goals. As the entire project team is equally incentivized to achieve the same set of goals, IPD requires the owner to assemble the team players as early as possible (Phase 0).

This early creation and agreement of project goals results in earlier engagement of the project team than in other delivery methods. During the pre-design phase (Phase 0), the IPD team has already advanced all of the criteria it will be bound under contract to deliver.

The most common contracting method in an Integrated Project Delivery approach is a **joint agreement** that includes the design firm, the construction firm, and the owner. The typical contract is a cost-plus-incentive-based contract built around target costs for all elements of the project and on the achievement of non-cost-related project goals.

Traditionally, procurement of professional and construction services will generally be accomplished in one of three methods: price-based, qualifications-based, or a combination of both (best value). On the procurement side, the IPD selection process is generally a **qualifications-based selection**, consistent with the objective of making sure all team members make good team partners to enhance the likelihood of the success of the renovation projects.

Procurements may also involve a one-step process, in which there is just a single round of submittals that determine the selection, or a two-step process, which may include a qualifications submittal as the first step and then a price proposal as the second step. The most common procurement method is the single project award. The chart below illustrates the use of the various options.

Selection Criteria / Project Delivery Method	Low Bidder	Best Value	Best Qualifications
	Selection is based solely on Price	Selection is based on a weighted combination of Price and Qualifications	Selection is based solely on Qualifications
Design-Bid-Build	Most Common	Common; Price evaluation based on Construction Cost	Rare
Construction Management at Risk	Rare	Most Common; Price evaluation based on CMAR Fees and General Conditions	Common
Design/Build	Common	Most Common; Price evaluation based on fees and GCs; may or may not include Construction Cost	Common
Integrated Project Delivery	Rare	Common	Most Common

Figure 18. Owner's guide to project Delivery methods Final_CMAA

Tendering is the process of selecting and appointing the main Consultant/Contractor and teams that will be in charge of developing the future phases of the project, from design to construction until operation and maintenance.

All conditions and requests will be integrated in the **Request for Proposal (RFP),** a business document that announces and provides details about the renovation project, as well as solicits bids from contractors/consultants who will help complete the project. The RFP will include:

- **The project overview**. The project will be defined covering: needs and values determination, Design Criteria and Conceptual Design (based on the BIM model of the current situation defined in the previous phase).
- **The project goals,** aligned with sustainable principles and EE objectives**.**
- **The Scope of Work**: Effective project scope definition enables all involved parties to understand the owner needs, and to work towards meeting those needs.
- **Current Roadblocks and Barriers to Success**.
- **The Evaluation metrics and qualifications-based selection criteria, following IPD principles.**
- The **Submission Requirements** and main deadlines.

- **Pre-contract BIM Execution Plan (BEP)**

To effectively integrate BIM into the project delivery process, it is important to define a **pre-contract BIM Execution Plan for future BIM implementation**. A BIM Project Execution Plan outlines the overall vision along with implementation details for the team to follow throughout the project.

EIRs are an important element of **Project BIM Implementation** as they are used to set out clearly to the bidder what models are required and what the purposes of the models will be. These requirements will be written into the BIM Protocol and implemented through the BIM Execution Plan.

The EIR is a key document with regards to communicating information requirements as well as establishing information management requirements. The EIR will act as a good basis from which to review the contents of the tenderer's BIM Execution Planning, confirming its completeness. The core content and guidance is split into the following sections:

Table 10. EIR's main sections.

Technical	Management	Commercial
- Software Platforms - Data Exchange Format - Co-ordinates - Level of Detail - Training	- Standards - Roles and Responsibilities - Planning the Work and Data Segregation Security - Coordination and Clash Detection Process - Collaboration Process - Health and Safety and Construction Design - Management - Systems Performance - Compliance Plan - Delivery Strategy for Asset Information	- Data drops and project deliverables - Clients Strategic Purpose - Defined BIM/Project Deliverables - BIM-specific competence assessment

Adaptations to the EIRs will be required to align with the requirements of the employer. Areas where adjustments are likely to be required include:

- **Type of asset**. This document was prepared on the assumption that the asset is a building – this will not be the case for all employers;
- **Project stages.** Data drops and associated information requirements are to be mapped against the project stages of a particular employer;
- **Information requirements**. Data drops are to be aligned against the needs of the project – e.g. new-build vs. on-going asset management;
- **Procurement strategy**. Data drops are to be aligned with the procurement strategy adopted by the employer (e.g. Cost-led, Integrated Insurance, two-stage open book)
- **IT requirements**. Collaboration tools and other employer-specific requirements are to be specified. For example, any collaboration site provided by the employer;
- **Detailed alignment of documents**. Terminology for information, stages, documents and roles described in the EIRs should match that used in specific appointment documents;
- **Detailed technical information requirements**. Space object properties are likely to vary by employer and asset type.

7.3 Phase [2] Planning

Objectives

The objective of this phase is to define the shared vision between the partners involved in terms of project scope, standards to be accomplished, requirements, etc. The strategic definition of the project started in the previous phase by the Owner/Promoter requirements establishment should be further developed with contributions from all the stakeholders.
In summary, the aspects that were collected in the Pre-contract BEP from the tender process are fully developed and agreed by all partners selected during the tender process in a Post-contract BIM Execution Plan (BEP).

- Inputs from previous phases

  Phase [0]:

  - Performance of existing building and data collection.
  - Results of Design KPIs calculations (base case).
  - BIM model of existing conditions.
  - Barriers and drivers identified.

  Phase [1]:

  - Target cost.
  - Employers Information Requirements (EIRs).
  - Pre-contract BIM Execution Plans (BEP).
  - Request for Proposal (RFP) /BID documents/ Contract.

- Outputs for next phases

  - Post-contract BIM Execution Plan (BEP).
  - Risk allocation.

Stakeholders involvement

As explained before and following a collaborative approach as LEAN, IPD and BEAM sustains, all the stakeholders participate in this phase.

Table 11 Main stakeholders involved in Strategic definition

Stakeholder	Involvement	Proposed BIM and IPD roles				
		BIM			IPD	
		Coor	Man.	Tech	PMT	CPD
Owner/Promoter (optional Project Manager)	Definition of financing mechanisms. Collaboration in Post-contract BEP. Risk allocation.	?	-	-	X	-
End users (tenants, citizens)	Participation on the strategy definition	-	-	-	-	-
Design team (s)	Post-contract BEP. Risk allocation.	X	X	X	X	X

	Construction team (s)	Post-contract BEP. Risk allocation.	-	X	X	X	X
	Implementation team (s)	Post-contract BEP. Risk allocation.	-	X	X	X	X
	Facility Manager (s)	Post-contract BEP. Risk allocation.	-	-	?	-	X
	Others (consultancy, etc.)	-	-	?	?	-	X
- not proposed | X proposed | ? depends on responsibilities							

Recommendations for phase development

The **planning phase** of the project is a relevant stage in the methodology proposed. In the three pillar methodologies considered, BIM, IPD and LEAN, all the stakeholders involved should agree and share the project objectives, in order to go in the same direction and increase the effectiveness during the process. Though previous phases have already been approached by a **collaborative process** with the implication of the different involved parties in different segregated activities, this phase will be decisive to reinforce it and to mark the way forward throughout the process.

The **IPD approach** recognizes that increased effort in planning results in increased efficiency and savings during construction, operation and maintenance. Thus, the thrust of the integrated approach is not to reduce design effort, but rather to greatly improve the design results, streamlining and shortening the much more expensive construction effort. In addition to shifting design decision making forward, redefinition of phases is driven by two key concepts:

a) The **integration of early input** from constructors, installers, fabricators and suppliers as well as from designers; and
b) The **ability to model and simulate the project** accurately using BIM tools.

The **master schedule as defined by LEAN** represents an overall view that identifies major project phases and documents milestones. Hence, it is an optimistic forecast of the major stages in carrying out a project, based on the early information provided in the contract documents.

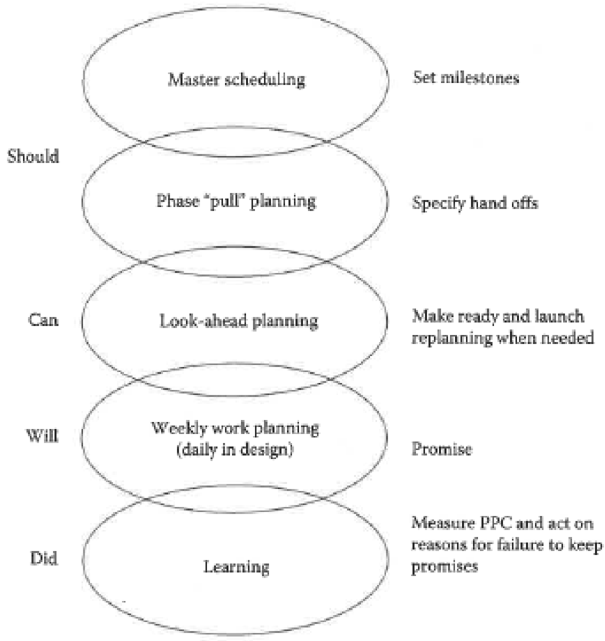


Figure 20. Interconnected conversations in The Last Planner System

The so-called **Last Planner** is the professional who prepares the weekly planner schedule, considering also the future work. It is measured as percent planned (PPC).

