POLITECNICO DI TORINO

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From BIM to Digital Twin: IoT based decision Support System for Facility Management

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"No problem is too small. Whatever good deed you do in the world, whatever it's helping someone on your block, or I don't know…throwing some elaborate dinner party for your friends. You are just as much of a hero as you are fighting a war.

EVERY. ACT.MATTERS."

To all my heroes

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Abstract

The subject of maintenance in Italy is a very delicate one that has always presented many critical issues. Despite the importance of maintenance in the life cycle of a building, it is often neglected to the detriment of internal well-being, the durability of the building itself and of the systems in terms of performance. A critical step is the handover between the design phase and the use and management phase. These two phases are continually thought of as two distinct and separate phases with the consequence of a great loss of data. Moreover, in recent decades, the construction world has undergone great transformations thanks to the advent of new technologies and the introduction of IoT sensors, BIM models, digital twins in this field. These technologies are increasing their application also in the maintenance phase that allow a continuous control and monitoring of data defining this type of maintenance a maintenance 4.0.

This thesis aims to identify the information flow that optimises the maintenance process of a fan coil system. This process is managed through IoT sensors and the BIM model of the environments. Thanks to the sensors it is possible to detect different types of faults and allow targeted and immediate interventions. This extends the lifecycle of the plant itself and enables reasoned decisions to be made, reducing maintenance costs. In addition, data collection makes it possible to plan intervention strategies based on the true trend of the data, allowing the optimisation of resources in terms of personnel and material.

In order to identify the necessary information, an initial analysis of the state of the art of maintenance management was carried out, linking IoT, BIM and the entire facility management. In a second phase, all phases of a building process were analysed in detail, all stakeholders to identify an information flow that eliminates data loss.

Finally, all the information identified was channelled onto a single platform and dashboards were created according to the stakeholders to facilitate maintenance management and the exchange of information, emphasising that maintenance includes a decision-making phase (e.g. who does what and when) and a technical design phase (how to intervene in the event of a fault).

Sommario

Il tema della manutenzione in Italia è un tema molto delicato che presenta da sempre molte criticità. Nonostante l'importanza della manutenzione nel ciclo di vita di un edificio, essa viene spesso trascurata a discapito del benessere interno, della durabilità dell'edificio stesso e degli impianti in termini di prestazioni. Un passaggio critico si rileva nel passaggio di consegne tra la fase di progettazione e quella dell'uso e di gestione. Queste due fasi sono continuamente pensate come due fasi distinte e separate tra di loro con la conseguenza di una grande perdita di dati. Inoltre, negli ultimi decenni, il mondo delle costruzioni ha subito grandi trasformazioni grazie all'avvento di nuove tecnologie e all'introduzione in questo campo della sensoristica IoT, dei modelli BIM, dei gemelli digitali. Queste tecnologie stanno aumentando la propria applicazione anche nella fase manutentiva che consentono un controllo e un monitoraggio continuo dei dati definendo questo tipo di manutenzione una manutenzione 4.0.

La presente tesi ha lo scopo di individuare il flusso informativo che ottimizza il processo manutentivo di un impianto di fancoil. Tale processo è gestito attraverso i sensori dell'IoT e il modello BIM degli ambienti. Grazie ai sensori è possibile rilevare diverse tipologie di guasti e consentendo degli interventi mirati e immediati. Ciò consente di allungare il ciclo di vita dell'impianto stesso e di prendere decisioni ragionate, diminuendo i costi relativi alla manutenzione. Inoltre, grazie alla raccolta dati è possibile programmare delle strategie di intervento basate sul vero andamento dei dati consentendo l'ottimizzazione delle risorse in termini di personale e materiale.

Al fine di individuare le informazioni necessarie, si è proceduto ad una prima analisi sullo stato dell'arte della gestione delle manutenzioni legando IoT, BIM e la tutta la gestione del facility. In una seconda fase, si sono analizzate in dettaglio tutte le fasi di un processo edilizio, tutti gli stakeholder per individuare un flusso informativo che elimini la perdita di dati.

Infine, tutte le informazioni individuate sono state fatte convogliare su un'unica piattaforma e in funzione degli stakeholders si sono create delle dashboard per favorire la gestione della manutenzione e lo scambio di informazioni sottolineando come la manutenzione racchiude in se una fase decisionale (ad esempio chi fa cosa e le tempistiche) e di progettazione tecnica (come intervenire nel caso di un guasto).

Acknowledgements

Before proceeding with my thesis, I would like to dedicate a few lines to all those who have been close to me in this journey of personal and professional growth.

A sincere thank you to Prof. Paolo Piantanida and Ing. Khurshid Aliev for their availability and for providing me, together with my supervisor Valentina Villa, with all the material I needed to write my thesis.

I would especially like to thank all the people who have been my safe haven over the last two years. This achievement is also thanks to you. Without your presence, your support and your love I would not be where I am.
Although I no longer have some of the dearest and most important people close to me, I have a hundred others who are just as important as those who left too soon.

A special thanks goes to my whole family for simply being my family and for loving me always and in any case. You are the heroes I admire most.
Thanks to mum, dad, Valeria, grandma Assunta and grandma Loreta, grandpa Pasquale and grandpa Augusto, my cousins Laura, Paolo, Elisa and Alessandro, aunt Rosaria, uncle Roberto and uncle Massimo, Simona, Vittorio, Elisa and Daniela.

A special dedication goes to my father, my grandparents (Augusto, Pasquale and Assunta) and Aunt Rosaria. Thanks to you I certainly know that love crosses all borders, even the most distant. With you, I have crossed the sky.