Weekly meetings are used to evaluate the team's performance during the preceding week. Root cause analysis is carried out to determine the reasons for underperformance, and the knowledge gained is used to improve the pending process in subsequent weeks.

Control sets up and manages schedules guarantee:

- The flow of work is structured for the project.
- Workflow is planned within the defined structure.
- Work is controlled to accomplish the plan.
- Weekly measurement evaluates accomplishment and permits fine tuning improvement.

The strategic definition starts by the **definition of the financial mechanisms or the business model** defined by the Owner/Promoter.

In parallel, it is expected to develop the **Post-contract BIM Execution Plan (BEP),** as a summary document in which all the activities will be collected supported by the BIM methodology. Planning issues as **schedule, milestones, partner's responsibilities**, etc. will be collected and agreed in this document. There is more information that could be considered as not initially expected in the BEP, but it is proposed to compile all the information in the same document. The sections to be defined in this document are (CIC 2010):

- Economic data.
- Objectives and BIM uses.

- Stakeholders definition.
- Common Data Environment (CDE).
- Standards.
- Data segregation and Data drops.
- Schedule.
- Collaboration meetings.
- Quality Control procedures.
- Responsibility matrix.
- Project delivery.
- Milestones.
- Others.

Finally, **risk allocation** of the project is a key aspect especially in Lean Construction and IPD Project Delivery Method in which **risks are shared between all the stakeholders involved in the process**. It should be identified the probability of appearance and impact of each risk, in order to avoid them if it is possible or to minimize their impact.

- **Financing mechanisms**

Despite the custom nature of multi-party agreements, three general forms have emerged: Project Alliances; Single Purpose Entities and Relational Contracts.

a) **Project Alliances**
The parties created a project structure where the owner guaranteed the direct costs of non-owner parties, but payment of profit, overhead and bonus depended on project outcome. This compensation scheme bound the parties to succeed or fail together. To reinforce Alliance teamwork, all significant decisions were made by facilitated consensus and the parties waived any claim between them, except for wilful default.

b) **Single Purpose Entities**
A Single Purpose Entity (SPE) is a temporary, but formal, legal structure created to realize a specific project. The SPE can be a corporation, limited liability company, limited liability partnership, or other legal form. In an integrated SPE, key participants have an equity interest in the SPE based on their individual skill, creativity, experience, services, access to capital or financial contribution. Typically, equity owners are paid for any services they provide to the SPE. However, an additional element of compensation is tied to overall project success.
The creation of a new, independent legal entity raises additional issues regarding taxation, corporate formalities, and management. Because the SPE is a separate entity, it must also be adequately insured.

c) **Relational Contracts**

Relational Contracts are similar to Project Alliances in that a virtual organization is created from individual entities. However, it differs in its approach to compensation, risk sharing and decision making. In a relational contract, the parties may agree to limit their liability to each other, but it is not completely waived. If errors are made, conventional insurance is expected to respond. Thus, there is a measure of traditional accountability. Compensation structures have project-based incentives, but there may or may not be any collective responsibility for project overruns. Decisions are developed on a team basis, but unlike the Project Alliance, the owner usually retains final decision rights in the absence of team consensus.
Because the balance of accountability, risk and control in Relational Contracts more closely follows traditional project structures, they may be **better suited to the needs and risk profiles** of certain projects and participants. In addition, Relational Contracts may offer a transitional structure to a **more completely integrated approach**.

- **Post-contract BIM Execution Plan (BEP)**

Based on the Pre-contract BIM Execution Plan, it will be further developed during this phase in order to outline the overall vision along with implementation details for the team to follow throughout the project. The plan should **define the scope of BIM implementation** on the project, **identify the process flow for BIM tasks**, **define the information exchanges** between parties, and **describe the required project and company infrastructure** needed to support the implementation.

Though the BEP will be mainly defined at this stage it will be **continuously updated** as additional participants are added to the project; and **monitored, and revised** as needed throughout the following phases of the project. The **Collaborative Design Platform (CDP)** developed in the 4RinEU project could be used to have all teams informed of the current advancement of each renovation project.

To develop the BIM Plan, a planning team should be assembled at this phase of a project. This team should consist of **representatives from all the primary project team members** including the owner, designers, contractors, engineers, major specialty contractors, facility managers, and project owner.

By developing a BIM Plan, the project and **project team members** can achieve the following value:

1. All parties will clearly understand and **communicate the strategic goals** for implementing BIM on the project.
2. Organizations will understand their **roles and responsibilities** in the implementation.
3. The team will be able to **design an execution process** which is well suited for each team member's business practices and typical organizational workflows.
4. The plan will **outline additional resources, training**, or other competencies necessary to successfully implement BIM for the intended uses.

5. The plan will **provide a benchmark** for describing the process to future participants who join the project.
6. The purchasing divisions will be able to **define contract language** to ensure that all project participants fulfil their obligations.
7. The baseline plan will provide a **goal for measuring progress** throughout the project.

The BEP will be based in defining **four different steps**:

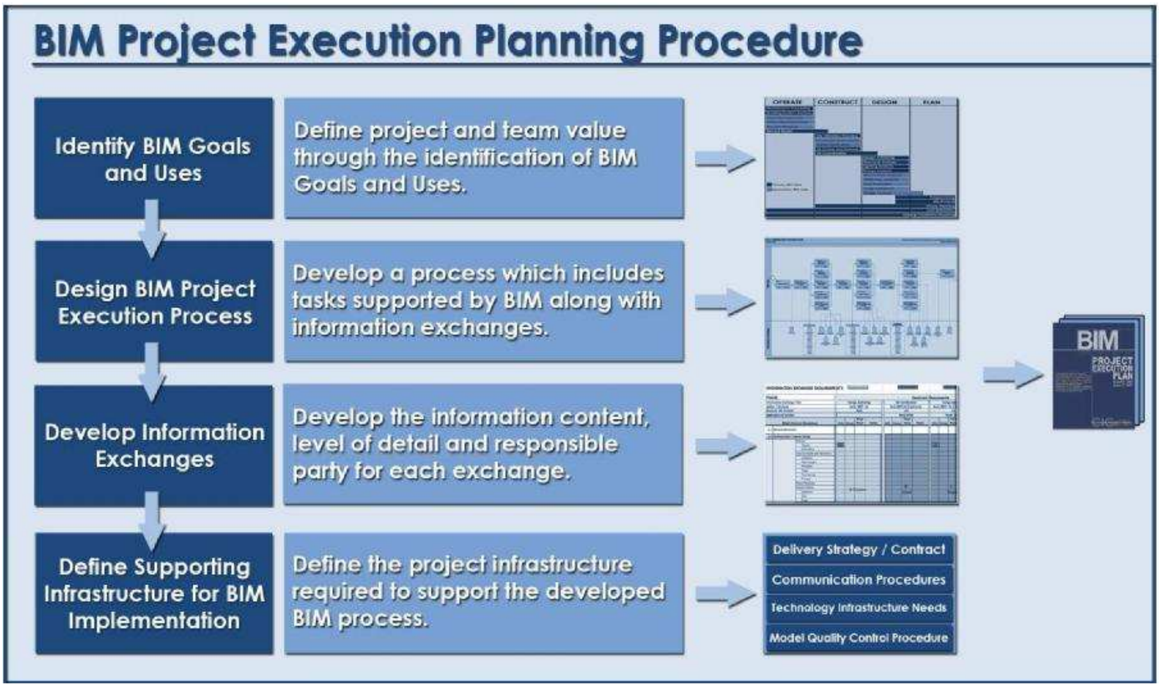


Figure 21. The BIM Project Execution Planning Procedure

Information Exchanges

Once the appropriate process maps have been developed, the information exchanges which occur between the project participants should be clearly identified. It is important for the team members, in particular the author and receiver for each information exchange transaction, to clearly understand the information content. When implementing a full 4RinEU approach, the plan for these exchanges could be carried out through the Collaborative Design Platform (CDP).