Thanks to Francesca, Maria Cristina, Loreta, Roberta, Vicenza, Nicola, Sandro, Amedeo, Antonella, Andrea, Patrizia, Eliana and Valentina for everything you have done for me, or for my sister and my mother. Words are not enough to show my gratitude to you. You will always have a special place in my heart.

In addition, a special thanks goes to my therapist because with her I was able to overcome one of the darkest moments of my life, to accept myself with all my imperfections, but above all I learned that sometimes it is ok not to be ok.

Finally, I thank all the people not mentioned above who made me smile, rejoice or who were simply there for me (even for a minute) when I needed them most. Thanks to Antonella, Elisa, Iliana, Martina, Daniela, Diego, Laura, Chiara, Catia, Pasquale, Francesca, Luca, Leonardo, Dario, Cristina, Alessia, Francesco, Patrizia P., Simona e Luigi.

I am very lucky to have all of you in my life.
Thanks again to everyone.

1. Introduction

As a result to the advent of digitalization and a wide diffusion of digital products, also industries and companies belonging to the construction world are showing a growing interest in the fully automated and interconnected industrial production.

This literature review shows how the Industry 4.0 philosophy has influenced the Architecture, Engineering, Construction and Operation (AECO) sector, in particular, the focus will be on facility management (FM) and its integration with BIM, Internet of Things (IoT) and Digital Twin (DT) technologies.

The purpose of this study is:

- to identify the current state of research, the objectives achieved and those to be pursued;
- to identify the research done on BIM, IoT and BIM-IoT integration for facility management.

The research was carried out on two digital peer-review data: Scopus and ResearchGate in which it was possible to identify the most relevant academic publications with the set objectives.

On the Scopus database, the research methodology was to first identify the keywords to be included in the database according to the topic. These words were "BIM", "Building Information Modeling", "IoT", "Internet of things", "Digital Twin", "DT", "Facility Management", "FM", "Integration of BIM-IoT", "Integration of BIM-FM", "Integration of BIM-DT", "Integration of BIM-IoT-DT for FM", "Integration of FM-DT". The next step was to choose: the year, the article type, publication title and subject area: Engineering.

The time frame identified is between 2016 and 2021. Research published before 2016 was automatically eliminated.

The publication types to choose from were:

- Review articles
- Research articles
- Encyclopaedia
- Book chapters
- Conference abstracts
- Book reviews
- Case reports
- Conference info
- Correspondence
- Data articles
- Discussion
- Editorials
- Errata

- Mini reviews
- News
- Patent reports
- Product reviews
- Short communications
- Software publications
- Others

But to further reduce the field of analysis, the publications that were not discarded and therefore studied are:

- Review articles
- Research articles
- Book chapters
- Conference abstracts
- Book reviews
- Case reports
- Conference info

In addition, four publication titles were identified that I felt were most relevant to the subject matter. However, in some cases and for some keywords, it was necessary to identify other alternative titles because in those selected there were no publications or they were of a very small number.

The publication titles select are:

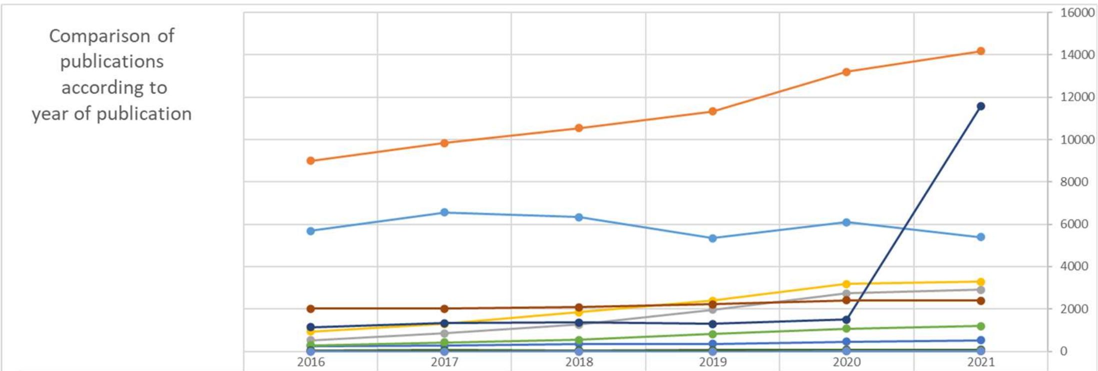
- Automation in Construction
- Energy and Buildings
- Journal of Building Engineering
- Building and Environment

The tables and graphs below show the results obtained in the research field "construction", broken down by year of publication, type of article and publication title. This type of analysis was carried out to highlight the general trend depending on the topic. In fact, these data are important to get a very general picture of the research being done.

The trend is also useful to understand the reasons for the results that have been achieved and what should be the next step in future studies, which aspects should be deepened or which have been deepened enough.

Number of publication								
KEY WORD	YEAR		KEY WORD	YEAR		KEY WORD	YEAR	
BIM	2021	528	DT	2021	5398	Integration of BIM-IoT	2021	85
	2020	460		2020	6099		2020	84
	2019	354		2019	5342		2019	43
	2018	352		2018	6342		2018	21
	2017	269		2017	6564		2017	15
	2016	249		2016	5688		2016	7
	YEAR			YEAR			YEAR	
Building Information Modeling	2021	14182	Digital Twin	2021	1194	Integration of BIM-FM	2021	36
	2020	13201		2020	1071		2020	36
	2019	11332		2019	815		2019	27
	2018	10547		2018	537		2018	33
	2017	9841		2017	426		2017	30
	2016	8992		2016	283		2016	25
	YEAR			YEAR			YEAR	
IoT	2021	2910	FM	2021	11568	Integration of BIM-DT	2021	31
	2020	2732		2020	1498		2020	30
	2019	1961		2019	1304		2019	10
	2018	1260		2018	1365		2018	7
	2017	858		2017	1338		2017	10
	2016	526		2016	1141		2016	5
	YEAR			YEAR			YEAR	
Internet of things	2021	3285	Facility Management	2021	2396	Integration of FM-DT	2021	57
	2020	3185		2020	2411		2020	59
	2019	2398		2019	2230		2019	54
	2018	1847		2018	2079		2018	51
	2017	1294		2017	2019		2017	62
	2016	935		2016	2015		2016	46
							YEAR	
						Integration of BIM-IoT-DT for FM	2021	2
							2020	3
							2019	0
							2018	1
							2017	0
							2016	1

Figure 1:Number of publication table



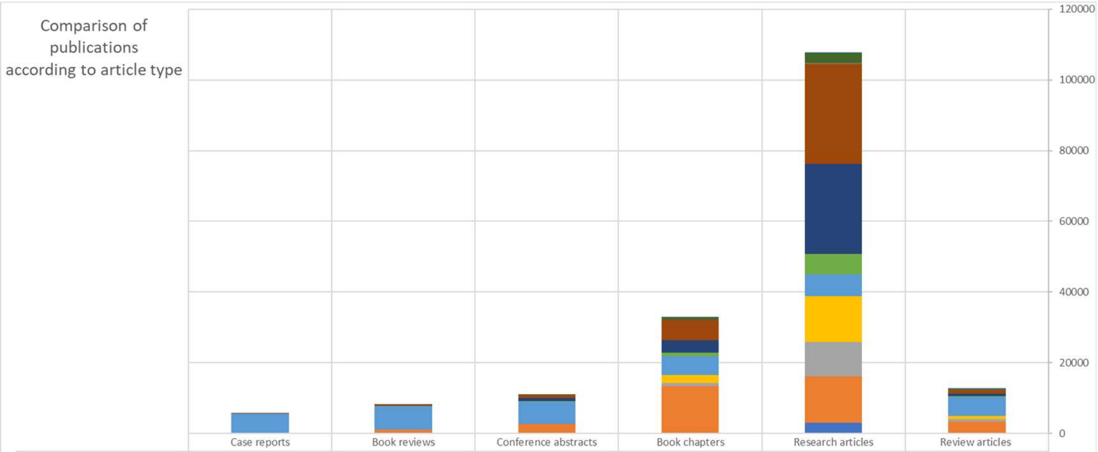
	2016	2017	2018	2019	2020	2021
BIM	249	269	352	354	460	528
Building Information Modeling	8992	9841	10547	11332	13201	14182
IoT	526	858	1260	1961	2732	2910
Internet of things	935	1294	1847	2398	3185	3285
DT	5688	6564	6342	5342	6099	5398
Digital Twin	283	426	537	815	1071	1194
FM	1141	1338	1365	1304	1498	11568
Facility Management	2015	2019	2079	2230	2411	2396
Integration of BIM-IoT	7	15	21	43	84	85
Integration of BIM-FM	25	30	33	27	36	36
Integration of BIM-DT	5	10	7	10	30	31
Integration of FM-DT	46	62	51	54	59	57
Integration of BIM-IoT-DT for FM	1	0	1	0	3	2

Figure 2:Number of publications comparative graph

Based on the selected filters, it can be seen that since 2016 there is a general upward trend in publications. The topic of BIM is the most analysed, but this is understandable as it is a topic that has been studied since 1974 and for this reason the research fields have expanded exponentially in recent decades increasing the potential of this tool and the field of application, not only that of construction.
On the other hand, the issue of facility management has grown rapidly in recent years. This can also be traced back to the current health emergency that has forced people to stay physically in their homes and has forced them to pay a lot of attention to the quality of the environment in which they find themselves (from the office to their homes). A lot of research has been done in order to improve well-being by trying to optimise resources.
Publications on the digital twin have a fluctuating trend with a slight decrease between 2020 and 2021. During the research, however, an increase in health-related publications on DT, such as remote interventions, was noted. This factor can also be traced back to the current health emergency.
The remaining publications have a similar and constant trend. In fact, it should be noted that few studies have been done on the integration between the different tools, certainly integration is one of the most complicated and difficult aspects.