INFORMATION EXCHANGE WORKSHEET

	Information
A	Accurate Size & Location, include materials and object parameters
B	General Size & Location, include parameter data
C	Schematic Size & Location

Responsible Party	
A	Architect
C	Contractor
CV	Civil Engineer
FM	Facility Manager
MEP	MEP Engineer
SE	Structural Engineer
TC	Trade Contractors

Information Exchange Title	Record Modeling			4D Modeling			3D Coordination			Design Authoring		
Time of Exchange (SD, DD, CD, Construction)	Construction			CD			CD			CD		
Model Reciever	FM			C			C, TC			ALL		
Reciever File Format												
Application & Version												
Model Element Breakdown	**Info**	**Resp Party**	**Additional Information**	**Info**	**Resp Party**	**Notes**	**Info**	**Resp Party**	**Notes**	**Info**	**Resp Party**	**Notes**
A SUBSTRUCTURE												
Foundations												
Standard Foundations												
Special Foundations												
Slab on Grade												
Basement Construction												
Basement Excavation												
Basement Walls												
B SHELL												
Superstructure												
Floor Construction												
Roof Construction												
Exterior Enclosure												
Exterior Walls												
Exterior Windows												
Exterior Doors												
Roofing												
Roof Coverings												
Roof Openings												
C INTERIORS												
Interior Construction												
Partitions												
Interior Doors												
Fittings												
Stairs												
Stair Construction												

Figure 22. Portion of the Information Exchange Spreadsheet template

After the BIM uses for the project have been identified, the project process maps are customized, and the BIM deliverables are defined, the team must develop the infrastructure needed on the project to support the planned BIM process. This will include the definition of the delivery structure and contract language; defining the communication procedures; defining the technology infrastructure; and identifying quality control procedures to ensure high quality information models.

The BIM Plan should address the following categories of information:

1. ***BIM Project Execution Plan Overview Information:*** the reason for creating it.
2. ***Project Information:*** The Plan should include critical project information such as project numbers, project location, project description, and critical schedule dates for future reference.
3. ***Key Project Contacts:*** contact information for key project personnel.
4. ***Project Goals / BIM Objectives:*** with the strategic value and specific uses for BIM on the project as defined by the project team in the initial step of the planning procedure.
5. ***Organizational Roles and Staffing:*** One of the primary tasks is to define the coordinator(s) of the BIM planning and execution process. This is particularly important when identifying the organization(s) who will initiate the development of the BIM Plan, as well as the required staff to successfully implement the plan.

6. ***BIM Process Design:*** through the use of process maps which are developed in the second step of the planning procedure.
7. ***BIM Information Exchanges:*** The model elements and level of detail required to implement each BIM Use should be clearly defined in the information exchanges requirements.
8. ***BIM and Facility Data Requirements:*** The owner's requirements for BIM must be documented and understood.
9. ***Collaboration Procedures:*** The team should develop their electronic and collaboration activity procedures. This includes the definition of model management procedures including file structures, permissions, as well as typical meeting schedules and agendas.
10. ***Model Quality Control Procedures:*** Monitoring procedure for ensuring that the project participants meet the defined requirements throughout the project.
11. ***Technology Infrastructure Needs:*** The hardware, software and network infrastructure required to execute the plan.
12. ***Model Structure:*** The team should discuss and document items such as model structure, file naming structure, coordinate system, and modelling standards.
13. ***Project Deliverables:*** The team should document deliverables required by the owner.
14. ***Delivery Strategy / Contracts:*** The IPD delivery strategy will impact implementation and it will also impact the language which should be incorporated into the contracts to ensure successful BIM implementation.

- **Risk allocation**

Risk is a function of the likelihood of a loss weighted by its severity. In contrast, exposure to risk is the number of possible avenues by which loss can occur. For example, the increased interdependence of collaborative projects increases the number of parties relying on another party's contributions and who could potentially initiate a lawsuit. But the same interdependent web can reduce the likelihood and severity of loss. Exposure may increase, although true risk decreases.

The foregoing traditional methods separate design from construction: designers focus on product design and not process design in order not to assume the constructor's risk. When evaluating **choosing IPD developments**, parties should determine how the different alternatives mitigate the business risks faced by the project and its participants, as well as how they respond to liability concerns.

- The primary advantages of an IPD contract involve:
  - IPD can produce a project more quickly than a conventional process (Design-Bid-Build).
  - There is a single point of accountability for design and construction.
  - Cost efficiencies can be achieved since the contractor and designer are working together throughout the entire process.

  - Change orders would typically arise primarily from owner changes.
  - The owner gains the benefit of having the opportunity to incorporate a contractor's perspective and input to planning and design decisions.
  - The ability to "fast-track" early components of construction prior to full completion of design.
  - The entire team's interests are aligned with the project goals making the chance of success, once underway, extremely high.

- Disadvantages to be considered:
  - Actual agreement on the criteria and the final IPD contract can be very difficult and can take an inordinate amount of time and effort, for which the owner may be paying, if not in money then in time.
  - Industry inexperience with working in non-adversarial team relationships makes the chance of failure most dependent on the behavior of individuals within the team. Damaging behavior is very difficult to control or to correct and can cause the breakdown of collaborative processes that are critical to success.
  - Objective selection of the team is very difficult to achieve and can rely on little more than instinct for an owner who does not already have a team or teams that it knows and works with well.
  - While team members are paid at cost for the work they do, prediction of and control of the effort comprising "cost" is difficult at the time the team is selected and even after the contract with fully agreed criteria is executed.
  - IPD contracts have not yet been tested in law, so the result of a failure within the team is unpredictable.

The IPD team reduces or eliminates risk by employing new conceptual and autonomic approaches to project delivery (Lichtig 2005). Following IPD implementation in the renovation projects imply risk sharing from the different involved parties. Contingency funds could be designated to address various categories of risk, including unaccounted for risks. The risk categories included permitting changes, construction deviations and price escalation. In a full 4RinEU implementation, this could leverage the Risk Assessment Guidance developed as Deliverable 4.2.

7.4 Phase [3] Design

Objectives

The objective of this phase is to **select the deep renovation design** to be implemented in the existing building. It has to be developed according to the guidance provided by the **BIM Execution Plan (BEP)** and the **specifications in the IPD agreement**.

- Inputs from previous phases

  Phase [0]:

  - Performance of existing building and data collection.
  - Results of Design KPIs calculations (base case).
  - BIM model of existing conditions.
  - Barriers and drivers identified.

  Phase [1]:

  - Target cost.
  - Employers Information Requirements (EIRs).
  - Request for Proposal (RFP) /BID documents/ Contract.

  Phase [2]:

  - Post-contract BIM execution Plan (BEP).
  - Risk allocation.

- Outputs for next phases

  - BIM model 3D, 4D, 5D, 6D.
  - Energy performance of detailed design.
  - Results of Design KPIs calculations (design/simulations).
  - Construction documents.

Stakeholders involvement

Although the main partner in charge of these activities is the Design team, it is really important that all stakeholders participate in the design, in terms of being able to forecast future problems or requirements related to construction, system manage, building use or implementation issues.

Also, it is key the involvement of the end users and/or tenants.

Table 12 Main stakeholders involved in Design Phase

Stakeholder		Involvement	Proposed LEAN- BIM and IPD roles				
			BIM			IPD	
			Coord	Man.	Tech.	PMT	CDP
	Owner/Promoter (optional Project Manager)	Participation in design selection.	?	-	-	X	-
	End user (tenants, citizens)	Participation in design selection.	-	-	-	-	-
	Design team (s)	Concept design, Design selection, Detailed design	X	X	X	X	X
	Construction team (s)	Design selection, Detailed design	-	X	X	X	X
	Implementation team (s)	Design selection, Detailed design	-	X	X	X	X
	Facility Manager (s)	Detailed design	-	-	?	-	X
	Others (consultancy, etc.)	-	-	?	?	-	X

- not proposed | X proposed | ? depends on responsibilities

Recommendations for phase development

As it was explained in section 5.1.1, MacLeamy diagram shows the potential of **combining IPD and BIM in design phase**. Thanks to a **deep collaboration** between the involved partners of the project during the design phase, it would be possible to achieve an **optimization of the construction phase**.

In terms of the activities that have to be done during this phase, they are similar to common energy renovation procedures. The **Collaborative Design Platform (CDP)** could be used to manage these activities.

In the first place, different alternatives for concept design or retrofitting packages are proposed for the renovation according to the base case analysis results, the Owner/Promoter requirements and End user's feedback.

Secondly, these preliminary designs are evaluated in regards to the previous objectives desired to be achieved and also remembering the target cost, supported by the Design KPIs. At this stage the renovation project is also evaluated from other perspectives as **Life**

Cycle Cost (LCC) or Life Cycle Analysis (LCA). The most cost-effective solution in the budget boundary is normally selected, although it is necessary to involve all the stakeholders, including the end users participation.

Finally, the **detailed design** of the renovation considering the selected retrofitting packages is carried out.

The difference of the process herein proposed with respect to traditional processes is the integration of **LEAN, IPD and BIM collaborative workflows and tools**, which were also defined in the BIM Execution Plan (BEP):

- The **collaborative work**. This affects the traditional workflows, modifying the traditional linear design process by integrating several iterations. The information can be gathered in a federated model shared by all the stakeholders.
- Designing tools that allow the collaborative work. Software to be used have been established previously in Pre and Post BEP, guaranteeing the interoperability and information exchange.
- The Common Data Environment (EN ISO 19650). Organization and digitization of information about buildings, including building information modelling (BIM)

The **holistic involvement of the main actors** of this phase will differ from the traditional scope of services that normally outlines a more individual vision of the team members according to each specific phase of the project. IPD relies heavily on an extensive and thorough design process that incorporates input and involvement of other team members, including constructors, during the design phase. We will differentiate three groups:

a) **Designers**

As a team member, the designer is necessarily involved in defining the design processes that will apply to the project.