Number of article type								
KEY WORD	ARTICLE TYPE		KEY WORD	ARTICLE TYPE		KEY WORD	ARTICLE TYPE	
BIM	Review articles	232	DT	Review articles	1338	Integration of BIM-IoT	Review articles	60
	Research articles	3093		Research articles	130936		Research articles	184
	Book chapters	183		Book chapters	91		Book chapters	13
	Conference abstracts	61		Conference abstracts	2944		Conference abstracts	0
	Book reviews	5		Book reviews	74		Book reviews	0
	Case reports	3		Case reports	4		Case reports	0
Building Information Modeling	ARTICLE TYPE		Digital Twin	ARTICLE TYPE		Integration of BIM-FM	ARTICLE TYPE	
	Review articles	3201		Review articles	263		Review articles	38
	Research articles	13084		Research articles	5908		Research articles	243
	Book chapters	13136		Book chapters	983		Book chapters	14
	Conference abstracts	2590		Conference abstracts	115		Conference abstracts	0
	Book reviews	1096		Book reviews	11		Book reviews	0
	Case reports	22		Case reports	0		Case reports	0
IoT	ARTICLE TYPE		FM	ARTICLE TYPE		Integration of BIM-DT	ARTICLE TYPE	
	Review articles	691		Review articles	633		Review articles	16
	Research articles	9618		Research articles	25426		Research articles	147
	Book chapters	944		Book chapters	3570		Book chapters	24
	Conference abstracts	67		Conference abstracts	839		Conference abstracts	0
	Book reviews	5		Book reviews	52		Book reviews	0
	Case reports	1		Case reports	3		Case reports	0
Internet of things	ARTICLE TYPE		Facility Management	ARTICLE TYPE		Integration of FM-DT	ARTICLE TYPE	
	Review articles	3285		Review articles	1133		Review articles	65
	Research articles	3185		Research articles	28093		Research articles	2654
	Book chapters	2398		Book chapters	5685		Book chapters	649
	Conference abstracts	1847		Conference abstracts	957		Conference abstracts	25
	Book reviews	1294		Book reviews	261		Book reviews	1
	Case reports	935		Case reports	15		Case reports	0
						Integration of BIM-IoT-DT for FM	ARTICLE TYPE	
							Review articles	4
							Research articles	2
							Book chapters	1
							Conference abstracts	0
							Book reviews	0
							Case reports	0

Figure 3:Article type table



	Case reports	Book reviews	Conference abstracts	Book chapters	Research articles	Review articles
Integration of BIM-IoT-DT for FM	0	0	0	1	2	4
Integration of FM-DT	0	1	25	649	2654	65
Integration of BIM-DT	0	0	0	14	243	38
Integration of BIM-FM	0	0	0	14	243	38
Integration of BIM-IoT	0	0	0	13	184	60
Facility Management	15	261	957	5685	28093	1133
FM	3	52	839	3570	25426	633
Digital Twin	0	11	115	983	5908	263
DT	5688	6564	6342	5342	6099	5398
Internet of things	2	45	6	2278	13033	845
IoT	1	5	67	944	9618	691
Building Information Modeling	22	1096	2590	13136	13084	3201
BIM	3	5	61	183	3093	232

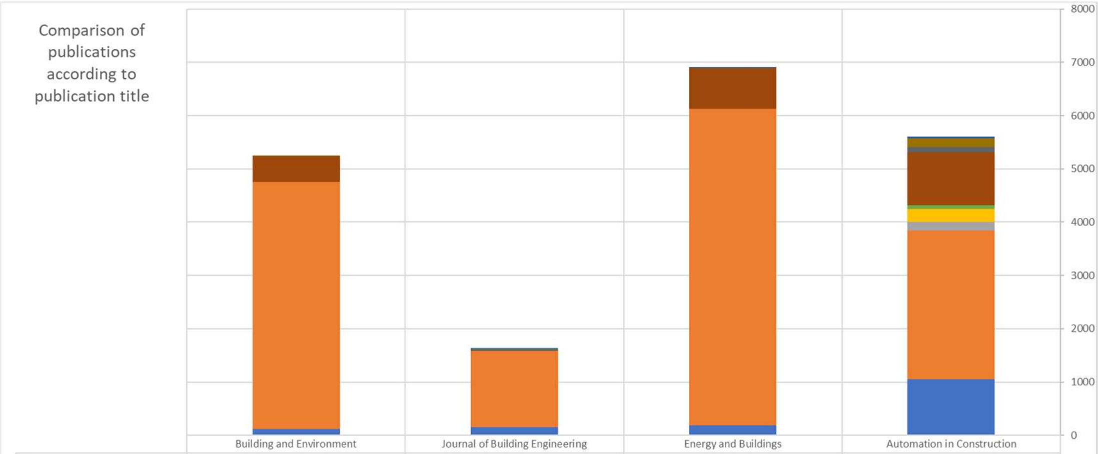
Figure 4: Kinds of Article comparative graph

The graph shows that the largest publications are related to research.

This trend is understandable as many of the aspects related to BIM, IoT, FM and DT are to be studied.

Number of publication title								
KEY WORD	ARTICLE TYPE		KEY WORD	ARTICLE TYPE		KEY WORD	ARTICLE TYPE	
BIM	Automation in Construction	1054	DT	Automation in Construction	0	Integration of BIM-IoT	Automation in Construction	106
	Energy and Buildings	185		Energy and Buildings	0		Energy and Buildings	10
	Journal of Building Engineering	157		Journal of Building Engineering	0		Journal of Building Engineering	23
	Building and Environment	115		Building and Environment	0		Building and Environment	6
Building Information Modeling	ARTICLE TYPE		Digital Twin	ARTICLE TYPE		Integration of BIM-FM	ARTICLE TYPE	
	Automation in Construction	2791		Automation in Construction	73		Automation in Construction	157
	Energy and Buildings	5940		Energy and Buildings	0		Energy and Buildings	4
	Journal of Building Engineering	1422		Journal of Building Engineering	0		Journal of Building Engineering	21
	Building and Environment	4637		Building and Environment	0		Building and Environment	5
IoT	ARTICLE TYPE		FM	ARTICLE TYPE		Integration of BIM-DT	ARTICLE TYPE	
	Automation in Construction	161		Automation in Construction	0		Automation in Construction	28
	Energy and Buildings	0		Energy and Buildings	0		Energy and Buildings	8
	Journal of Building Engineering	0		Journal of Building Engineering	0		Journal of Building Engineering	5
	Building and Environment	0		Building and Environment	0		Building and Environment	0
Internet of things	ARTICLE TYPE		Facility Management	ARTICLE TYPE		Integration of FM-DT	ARTICLE TYPE	
	Automation in Construction	241		Automation in Construction	990		Automation in Construction	0
	Energy and Buildings	0		Energy and Buildings	763		Energy and Buildings	0
	Journal of Building Engineering	0		Journal of Building Engineering	0		Journal of Building Engineering	0
	Building and Environment	0		Building and Environment	482		Building and Environment	0
						Integration of BIM-IoT-DT for FM	ARTICLE TYPE	
							Automation in Construction	3
							Energy and Buildings	0
							Journal of Building Engineering	1
							Building and Environment	0

Figure 5: Publication title table



	Building and Environment	Journal of Building Engineering	Energy and Buildings	Automation in Construction
Integration of BIM-IoT-DT for FM	0	1	0	3
Integration of FM-DT	0	0	0	0
Integration of BIM-DT	0	5	8	28
Integration of BIM-FM	5	21	4	157
Integration of BIM-IoT	6	23	10	106
Facility Management	482	0	763	990
FM	0	0	0	0
Digital Twin	0	0	0	73
DT	0	0	0	0
Internet of things	0	0	0	241
IoT	0	0	0	161
Building Information Modeling	4637	1422	5940	2791
BIM	115	157	185	1054

Figure 6:Publication title comparative graph

On the other hand, this graph shows that in the world of construction the most discussed and studied topic is that of BIM and that there is little research on IoT sensors and digital twins in the field of construction and that these are aspects that have yet to be explored in depth. Where there were topics not covered in the selected publications, the searches moved on to other titles, which were analysed on a case-by-case basis and according to their relevance to the research aims.

The next step was to identify publications that were relevant to the research and could be downloaded.

The search method on ResearchGate database was simpler because it was only necessary to insert the topic and based on the publications, I chose the most relevant and downloadable ones.

All selected publications were assigned a WBS code. The code consists of a sequential number (depending on which article I studied first), the topic covered and the year of publication. Articles that have "Example" and "Sensors" in the code are respectively articles that are based on a case study that spans topics and articles that are based on very specific topics. In addition, there are some articles relating to years prior to 2016, this has been done for greater clarity of the subject matter.

Below is a table of the articles studied. In addition to this study, further siteographic research was carried out in order to gain a more in-depth understanding of the various topics covered.

Progressive	Topic	Year	Code	Progressive	Topic	Year	Code
1	_BIM_	2020	1_BIM_2020	32	_ESEMPIO_	2021	32_ESEMPIO_2021
2	_BIM_	2021	2_BIM_2021	33	_ESEMPIO_	2020	33_ESEMPIO_2020
3	_BIM_	2019	3_BIM_2019	34	_BIM_	2015	34_BIM_2015
4	_BIM FM_	2019	4_BIM FM_2019	35	_FM_	2017	35_FM_2017
5	_BIM IoT_	2018	5_BIM IoT_2018	36	_BIM_	-	36_BIM_-
6	_BIM_	2017	6_BIM_2017	37	_BIM_	2017	37_BIM_2017
7	_BIM_	2018	7_BIM_2018	38	_ESEMPIO_	2020	38_ESEMPIO_2020
8	_DT_	2021	8_DT_2021	39	_BIM_	2019	39_BIM_2019
9	_DT IoT_	2021	9_DT IoT_2021	40	_ESEMPIO_	2015	40_ESEMPIO_2015
10	_DT_	2020	10_DT_2020	41	_BIM FM_	2020	41_BIM FM_2020
11	_DT_	2019	11_DT_2019	42	_BIM_	2020	42_BIM_2020
12	_DT_	-	12_DT_-	43	_FM_	2014	43_FM_2014
13	_DT_	2020	13_DT_2020	44	_FM_	2008	44_FM_2008
14	_DT_	2019	14_DT_2019	45	_SENSORI_	2015	45_SENSORI_2015
15	_DT_	2019	15_DT_2019	46	_FM_	2020	46_FM_2020
16	_DT_	2019	16_DT_2019	47	_FM DT_	2021	47_FM DT_2021
17	_BIM FM IoT_	2021	17_BIM FM IoT_2021	48	_FM DT_	2018	48_FM DT_2018
18	_BIM FM_	2020	18_BIM FM_2020	49	_FM IoT_	2019	49_FM IoT_2019
19	_FM_	2020	19_FM_2020	50	_BIM_	2021	50_BIM_2021
20	_BIM FM_	2017	20_BIM FM_2017	51	_BIM_	2021	51_BIM_2021
21	_BIM IoT_	2020	21_BIM IoT_2020	52	_FM DT_	2020	52_FM DT_2020
22	_BIM_FM_	2017	22_BIM_FM_2017	53	_FM_	2012	53_FM_2012
23	_IoT_	2021	23_IoT_2021	54	_FM_	2015	54_FM_2015
24	_IoT_	2021	24_IoT_2021	55	_BIM FM_	2016	55_BIM FM_2016
25	_IoT_	2021	25_IoT_2021	56	_FM_	2015	56_FM_2015
26	_IoT_	2021	26_IoT_2021	57	_BIM FM_	2020	57_BIM FM_2020
27	_IoT_	2021	27_IoT_2021	58	_IoT DT_	2021	58_IoT DT_2021
28	_IoT_	2021	28_IoT_2021	59	_IoT BIM FM_	2021	59_IoT BIM FM_2021
29	_IoT_	2021	29_IoT_2021	60	_IoT_	2020	60_IoT_2020
30	_BIM IoT_	2018	30_BIM IoT_2018	61	_IoT_	2021	61_IoT_2021
31	_BIM_	2017	31_BIM_2017	62	_IoT_	2022	62_IoT_2022

Figure 7: WBS code of the article cite

The following state of the art has been structured in four separate sections, each dealing with a specific topic in order to obtain an overview of the individual topic. Following this, there is a section focusing on facility management and its integration with BIM, IoT and DT.