Integrated projects allow for more **extensive pre-construction efforts related to identifying and resolving potential design conflicts** that traditionally may not be discovered until construction.

Frequent interactions with other team members during the design phase necessitates that designers provide numerous iterations, and additional responsibility, of their design documents to other team members for their evaluation and input.

b) Constructors

It is important to highlight their **early involvement on the project and their participation within the integrated team**. During the Design Phase, constructors will provide strategic services such as schedule production, cost estimating, phasing, systems evaluation, constructability reviews, and early purchasing programs. Therefore, the timing of these services is advanced. This increased role during the design phase requires the constructor to provide, on a continuing basis, estimating services and/or target value design services during the design phase.

c) **Owner**

The Owner takes on a **substantially greater and more active role** in evaluating and influencing design options. Additionally, at this stage, the Owner is required to participate in establishing project metrics. As member of the decision making body, the owner will be involved on more project-related specifics and be required to act quickly in this regard to allow the project to continue efficiently.

- **Concept design**

Conceptualization begins to determine WHAT is to be built, WHO will build it, and HOW it will be built.

Performance goals should be developed at this stage including: Size, Sustainable or green criteria, Economic performance based on the complete building life span until operation and maintenance; Successful outcome metrics (e.g. cost, schedule, quality, etc.).

Cost structure will be developed earlier in the process and in greater detail than a conventional project. Costs may be linked to the BIM Model to enable rapid assessment of design decisions and will be detailed by system, providing an understanding of the cost range and importance of each system.

Key Parties as Facility Managers will assess areas where greatest EE improvements could be possible.

Initial benchmarking comparison should be performed to assess project costs against market rates.

Preliminary work schedule would be developed and linked to the developing BIM model. Communication methodologies and process guidelines will be established within the **Collaborative Design Platform**, considering for example: administration and maintenance of BIM(s); Source of truth for all data; Interoperability criteria; Data transfer protocols; Level of detail development by phase and Development of tolerances.

At this stage it would be optimal to incorporate from the **Prime Constructor:**

- Cost information: comprehensiveness and integration into model.
- Constructability
- Initial procurement and construction schedule, including integration into the BIM model.
-

And from **Suppliers and facilitators:**
- Specific cost data

- Identification of long lead items.
- Product data sheets.
- Life cycle and energy efficiency data of the main facilities to be considered in the renovation.

- **Design selection**

During Design Selection, the project begins to take shape. Major options are evaluated, tested and selected. At this stage, it should be selected the renovation package procedure to be followed.

In this phase, the project within the Collaborative Design platform (CDP) is further customised to the real needs.

At this stage major Design KPIs are calculated for the design alternative selection in order to obtain the maximum savings within the renovation. This phase could leverage the cost-effective rating system developed as 4RinEU Deliverable 4.2.
End users participation at this phase is much appreciated in order to customise the design to the real needs and final end. This can leverage the advice from 4RinEU Deliverable 3.5.

According to the results obtained, it will be defined the renovation packages to be covered within the project and the order selection.

- **Detailed design**

The Detailed Design phase concludes the **WHAT phase** of the project. During this phase, all key design decisions are finalized. Detailed Design under IPD comprises much of what is left to the Construction Documents phase under traditional practice, thus the **Detailed Design phase involves significantly more effort** than the traditional Design Development phase.

Building is fully and unambiguously **defined, coordinated and validated**. All major building systems are defined, including any furnishings, fixtures and equipment within the scope of the project. All building elements are fully engineered and coordinated. The team will have collaborated to resolve any inconsistencies, conflicts or constructability issues.
Agreement is reached on tolerances between trades **to ensure constructability** and to enable as much prefabrication as possible. Quality levels are established. Prescriptive Specifications are completed based on prescribed and agreed systems.

Cost is established to a high level of precision.
Construction schedule is established to a high level of precision.

7.5 Phase [4] Construction

Objectives

The objective of this phase is to achieve the final delivery according to the design and milestones defined in previous phases. The information of the final construction is gathered in the as-built BIM model. It is necessary to verify that the final product accomplishes the initial EIRs and the objectives fixed in the BEP and IPD agreement, including energy or sustainability targets.

- Inputs from previous phase

Phase [1]:

- Target cost.
- Employers Information Requirements (EIRs).
- Request for Proposal (RFP) /BID documents/ Contract.

Phase [2]:

- Post-contract BIM execution Plan (BEP).
- Risk allocation.

Phase [3]:

- BIM model 3D, 4D, 5D, 6D.
- Construction documents.

- Outputs for the next phase
  - As-built BIM model

Stakeholders involvement

Design and industrial partners are expected to collaborate in this phase through the Requests for Information (RFI), although Construction and Implementation teams are in charge of the retrofitting works.

Table 13 Main stakeholders involved in Construction Phase

Stakeholder	Involvement	Proposed LEAN, BIM and IPD roles				
		BIM			IPD	
		Coord	Man.	Tech.	PMT	CDP
Design team (s)	Feedback to Request for Information (RFI)	X	X	X	X	X
Construction team(s)	Construction/Implementation process. Request for Information (RFI)	-	X	X	X	X
Implementation team(s)	Construction/Implementation process. Request for Information (RFI)	-	X	X	X	X

	Others (consultancy, etc.)	-	-	?	?	-	X

- not proposed | X proposed | ? depends on responsibilities

Recommendations for phase development

The most innovative aspect proposed for this phase compared to the traditional process is the **integration of Lean Construction principles** in relation with the **optimization of the process reducing waste.**

Last Planner System (LPS) is a tool or methodology based on a *pull* system instead of the traditional *push*, developed by the same creators of the Lean Construction concept. The components of LPS are (Pons 2014):

- Anticipated planning
- Planning compromise
- Learning

To develop this methodology it is necessary to develop three scales of plans (Pons 2014):

- Master plan, what should be done. It is done at phase level.
- Intermediate plan, what can be done.
- Weekly plan, what will be done.
- Learning, from what *was* done.

Also the Construction KPIs included in Annex 1 could help the accomplishment with the Lean Construction principles. It should be taken into account that it is necessary to consider them during planning activities so the tools applied for this allow the comparison between what was planned and really executed that is pursued in some of the indicators.

During the process, the Design team(s) and the Construction/Implementation team(s) are in contact to solve any doubts or issues that could appear through Requests for Information (RFI), although they are expected to be reduced to the minimum thanks to the integration of IPD, BIM and Lean concepts.

Finally, after construction and implementation works are finalized by the corresponding teams, the as-built BIM model is delivered to the FM to be used during the O&M phase.

- **Construction Documents**

During this phase, effort shifts from WHAT is being created to documenting **HOW it will be implemented.** The goal of Implementation Documents phase is to complete the determination and documentation of how the design intent will be implemented, not to change or develop it.

The traditional shop drawing process is merged into this phase as constructors, trade contractors and suppliers document how systems and structure will be created. In addition, this phase generates the documents that third parties will use for permitting, financing and regulatory purposes.

Because the Detailed Design phase concludes with the design and all building systems "fully and unambiguously defined, coordinated and validated," the Implementation Documents phase comprises less effort than the traditional Construction Documents phase.

Construction means and methods are finalized and documented.
Construction schedule is finalized and agreed upon.
Cost is finalized and agreed upon.
Costs are tied to the BIM model.

The **specifications are finalized**, supplementing the model with narrative documentation of the design intent wherever necessary.

Implementation Documents define and visualize the project for participants who aren't involved in the development of the model, providing:

- A "finance-able" project (a completed model that gives "the bank" sufficient detail to finance the project).
- Bid documents for parties outside the integrated process.

The "**shop drawing**" phase that in traditional phases occurs after Construction Documents will be largely completed during the Implementation Documents phase.

Prefabrication of some systems can commence because the model is sufficiently fixed (object sizes and positions are frozen) to allow early purchasing and prefabrication to begin.

- **Construction process optimization recommendations**

As in any process improvement endeavor, **measurement is all important**. You cannot improve what you cannot measure. Lean project delivery can raise the reliability of work plans to 85% or more.

In the context of **Lean construction**, the desired outcome is to have minimal variability along the construction process.

It is widely recommended to use a **Statistical Process Control (SPC)** and PPC values. SPC involves the use of **control charts** to track performance of a process and diagnose the nature of the variation it exhibits. The control chart is an important statistical tool that enables owners **to minimize the variation in process and the resulting defect**s. In Lean-based construction projects, The **Last Planner System** requires the tracking of PPC in order to calibrate the reliability of each actor. Last Planner System's principles are:

- Assumption: Construction project work plans are really forecasts.
- Planning is more detailed the closer one gets to doing the work.
- Plans are made in collaboration with those who will do the work.
- Constraints should be identified and removed by a team effort.
- Constructions team members must make reliable promises.
- Plan failures/breakdowns should be treated as an opportunity for learning, not for negative actions.