1. 1 Building Information Modelling (BIM)

The Building Information Modelling (BIM) is a method for optimizing the planning, realization, and management of buildings with the help of software. All relevant data of a building can be collected, combined and linked digitally.

The idea of a 3D modelling was born in 1974 in a publication by Charles M. Eastman concerning research developed at Carnegie-Mellon University in Pittsburgh (USA), entitled *"An outline of the building descriptive system"*. Eastman illustrated an *"outline of the building description system"* that he obtained through the aggregation of 3D graphic elements capable of containing geometric, materials, etc. information.

The potential of BIM lies in five keywords:

- *Interoperability*: an exchange of information between the various professional figures and beyond (from the designer to the end user);

- *Multidisciplinary*: the possibility to work with different disciplines in a single model (integrated design);

- *Speed*: the rapidity of reading the necessary information in every phase of the process (from design to management);

- *Transparency*: all the information of the building are in a single model and are available to all;

- *Sustainability*: one of the consequences of an integrated design is to allow productivity and better management of the work itself.

Due to this potential, BIM is no longer considered only as a three-dimensional design, but its application fields have increased in the last five years. For example, Zhang et al. [1] investigated a possible use of BIM for Smart Built Environments (SBEs) by creating a useful tool to detect defects in SBEs. Designing SBEs with BIM is advantageous for two reasons. Firstly, from the knowledge of the building model it is possible to define the layouts of sensors. Secondly, BIM is a database of the physical information of smart objects.

Additionally, [2] presents one possible use of the BIM model for the evaluation of holistic renovation scenarios with the goal of decreasing decision time and improving the accuracy and the precision of the project.

Instead, there have been studies investigating the integration of BIM with sensors. For example, Liu and Deng [3] developed a method, integrating BIM and sensors, to create a sustainable construction design. Secondly, Rasmussen et al. [4] showed the potential of the integration of Building Information Modelling and Sensor Observations using Semantic Web. They affirmed that future research should focus on *"dedicated tools for assisting in modelling the sensors and actuators in their context of the building, the control strategies, thermal simulations etc."*

Furthermore, the research of Riaz et al. [5] aims to *"investigate the integration of real-time monitoring of thermal conditions within confined work environments through wireless sensor network (WSN) technology when integrated with building information modelling (BIM)."*

They have illustrated that the choice of database needs to be based on four factors:

- system architecture.
- ability to communicate at very high data exchange rates.
- performance at high data rate.
- hold extremely large data amounts.

Lastly, [6] demonstrated a BIM-sensor integrated for the maintenance management of piping in building MEP systems. In fact, Jing et al. have developed a platform that can "*link the digital modelling with sensor-based data monitoring and collection to achieve high efficient maintenance for MEP systems* and *provide services including* *access, extract, storage, sharing and update of historic maintenance information about building piping."* [6]

Whitlock et al. [7] studied a method to apply the BIM methodology to the Construction Logistics Management (CLM) demonstrating several improvements in site safety, comprehension of logistics information, efficiency on site, and effectiveness of layout planning.

Zhang and Jia [8] proposed a dynamic BIM model for construction material recycling. This research, conducted in China, led to the determination that the use of the BIM-based model reduced waste and increased the use of recyclable materials. According to them, *"more efficient construction and demolition waste (CDW) management and minimization can be achieved through BIM."*

One of the challenges in this field is to integrate a BIM model with real-time data and its processing, Alves et al. [9] proposed a language named Building Information Modelling Sensor Language (BIMSL) that manages to process data despite the complexities of a BIM model and Johansson et al. [10] showed a prototype BIM viewer that allow the real-time visualization of large and complex building models.

Future studies should focus on improving the interoperability of a BIM model [11] through doing file formats (such as IFC) and real-time data processing.

1. 2 Internet of things (IoT)

The Internet of Things (IoT) is a technology that maximizes the ability to collect and use data from a multitude of sources in order to improve the digitization and automation of processes.

The concepts behind this technology were developed in 1982, by researchers at Carnegie Mellon University who applied sensors and a network connection to a soda dispenser at the University to test its operation.

The concepts of the Internet of Things formed the foundation for the first developments of radio frequency identification (RFID) technology, designed to facilitate the management of objects by computers. Its use is eventually extended to any object capable of interacting in a network, thus participating in the creation of a digitized, flexible and intelligent process.

Strous et al. [12] provide the following definition:

"The Internet of Things (IoT) is the inter-networking of physical devices (also referred to as "thing", "object", "connected devices" or "smart devices") such as vehicles, buildings, and other items such as home appliances embedded with electronics, software, sensors, actuators, and network connectivity, which enable these devices to collect and exchange data and interact with others over the Internet, possibly for remote monitoring and control."

The Internet of Things benefits from developments that enable digital and communication capabilities in various devices, leveraging standard platforms such as

Arduino or Raspberry, Wi-Fi, Bluetooth or ZigBee (another wireless communication standard), networks depending on the local processing power required, amount of data to be transferred, distance or energy limitations (e.g. in battery-powered IoT sensors).

Depending on the IoT applications may require the use of Edge Computing [13], to perform aggregation and real time processing of data. Although Edge computing improves IoT systems, Ashouri et al. [13] have identified shortcomings that need to be investigated such as metrics for the less measured quality or the trade-off handling. And then for the interaction with cloud services capable of performing sophisticated analysis on big data, machine learning and appropriate frameworks and middleware software.

Although the application areas of IoT are multiple, the architecture has a recurring structure. The IoT consists of five fundamental elements described below. [14]

The visible and integrated component in the environment is constituted by the sensors (first element), i.e. the terminals of the system. They have the function of continuously monitoring and acquiring various parameters (such as temperature or the presence of people) or performing actions based on instructions received (e.g. open windows).

The sensors interface with the network (second element), which is the connection structure and has the function of linking. These networks transfer data to the cloud (third element), which has the task of collecting and storing such data.

Within the cloud, resides the core of the IoT framework: the algorithms (fourth element). They have the fundamental function of carrying out the computational and decision-making processes in order to achieve the goals set for the system. Finally, once the analyses have been sent to the actuators to be executed, they are shown in the user interfaces (fifth element) in the form of results to allow the user to make decisions according to the detected environmental state.

These elements can be included in three levels of operation [15]:

- Physical layer;
- Cloud layer;
- Communication layer;
- Service layer.

The physical layer consists of the sensors and actuators that collect data and information from the physical world, leveraging different technologies, such as video cameras, GPS, and wireless sensor networks (WSNs).

The cloud layer includes all technologies such as computing, database and big data processing. In this layer data is collected and analysed.

However, the functions of processing and transmission of data are carried out by the communication layer, also known as the network layer. There are many wireless technologies (e.g. Wi-Fi, Bluetooth, RFID) and numerous communication protocols (such as IPV6, MQTT, HTTP, ZigBee) that allow monitoring and control of the environment under examination.

The last layer, namely the service layer, has the task of showing the results of the analysis to the users through an easy to interpret interface.

IoT technology has had a big expansion as it can be adopted in many fields of application. [16] One of the areas in which this technology has been able to expand rapidly is that of security and safety. In fact, IoT makes it possible to improve the quality of services by connecting the supervisory elements.

The Industrial Internet of Things (IIoT) has been defined in the manufacturing sector. IoT devices are designed to operate exclusively from the perspective of Industry 4.0 and to aim at optimising production processes.

Espinoza et al. [17] studied the impact of IoT on productivity in Europe. They confirmed that "*from the producer perspective, the IoT stimulates productivity and economic growth in general as the IoT technology offers the possibility to transform agriculture, industry, and energy production and distribution by increasing the availability of information along the value chain of production using networked sensors.*"

Other areas that are including IoT applications are those related to smart health for remote patient monitoring [18], to smart farming with the inclusion of smart sensors for the monitoring of climatic conditions and zootechnics for the monitoring of farm animals.

Although, in recent years, there have been great margins for improvement and an increase in the use of these systems, one of the issues of greatest interest and importance concerns the security of data and privacy of users. [18] In fact, it is not to be underestimated the aspects related to the protection of the entire structure by identifying the weak points of this structure that could facilitate external intrusions, giving space to the so-called cyber crime.

One of the weaknesses in information security, is the human factor. In fact, one of the main goals that should be targeted with IoT deployment is to make people aware of IoT technologies in the environment. [19]

IoT technology has expanded its applications within the built environment, one among them is the connection between BIM and IoT. [20] Using IoT devices to serve a BIM process amplifies its efficiency, and the uses can be varied, from predictive maintenance, energy savings, security management, logistics efficiency, and more. The [21] illustrates the efforts to develop a platform (Otaniemi3D) with the aim of integrating data from the environment with IoT sensors and thus provide information by integrating BIM and IoT devices through open messages standards.

In conclusion, research in recent years has been increasingly focusing on improving the architecture of IoT systems, especially data management, collection, and processing. Nitschke and Williams [22] confirm that *"IoT is more complex than a sensor-network and can be considered as a new Information Infrastructure (II), spanning across borders and domains, having no fixed notion of "user" and involving multiple stakeholders."*

Additionally, since there was a rapid use of IoT low power networks (smart cities, smart buildings, to smart homes, smart factories, etc.), future research have to focus on design efficient solutions for management this IoT low power networks to control the heterogeneity IoT networks while ensuring security and privacy. [23]

1. 3 Digital Twin (DT)

The concept of Digital Twin (DT) grew out of a 2002 presentation by Michael Grieves, now chief scientist for Advanced Manufacturing at the Florida Institute of Technology, on the establishment of a Product Lifecycle Management (PLM) center.

The aerospace industry has pioneered the use of digital twins. In fact, NASA was the first to experience its potential, since the dawn of space exploration, even before it was identified and theorized since it is a context in which it is necessary to control, maintain and repair distant systems. Subsequently, the US Space Agency launched studies that led to the use of digital twins in multiple contexts, being able to simulate conditions of use. The name was found only in the first years of the second millennium thanks to the advent of the Internet of Things and the digital twin has found evolution, fulfilment and development.

To date, definitions of DT are numerous in the literature. Ferreira et al. [24] define a DT as “a *comprehensive representation of a product or process into a digital world; it plays a vital role in the product lifecycle and helps to the horizontal integration of the production process”.*

According to Rasheed et al. [25] “DT *can be defined as a virtual representation of a physical asset enabled through data and simulators for real-time prediction, optimization, monitoring, controlling and improved decision making.”*

Differently for Schluse et al. [26] *“DTs represent real objects or subjects with their data, functions, and communication capabilities in the digital world.”*

To summarize, the Digital Twin integrates IoT, Artificial Intelligence, Machine Learning and Analytics with a graphical and/or spatial representation to create digital simulation models that update and change according to their physical counterpart.