Improving the efficiency of individual activities does not necessarily improve the efficiency of the overall process. Leanness is increased by reducing or eliminating the "waste" (or delays) that occurs between activities in order to increase **overall construction process efficiency.**

At each **weekly meeting**, time is devoted to learning why certain tasks were not accomplished in the previous week before creating a weekly plan for the work to be executed in the following week. Incomplete plans are studied to determine the root causes (reasons for non-completion) and why they were not completed in order **to improve the effectiveness of future work plans**.

We can outline the following:

- **Percent plan complete (PPC),** which measures the degree to which work is completed as planned.
- **Reasons for non-completion**: these reasons are tabulated by studying incomplete plans to determine the root causes for lack of completion.

The following **Lean Performance Measures or KPI's** should be considered at the construction:

1. **Cycle time:** time it takes from start to finish to complete a task or to provide a service.
2. **Value creating time:** process time spent to transform raw materials and information (i.e. through BIM) into a usable product or service requested.
3. **Lead time:** time taken to move one transaction through the entire process.
4. **Takt time:** available working time per day.
5. **Production efficiency:** units produced/Takt time.

Some of the **main recommendations** to improve and optimize the construction process should be:

- **Clear and Collaborative Communication** of project plans.
- **Continuous improvement** philosophy: **Value Stream Mapping** (both value added and nonvalue added) and **Lessons learned,** in order to reveal what can be improved.
- **Training, teamwork, multi-skilling.**
- **Daily progress reporting and improvement meetings.**
- **Optimize the project, not the pieces.** Project optimization involves having project teams collaborate to identify and implement solutions that are best for the overall project.
- A **well motivated, well trained, flexible and fully engaged workforce**.
- A **commitment to reducing or eliminating waste (or delays),** considering workplace organization and **standardization**, in relation to D2.7.
- A **commitment to cost and performance measures**.
- The use of **Information Technology (BIM)** along the construction process. **The Clash Detection system** will help to detect collisions or interferences through the systems (structure, facilities, etc.) before and during the construction process.
- Include **responsible sustainability practices:**
    - Using resources efficiently and minimizing raw material resource consumption.
    - Maximizing resource reuse.
    - Utilizing renewable energy sources.
    - Creating a healthy working environment.
    - Building facilities of long-term value.
    - Protecting and/or restoring the natural environment.

Within the **BIM methodology** implemented, the **contractor's BEP** should also clearly communicate how the integrity of the model and other data sources will be maintained including details of:

- Model and data compliance, including references to standards and to compliance.
- Software used by the contractor and their supply chain.
- Quality assurance/control procedures.
- Software used to support quality control procedures.
- How the contractor is monitoring the state of as-built construction so that this can be reflected in the model/s.

It is expected that all project team members will use **clash-detection** software as appropriate to determine field conflicts by comparing the 3D models. The whole project team, including the contractor and its supply chain, must provide proposals for how models and information will be coordinated, managed and reported throughout the project lifecycle.

The project team is to demonstrate visually its use of the latest federated multi-disciplinary 3D model for co-ordination purposes. This should be done in formal progress meetings where the team will review the development and model progress. The contractor will be responsible for setting up and leading these meetings. The latest federated model must be made available at all progress review meetings in accordance with the agreed process in order to demonstrate the proposed design and its state of progress and also to address co-ordination issues.

BIM can include **3D Control and Planning (Digital Layout), Phase Planning (4D modelling) and Site Utilization Planning**, processes in which a 4D model is used to graphically represent both permanent and temporary facilities on site, with the construction activity schedule. Additional information incorporated into the model can include labor resources, materials and associated deliveries, and equipment location. Because the 3D model components are directly linked to the schedule, site management functions such as visualized planning, short-term re-planning, and resources can be analyzed over different spatial and temporal data. 4D modeling is a powerful visualization and communication tool that can give a project team, including the owner, a better understanding of project milestones and construction plans.

3D Coordination is another BIM process in which **Clash Detection software** is used during the coordination process to determine field conflicts by comparing 3D models of building systems. The goal of clash detection is to eliminate the major system conflicts prior to installation.

BIM also may integrate **Construction System Design (Virtual Mockup) and Digital Fabrication process** in order to optimize the construction stage.

- **Commissioning**

The National Conference on Building Commissioning has officially defined "Total Building Commissioning" as: a "*Systematic process of assuring by **verification and documentation**, and **from the design phase to a minimum of one year after construction**, that **all facility systems perform interactively in accordance with the design documentation and intent**, and **in accordance with the owner's operational needs**, including preparation of operation personnel".*

In effect, a building commissioning is an excellent **quality assurance mechanism**. It is optimally applied to all phases of a construction project-programing/predesign, design, construction/installation, acceptance, occupancy, and post occupancy. It focuses on verifying and documenting that the facility and all of its systems and assemblies are planned, designed, installed, tested, operated, and maintained **to meet the OPR** (Owner Project Requirements) settled at the first phases.

Lean Construction requires a collaboration of all design and construction stakeholders, as already mentioned before. **Commissioning agents improve both the design and construction processes** by enabling designs that use resources cost effectively, and that benefit from the quality assurance provided by the commissioning process. This approach **minimizes waste**, not only in the design of facilities, but also in their subsequent operation.

I**n the case of 4RinEu-based** deep renovations, it is important to implement **commissioning procedures based on energy efficiency standards.**

An important benefit of the commissioning process is the quality assurance provided by ensuring that installation work is faithful to the plans and specifications. Problems and conflicts are detected early when the CxA (Commissioning Agent) asks installers to verify installation details at a time when corrective work can be done cost-effectively if it is needed. In the case of HVAC this can be very beneficial. The Cx review process ensures that user/client satisfaction is secured with the final product, in keeping with lean principles. The scope of the commissioning will include HVAC systems, EMS, lighting control systems, electrical power distribution systems, fire protection system and alarms, telephone and intercommunications, CCTV systems, elevator controls and building envelope.

Building performance can be validated by using the commissioning process for quality assurance beyond the requirements of **LEED standards**, assuring that a facility's systems are functioning as designed, as i.e. by demonstrating that there are no leaks or early points of failure at the building envelope.

CxA is an objective, independent advocate for the building owner, with significant design and hands on experience with building mechanical and electrical systems.

Commissioning **reduces a building owner's total cost** of ownership. Energy costs are a major component of a building's operating costs.

Other benefits of Commissioning:

- It clarifies owner's project requirements (**OPR).**
- Project designs have **fewer errors/imperfections**.
- **Project cost is reduced**, as change orders are avoided.
- **Delays, waste, and rework are minimized**.
- Punch lists are reduced.
- **Decision-making and construction are speeded up**.
- The **operation and maintenance of facilities are improved**, especially with regard to electrical, mechanical, and plumbing. **Operating costs (including energy) are reduced because of optimum performance.**
- There is **trouble-free turn over**--systems are fully functional**.**
- There are **fewer warranty calls** to contractors.
- **Equipment life is extended**, a sit works within normal limits.
- **Air quality is improved** and occupants experience fewer illness.

In a 4RinEu-based project it is important to include within the commissioning scope the **Energy-efficiency measures** to be implemented at each case.

The early involvement of the commissioning by the first phases of the process will enable designers to adopt a holistic design that incorporated energy efficiency and sustainability, minimizing environmental pollution and maximizing life-cycle effectiveness.

BIM also integrates Building Systems Analysis and Building (Preventative) Maintenance Scheduling, in order to improve building performance, to reduce repairs, and to reduce overall maintenance costs. The resources required are:

- Design review software to view Record Model and components.

- Building Automation System (BAS) linked to Record Model.
- Computerized Maintenance Management System (CMMS) linked to Record Model.
- User-Friendly Dashboard Interface linked to Record Model to provide building performance.
- Information and/or other information to educate building users.

BIM Quality Control System includes the check that should be performed to assure quality:

Table 14. Quality Control System template

CHECKS	DEFINITION	RESPONSIBLE PARTY	SOFTWARE PROGRAM(S)	FREQUENCY
VISUAL CHECK	Ensure there are no unintended model components and the design intent has been followed.			
INTERFERENCE CHECK	Detect problems in the model where two building components are clashing including soft and hard.			
STANDARDS CHECK	Ensure that the BIM and AEC CADD Standard have been followed (fonts, dimensions, line styles, levels/layers, etc).			
MODEL INTEGRITY CHECKS	Describe the QC validation process used to ensure that the Project Facility Data set has no undefined, incorrectly defined or duplicated elements and the reporting process on non-compliant elements and corrective			

- **Handover and close-out**

This stage should be seen as the **"in inspection" of the "as-built information**" extracted from the updated BIM model after the construction phase ends- i.e., accepting the building/facility/asset into service. There should not be any questions at this stage, but simply **confirmation and verification**.

Facility Managers (FM) should ensure the handover process has already validated and transferred relevant data into **CAFM (computer aided facilities management) / IWMS (integrated workplace management systems)** as defined in the **EIRs defined at the beginning of the process**. The handover process should allow for CAFM/IWMS integration with other systems as required at each project. All O&Ms should be completed and signed off with the client and FM team within the CDE (common data environment) - or appropriate sign of system. FM should also test that they can **access all BIM models** passed to them.

Handover should be considered as a handover of a completed project, with the EE solutions implemented, tested, validated by the client and, after staff training, signed off as completed.

7.6 Phase [5] Operation & Maintenance

The target of this phase is to guarantee the achievement of the project objectives. Later, the maintenance of the building is carried out during its lifetime and managed by the Facility Manager.

Objectives

- Inputs from previous phases

  Phase [0]:

  - Results of Design KPIs calculations (base case).

  Phase [3]:

  - Results of Design KPIs calculations (design).

  Phase [4]:

  - As-built BIM model.

Stakeholders involvement

In this phase only the stakeholders that will be involved in the building activities during its lifetime are expected to participate, but specially the FM that will be the responsible of update the as-built BIM model with all the interventions done over the building during the O&M phase.

Table 15 Main stakeholders involved in Operation & Maintenance Phase

Stakeholder	Involvement	Proposed LEAN, BIM and IPD roles				
		BIM			IPD	
		Coord.	Man.	Tech.	PMT	CDP
Owner/Promoter (optional Project Manager)	Building exploitation.	-	-	-	X	-
End user (tenants, citizens)	Building use.	-	-	-	-	-
Facility Manager (s)	Building systems management.	X	X	X	X	-
Others (consultancy, etc.)	-	-	-	-	-	-

- not proposed | X proposed | ? depends on responsibilities

Recommendations for phase development

M&V procedure has to be carried out if it is included in the initial requirement for the evaluation of the objectives accomplishment. It should also have been defined and

installed previously a monitoring system and a monitoring period, if the evaluation is expected to be done with these data.
The most common protocol is the **International Performance Measurement & Verification Protocol** (IPMVP) that proposes 4 options according to the available data before and after the renovation:

- Option A – Key parameter measurement
- Option B – All parameter measurement
- Option C – Whole facility
- Option D – Calibrated simulation

Finally, in order to understand the impact after renovation and the achievement of the project objectives it is recommended to compare the following results of **Design KPIs** calculations:

- Base case
- Selected design
- Real building after implementation of EE measures with monitoring data or other available data according to the option selected.

Lessons learnt can be collected for future deep renovation projects or future retrofitting in the same building.

- **M&V procedure**

The M&V procedure should specify the activities that allow the assessment of the retrofit regarding **energy consumption, comfort and IAQ.** Each building and retrofit project are a specific process so that the procedure, starting from a general framework, should be designed accordingly.
Effective measurement and verification (M&V) systems are crucial not only to capture the energy efficiency gains but also to appropriately capture multiple benefits of energy efficiency (MBEE) so investment and policy decisions are better informed and enabled.
M&V should be a critical aspect of any retrofit project in order **to ensure value for money** as well as **provide the basis of performance-based payment mechanisms**. M&V is essential to assess resource savings and to ensure that savings persist over time.

Energy efficiency practitioners use M&V for several reasons, such as, to:

- **Improve engineering design** and project costing.
- **Enhance energy savings** through adjustments in facility operations and maintenance.
- Document financial transactions (e.g., for energy efficiency projects where financial payments are performance based).
- **Enhance financing** for energy efficiency projects.
- **Support development** of broader energy efficiency programs.

It is important that the designer group, the owner and the construction company share the information regarding the expected performance, the “as-built” information and the cost of the measures implemented, within others. It is also important to have a good documentation of the construction process, especially if the measures implemented refers to the envelope, since later it will be very difficult to identify the causes of some problems that may arise, i.e. windows installation, insulation of roof and envelope, airtightness, piping and ventilation ducts installation. For these reasons, it is recommended that a **commissioning process** is carried out **aligned with the M&V procedure.**

Since the retrofit is an action inside the building stoke of a real estate, it is important to evaluate the building performance along the life spam of the building. Therefore, the M&V can be organized as a first step of a continuous assessment of the building or a periodical assessment. This aspect should be discussed with the building owner at the beginning of the process, including a first draft of an M&V plan during the early phases that outlines how the **performance of the project (KPI's)** will be monitored and assessed.

A few strategies for keeping M&V costs low while maintaining the rigor include the following:

- **Use extensive metering in the baseline period** and stipulate values for the parameters that cannot be metered.
- **Verify KPI's** using periodic rather than continuous data collection (not to be confused with continuous M&V) to reduce data collection and management issues.
- Rely upon existing instrumentation, energy management systems, and energy management behavioural practices.

The **following steps** are recommended for incorporation of MBEE in the analysis of a 4RinEu-based project:

1) **Identify the benefits** most relevant to original established goals (OPR and EIRs).
2) Determine the goal of **quantifying the benefits** (advertising, stakeholder engagement, program decision and impact evaluation).
3) Consider MBEE **at the beginning of the process**, during the first phases of design and planning.
4) Develop the evidence base and establish reference studies (Baseline).
5) **Streamline the quantification process** by adopting/developing appropriate model and tools **(BIM).**

- **Impact after renovation**

The **IPMVP (International Performance Measurement and Verification Protocol)** is used to have a common reference framework for having a minimum level of metrics that are accepted at international level by the market and stakeholders. However, especially with the detailed assessment, it can be carried out using different approaches.

For a **deep retrofit process** it is necessary to have both the energy dynamic model of the building with the real time monitoring data, since the monitoring data are not enough and cost effective to evaluate all the measures that are usually implemented. The calibrated model and monitoring data will be used to compare the **post-retrofit scenario** (obtained after the M&V procedure) with the **design scenario** (design selected at the Phase [2] Planning and the Phase [3] Design) and with the **pre-retrofit scenario** (Baseline outlined within the Phase [0] Base case analysis).

This comparison will be made through the defined **Design KPIs** of the retrofit project. Design KPIs are also developed by the 4RinEU project through deliverable D2.1.

This assessment is useful to **identify the savings achieved**, the **discrepancy with the design condition**, the **related uncertainty and a realistic payback time** of the retrofit. It will also enable the **evaluation of the real performance** of the 4RinEU deep renovation packages, considering each measure implemented and not only the overall result, according to the five different areas as already outlined.

Table 16. Design and Construction KPI's, indicators and methods for measurement.

DESCRIPTION	INDICATORS	METHODS
1. Energy		
Energy demand for heating	Unit of energy demand for heating [kWh] - [kWh/m2] [kWh/(m2 HDD)] and monetary value.	Measurement and power modelling
Energy demand for DHW production	Unit of energy demand for DHW production [kWh] - [kWh/m2] and monetary value.	Measurement and power modelling
Energy demand for ventilation	Unit of energy demand for ventilation [kWh] - [kWh/m2] and monetary value.	Measurement and power modelling
PV system energy produced	Unit of PV energy produced [kWh] - [kWh/m2] - [kWh/m2PV surface]	Measurement
Energy demand for lighting and appliances	Unit of energy demand for lighting and appliances [kWh] - [kWh/m2]	Measurement and energy modelling
Electricity self-consumed	Unit of electricity self-consumed [kWh] - [kWh/m2]	Measurement and modelling
ST system energy produced	Unit of ST system energy produced [kWh] - [kWh/m2] - [kWh/m2ST surface]	Measurement and modelling
ST energy balance	Unit of ST energy balance [%]	Modelling Measurement
2. Comfort and Indoor Air Quality		
Number of hours category IV cold	Unit of hours [h]	Measurement
Number of hours category IV hot	Unit of hours [h]	Measurement
Over-heating Degree Hours	Unit of over-heating Degrees [°C]	Measurement
Indoor Air Quality		Survey of willingness to pay or comparison
3. Environment		
CO2 emission of the building	Unit of CO2 emissions [kg/year]	Measurement
4. Economy		
Investment cost	Unit of investment cost [€] – [€/m2]	Measurement
Net Present Value	Unit of Net Present Value [€]	Measurement

DESCRIPTION	INDICATORS	METHODS
Energy cost before and after renovation	Unit of Energy cost before and after renovation [€]	Measurement
5. **Building site management**		
Health and Safety (HS)		
HS – AR – CS/WS Accidents rate	Number of accidents [-]	Measurement
HS – AF – CS/WS Accidents frequency	Unit of frequency of accidents [No./h]	Measurement
HS – AC – CS/WS Accidents cost	Unit of accidents cost [€/h]	Measurement
HS – IR – CS/WS Incidents rate	Unit of incidents rate [-]	Measurement
HS – IF – CS/WS Incidents frequency	Unit of incidents frequency [No-/h]	Measurement
Site Work Logistics (SWL)		
SWL – TO – CS/WS Transportation optimization	Percentage [%]	Measurement
SWL – IE – CS/WS Inventory excess	Percentage [%]	Measurement
SWL – DDI – CS/WS Delay due to inventory	Percentage [%]	Measurement
Budget (B)		
B – NPM – CS/WS Net profit margin	Unit of Net profit margin [€]	Measurement
B – CCF – CS/WS Change cost factor	Unit of Change cost factor [-]	Measurement
B – IRe – CS/WS Impacts of repairs (internal)	Unit of impact of repairs [No]	Measurement
B – IRi – CS/WS Impact of repairs (internal)	Unit of impact of repairs [No]	Measurement
Productivity – Time management (PTM)		
PTM – TWD – CS/WS Total works duration	Unit of total works duration [days]	Measurement
PTM – TD – CS/WS Task duration	Unit of task duration [days], [h]	Measurement
PTM – PDW – CS/WS	Percentage of delivered works by cost [%]	Measurement
PTM – TD – CS/WS Task Delay	Percentage of task delay [%]	Measurement
PTM – WD – CS/WS Total delay	Percentage of total delay [%]	Measurement
PTM – IR – CS/WS Tome impact of repairs	Percentage of tome impact of repairs [%]	Measurement
PTM – RP – CS/WS Re-planning	Unit for re-planning [No. / months]	Measurement
Work Site Sustainability (WSS)		
WSS – EC – CS/WS Electricity consumption	Unit of electricity consumed [kWh/m2]	Measurement
WSS – OC – CS/WS Oil consumption	Unit of oil consumed [liters / m2]	Measurement
WSS – WC – CS/WS Water Consumption	Unit of water consumed [m3 / m2]	Measurement
WSS – LR – CS/WS Landfill rate	Unit for landfill rate [Tn / m2]	Measurement
WSS – RCR – CS/WS Recycling rate	Unit for recycling rate [Tn / m2]	Measurement
WSS – RUR – CS/WS Re-using rate	Unit for reusing rate [Tn / m2]	Measurement

8. Conclusions

The 4RinEU methodology to implement deep renovation projects outlines a **new way of management**, considering the current barriers and challenges addressed in the building construction industry. Renovation projects are usually not approached as an integrated process according to the complexity required, but as a service delivery indifferent to the difficulty and multiplicity of the interactions existing among the involved parties and developed activities. Furthermore, there is a lack of objectives definition with an obsolete management scheme and a poor interaction between the stakeholders, producing non-optimal global solutions, with the non-compliance of the targets defined and the increase of the final costs, in most of the cases.

The 4RinEU methodology offers an **innovative way to optimize** the whole building process**,** giving a **global solution reducing the final costs** while **fulfilling the client's requests** by the **integration of three systems**: **IPD** for collaborative work**, BIM** as an implementing tool and **LEAN** as a process optimization, used across 6 phases:

- **[0] Base case analysis (Baseline)**, where the existing building is analysed from the energy perspective and the base case (**BIM model**) situation is established, together with the **EIRs** from the Client and a first approach of **KPIs**.
- **[1] Procurement.** Based on the baseline obtained from the previous phase, the owner defines the objectives and requirements for the project development, defining the tender process and selecting the teams to collaborate in the project, **following mainly IPD principles**.
- **[2] Planning.** Main stakeholders involved in the process define altogether the relevant aspects for the project's development, especially regarding schedules, milestones and responsibilities. Definition of **BIM Execution Plan (BEP)** and **risk allocation, following LEAN and IPD principles.**
- **[3] Design.** The different packages for deep renovation are defined, in comparison with the baseline and according also to a cost-effective analysis. In this phase the following outputs are defined: **BIM model** 3D, 4D, 5D or 6D, **energy performance** of detailed design, **results of design KPIs** and **design documents.**
- **[4] Construction.** The selected renovation package is implemented according to the specifications defined during the design phase. The information of the final construction is gathered in the **as-built BIM model.** It is necessary to verify that the final product accomplishes the **initial EIRs** and the objectives fixed in the **BEP and IPD agreement**, including **energy or sustainability targets**. **Commissioning** is an excellent quality assurance mechanism.
- **[5] Operation & Maintenance.** In this phase the Measurement and Verification **(M&V)** protocol is applied to evaluate the achievements of the project's goals together with the Return on Investment **(ROI)** during the first years of operation.

This will be based on the established **KPIs** together with the **as built BIM model** that will outline the results obtained during the operation of the first years.

While in 4RinEU the **BIM strategy** is conceived as the framework or **conductive thread** for the phase's development, **IPD** improves the **contract procedures and responsibilities** of the **stakeholders' involvement from the first stages** of the project and **LEAN optimizes the general process,** mainly during construction, operation and maintenance**, increasing value** for the Client while **reducing material costs.**

The following objectives pursued by IPD, BIM and Lean philosophies should be considered as the **way forward for a 4RinEu-based deep renovation project** while considering the local constraints and regulations.

1. **Integration** of all parties and teams participating **collaboratively** from the first stages of the project with a **clear definition of roles and responsibilities**. This is based on **shared risks and rewards** between all involved parties.
2. **Smooth Coordination** provided by the **CDP and the BIM model** that ensures a successful coordination of all changes and a **collaborative workflow** during the whole process and more specifically from the design, construction until operation and maintenance, controlling the impacts in costs and time duration, while providing a communicative channel between all involved parties.
3. **Targets achievement** by clarifying upfront project schedules, costs and objectives, to integrate all client requirements from the beginning of the project.
4. **Time Control** of the development plan of the project, providing early identification and mitigation of the time deviations.
5. **Cost Control** by early identification and mitigation of the budget deviations, reducing and avoiding modified projects. This is also reached by a complete definition and a defined level of detail and costs necessary for the project, while minimizing the overall risks.
6. **Full integration between project time, costs and final quality.**
7. **Final performance measurement by defined KPIs** aimed to monitor the state of progress of the most relevant aspects in each phase of the project, from inception to operation and maintenance, with a focus on the **energy efficiency measures** considered in each demo site.
8. **Maximize value and reduce material costs (and waste)** at the project delivery level, while **improving the overall performance** of the project.

9. **Pursuit of sustainable developments** based on the decrease of the energy consumption and the reduction of carbon emissions in Deep Renovation projects, while attending the triple bottom line of **environmental, economic and social benefits.**

9. Annex 1. Construction KPIs

The following Construction Phase KPIs are defined to support the supervision of works, with the aim of avoiding 'waste' during the process in alignment with LEAN Construction principles. They can be applied in the context of the 4RinEU Strategy for management of deep renovation implementation, following the recommendations explained in the present document.

The 25 KPIs are sorted in five different areas according to their field of application:

- Health and Safety (**HS**) – 5 KPIs
- Site work logistics (**SWL**) – 3 KPIs
- Budget (**B**) – 4 KPIs
- Productivity – Time management (**PTM**) – 7 KPIs
- Work site sustainability (**WSS**) – 6 KPIs

Some of them can be applied in two different situations:

- Construction site (**CS**)
- Production of premanufactured elements inside workshop (**WS**)

In addition, the following recommendations are suggested to be considered:

- The periodicity of calculation during Construction Phase should be defined by the stakeholders involved, according to works duration and the available resources.
- Some of the indicators are confidential or sensitive data from the construction company, not recommended to be shared.
- It has to be taken into account that to maximize their potential, the calculation of these indicators should be foreseen in the first stages of the project process or at least during Design Phases.

Name[1]			Description	Formula	Units	Periodicity[2]					External Reference
						W	Mo	Mi	Mi-P	EW	
[1]CS = Construction Site; Workshop = WS [2]W = Weekly; M = Monthly; Mi = Milestone ; Mi-P = Milestone payment; EW = End of works											
Health and Safety (HS)											
HS – AR	CS WS	**Accidents rate**	Number of reportable accidents in a period compared to the average number employed in that period	Number of accidents (No.) / Average number of workers (No.)	[-]	x	x	x		x	-
HS – AF	CS WS	**Accidents frequency**	Number of reportable accidents in a period compared to the total site work hours	Number of accidents (No.) / Man*hours (h)	[No. /h]	x	x	x		x	-
HS – AC	CS WS	**Accidents cost**	Direct and indirect costs of accidents in a period compared to the total site work hours	Cost of accidents (€) / Man*hours (h)	[€/h]	x	x	x		x	Partially based on Hany Abd Elshakour et al 2012 [1]
HS – IR	CS WS	**Incidents rate**	Number of reportable incidents in a period compared to the number of workers in a period	Number of incidents (No.) / Number of workers (No.)	[-]	x	x	x		x	Partially based on Hany Abd Elshakour et al 2012 [1]
HS – IF	CS WS	**Incidents frequency**	Number of reportable incidents in a period compared to the total site work hours	Number of incidents (No.) / Man*hours (h)	[No. /h]	x	x	x		x	-
Site Work Logistics (SWL)											
SWL - TO	CS WS	**Transportation optimization**	Total hours of unnecessary movement and handling of goods compared to the total hours of transport	Unnecessary machine hours (h)*100 / Total machine hours (h)	[%]	x	x	x		x	Conceptually based on definitions of O'Connor, R., and Swain, B., 2013 [2]
SWL - IE	CS WS	**Inventory excess**	Total cost of excess of inventory compared to total cost of the works	Cost of inventory excess (€)*100 / Total cost of the works (€)	[%]	x	x	x		x	Conceptually based on definitions of Corfe, c., 2013[3]
SWL - DDI	CS WS	**Delay due to inventory**	Total number of hours of delay due to lack of inventory compared to the total amount of hours of the works	Total number of hours of delay (h)*100 / Total amount of hours of the works (h)	[%]	x	x	x		x	-
Budget (B)											
B - NPM	CS WS	**Net profit margin** (Sensitive data)	Profitability of the construction: Net profit after taxes compared	Net profit (€)*100 / Total revenue (€)	[%]				x	x	Partially based on Hany Abd

			to the total revenue of the works								Elshakour et al 2012 [1]
B - CCF	CS WS	**Change cost factor**	Total cost of changes in works (due to design flaws) compared to the initial budget of the works	Cost of changes (€)*100 / Total initial cost (€)	[%]				x	x	Partially based on Hany Abd Elshakour et al 2012 [1]
B - IRe	CS WS	**Impact of repairs (external)**	Total direct cost of field rework compared to the budget to receive for the works	Cost of repairs (€)*100 / Budget (€)	[%]				x	x	Partially based on Hany Abd Elshakour et al 2012 [1]
PTM-TWD	CS WS	**Impact of repairs (internal)**	Total direct cost of field rework compared to the total cost if there are no repairs	Cost of repairs (€)*100 / (Total cost - Cost of repairs) (€)	[%]				x	x	Partially based on Hany Abd Elshakour et al 2012 [1]
Productivity – Time Management (PTM)											
PTM-TWD	CS WS	**Total works duration**	Duration of all the works of the retrofitting	Duration in working days	[Days]					x	-
PTM-TD	CS WS	**Task duration**	Duration of an specific task of the renovation (Must be measured for each 4RinEU technologies to demonstrate time savings compared to traditional systems) - *Prefabricated multifunctional façade* - *Plug and play Energy Hubs* - *Smart ceiling fan*	Duration in working days Duration in working hours	[Days] [h]			x		x	-
PTM - PDW	CS WS	**Percentage of delivered works by cost**	Cost of the works finished compared to the total cost of the works (Periodic assessment to be compared with the initial planning)	Cost of delivered works (€)*100 / Total cost (€)	[%]	x	x	x		x	Partially based on Forbes, Lincoln H. Modern Construction [5]
PTM - TD	CS WS	**Task delay** (to be measured in the main tasks of the project)	Total number of hours of delay in a specific task compared to the initial planning	Total number of hours of delay in a specific task (h)*100 / Planned duration of the task (h)	[%]	x	x	x		x	Conceptually based on definitions in Corfe, C., 2013 [3]
PTM - WD	CS WS	**Total delay**	Sum of hours of delay for each task compared to the sum of the planned hours for each task	Total number of hours of delay (h)*100 / Planned duration (h)	[%]	x	x	x		x	Conceptually based on definitions in Corfe, C., 2013 [3]

PTM - IR	CS WS	**Time impact of repairs**	Number of hours of repairs compared to the total amount of hours	Time in repairs (h)*100 / Total hours (h)	[%]	x	x	x		x	Conceptually based on definitions in Corfe, C., 2013 [3]
PTM - RP	CS WS	**Re-planning**	Number of times that planning is redone compared to the total duration of the works (in months)	Number of times that planning is redone (No.) / Works duration (months)	[No. / months]					x	-
Work site sustainability (WSS)											
WSS - EC	CS WS	**Electricity consumption**	Total electricity consumption during works compared to the total amount of built-surface	electricity (kWh) / Built-surface (m^2)	[kWh / m^2]	x	x	x		x	-
WSS - OC	CS WS	**Oil consumption**	Total oil consumption during works compared to the total amount of built-surface	Oil (liters) / Built-surface (m^2)	[liters / m^2]	x	x	x		x	-
WSS - WC	CS WS	**Water consumption**	Total water consumption during works compared to the total amount of built-surface	Water (m^3) / built-surface (m^2)	[m^3 / m^2]	x	x	x		x	-
WSS - LR	CS WS	**Landfill rate**	Total weight of material sent to landfill compared to the total amount of built-surface	Landfill waste (Tn) / Built-surface (m^2)	[Tn / m^2]	x	x	x		x	-
WSS - RCR	CS WS WS	**Recycling rate**	Total weight of material sent to recycling plant compared to the total amount of built-surface	Recycled waste (Tn) / Built-surface (m^2)	[Tn / m^2]	x	x	x		x	-
WSS - RUR	CS WS	**Re-using rate**	Total weight of material reused in the works compared to the total amount of built-surface	Reused material (Tn) / Built-surface (m^2)	[Tn / m^2]	x	x	x		x	Partially based on Summerson, S. et al [4]

[1] Hany Abd Elshakour M. Ali, Ibrahim A. Al-Sulaihi, Khalid S. Al-Gahtani. (2012). *Indicators for measuring performance of building construction companies in Kingdom of Saudi Arabia*. Civil Engineering Department, College of Engineering, King Saud University, Saudi Arabia.

[2] O'Connor, R., and Swain, B. (2013). *Implementing Lean in construction: Lean tools and techniques – an introduction*. CIRIA, C730. London.

[3] Corfe, C. (2013). *Implementing lean in construction: Lean and the sustainability agenda*. CIRIA, C726. London.

[4] Summerson, S., Atkins, J., Harriers, A. BREEAM In-Use. *Driving sustainability through existing buildings*. Briefing paper. United Kingdom.

[5] Forbes, Lincoln H. Modern Construction*: Lean Project Delivery and Integrated Practices / Lincoln* H. Forbes, Syed M

10. References

AIA Contract Documents. The Industry Standard. (2015). *AIA Contract Documents. Contract relationship Diagrams*.

AIA Document C191™ - 2009. (2009). *Standard Form Multi-party Agreement for Integrated Project Delivery.*

AIA. (2007). *Integrated Project Delivery: A Guide*.

Ballard, G. (2000). *Lean Project Delivery* System. LCI White Paper-8. Lean Construction Institute.

Ballard, G. (2000). *The Last Planner System of Production Control*. Schoold of Civil Engineering. Faculty of Engineering. The University of Birmingham.

Bhargav, D., Koskela, L., Kiviniemi, A., Tzortzopoulos, P., Owen, R. (2013). *Implementing Lean in construction. Lean construction and BIM.* CIRIA, C725. University of Salford, Queensland University of technology, London, UK.

Bhargav, D., Koskela, L., Kiviniemi, A., Tzortzopoulos, P., Owen, R. (2013). *Implementing Lean in construction. Lean construction and BIM.* CIRIA, C725. University of Salford, Queensland University of technology, London, UK.

buildingSMART. *¿Qué es BIM?* Available at: https://www.buildingsmart.es/bim/qu%C3%A9-es/

Construction Management Association of America (CMAA). (2012). *An Owner's Guide To Project Delivery Methods*.

ConsensusDocs 300. *Standard form of tri-party agreement for collaborative project delivery.*

Corfe, C. (2013). *Implementing lean in construction: Lean and the sustainability agenda*. CIRIA, C726. London.

espacio BIM. (2017). EIR o Employer’s Information Requirements. https://www.espaciobim.com/eir-employers-information-requirements/

Forbes, Lincoln H. Modern Construction*: Lean Project Delivery and Integrated Practices / Lincoln* H. Forbes, Syed M.

Ghassemi, R., Becerik-Gerber, B. (2011). *Transitioning to Integrated Project Delivery: Potential barriers and Lessons Learned*. Lean Construction Hournal 2011 pp32-52.

Hany Abd Elshakour M. Ali, Ibrahim A. Al-Sulaihi, Khalid S. Al-Gahtani. (2012). *Indicators for measuring performance of building construction companies in Kingdom of Saudi Arabia*. Civil Engineering Department, College of Engineering, King Saud University, Saudi Arabia.

Howell, Gregory A. (1999). *What is Lean Contruction*. 26-28 July 1999, University of California, Berkeley, CA, USA.

MBIMS. (2007). Available at http://www.wbdg.org/pdfs/NBIMSv1_p1.pdf

O’Connor, R., and Swain, B. (2013). *Implementing Lean in construction: Lean tools and techniques – an introduction*. CIRIA, C730. London.

PAS1192-2:2013. *Specification for information management for the capital/delivery phase of construction projects using building information modelling.* The British Standards Institution (BSI).

Pons Achell, Juan Felipe. (2014). *Introducción a Lean construction*. Fundación Laboral de la Construcción.

Summerson, S., Atkins, J., Harriers, A. BREEAM In-Use. *Driving sustainability through existing buildings*. Briefing paper. United Kingdom.

The Computer Integrated Construction (CIC) Research Group of The Pennsylvania State University. (2010). *BIM Project Execution Planning Guide*. Version 2.0. buildingSMART alliance™ (bSa) Project. Available at: http://www.engr.psu.edu/BIM/PxP. Licensed under the Creative Commons Attribution-Share Alike 3.0 United States License.

U.S. Department of Energy. (2012). *How to guide for Energy-performance-based Procurement. An Integrated Approach for Whole Building High Performance Specifications in Commercial Buildings.* Building Technologies Program. Energy Efficiency & Renewable Energy.

Womack, J., Jones, D., (1996). *Lean Thinking: Cómo utilizar el pensamiento lean para eliminar los despericios y crear valor en la empresa.* Free Press.