Despite multiple definitions, they all share three distinctive elements:

1. The Digital Twin is a virtual replica of a potential or actual physical element (Physical Twin), such as an asset, process, person, place, system, or device.

2. The virtual object contains all the information about how a physical element operates and evolves during its life cycle, according to the defined objectives.

3. There is a connection between the physical element and the virtual one thanks to the real-time data exchange that is collected by sensors placed on the real element.

The architecture of a Digital Twin consists of three layers. A Connectivity layer that contains the set of sensors placed on the physical twin via IoT, SCADA or Historian. A Modelling and Simulation layer consisting of a variety of solutions such as sector simulators. An Insights and Visualization layer that refers to web interfaces, Analytics tools up to Mixed Reality.

In addition to these three layers, there is a "Learning Feedback", which allows the use of historical data to improve the behaviour of the Digital Twin and to update it according to the changes of the physical twin.

DT applications are multiple. Schluse et al. [26] demonstrated a new approach that allows a connection between model-based systems engineering (MBSE) and simulation thanks to the application of Experimental Digital Twins (EDTs).

Ferreira et al. [24] demonstrated a use of a service-oriented DT for a vehicle chassis to detect flaws in the modelling or drawing of the product itself.

Khajavi et al. [27] studied a framework to determinate the improved position of the sensors on a building facade to enable a DT. Various benefits are derived from this monitoring: lowering maintenance cost, increasing occupants' comfort and lowering the management and operational cost of the building.

On the other hand, Xu et al. [28] studied a method for detecting errors in a car body-side production line using a digital-twin-assisted fault diagnosis method using deep transfer learning (DFDD). They have established that *"the risk of accidental breakdown is greatly reduced, making smart manufacturing sustainable, reliable and efficient"*.

Otherwise, Rasor et al. [29] showed an application of DT in manufacturing value chains and Riedelsheimer et al. [30] have focused on how to use a DT to improve the optimization of sustainability indicators (energy consumption during the product life-cycle). The latter found that it is still necessary to study the complexity of the data to be analysed and the automation of certain processes.

The fields of application of the DT are multiple and more and more experiments are being carried out.

For example, the case of the Brazilian tractor manufacturer Stara, which thanks to the IoT sensors installed on the equipment and the performance monitoring, provides farmers with a view in real time of the best conditions to plant crops and improve yield, with an optimization in the use of seeds and fertilizers.

Regarding construction industry sector, Boje et al. [31] studied "*the creation of a comprehensive Construction Digital Twin, which demands a real-time connection to the Physical Twin and all its relevant components."*

Otherwise, ENI uses the digital twin in a formative way. That is, the employees wear sensorized equipment (gloves and glasses) to move in augmented reality within the digital twin of an existing system. In this way, it is possible to simulate interventions in supervision and safety.

On the other hand, on a large scale, Singapore offers 3D semantic modeling of the city, the so-called Virtual Singapore, to which data is associated (the characteristics of public transport, electricity consumption, building components and infrastructures, climate information or traffic). This is useful both in planning and sustainable urban development, simulating an evacuation.

Another example of large-scale digital twins is the port of Rotterdam, which has set itself the goal of being the first digital port by 2030.

In conclusion, in the AEC sector, the digital twin is also seen as an evolution of BIM. But the digital twin, unlike the BIM, thanks to the IoT allows, in addition to the design, real-time monitoring of the solution. In Japan, Kajima Corporation began using digital twins to maintain the infrastructure and verify structural problems. In Italy, the digital twin of the Polcevera viaduct (Cymon) was created, replacing the Morandi bridge in Genoa.

1. 4 Facility management (FM)

The discipline of Facility Management was born in the United States in the early '80s in a difficult period for the North American economy because differentiated offers with greater freedom and a wider choice were emerging more and more. US companies realized that a change was needed, that is to rethink the organization of the company itself to make it able to face the new market. Therefore, among the strategies put in place to overcome the crisis there was the identification of the value of the service activities as a basic element for the business and the consequent need to manage them. This is what led to the birth of the discipline of Facility Management and the role of the Facility Manager.

According to the International facility management association (IFMA), facility management (FM) is "a *profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process and technology".*

Always in accordance with IFMA, facility management and the work of facility managers can be divided into three basic aspects:

- Strategic aspect
- Analytical aspect
- Management-operational aspect

On the strategic side, facility management has the role of planning maintenance by identifying the maintenance strategy to be adopted, managing the budget and allocating costs and workload.1

On the other hand, from an analytical point of view, the purpose of FM is also to identify the actual business needs for services by assessing the results obtained.

Finally, the third aspect concerns the operational management of services, i.e. the definition of procedures and their implementation by coordinating the activities of technicians and suppliers, tracking maintenance operations and managing critical issues.

Another way of classifying facility management activities is to divide them into two groups: soft services and hard services. The former are services that make the working environment comfortable and suitable for the activity being carried out, the latter are the services that ensure respect for the health, safety and welfare of employees.

Examples of Soft Facilities Management are:

- Landscaping
- Window cleaning
- Cleaning
- Security
- Post management
- Waste management
- Catering
- Car parking

Examples of Hard Facilities Management are:

- Lighting
- Plumbing
- Heating
- Air Conditioning
- Building maintenance
- Fire safety systems

Instead, according to UNI EN 15221 – 1:2007 - Terms and definitions, the facility management is a *“integration of processes within an organisation to maintain and develop the agreed services which support and improve the effectiveness of its primary activities”.*

In fact, the term facility management refers to the business discipline that deals with the management, organisation and coordination of workspaces with the aim of ensuring the requirements of functionality and comfort to be able to carry out their tasks in the best way, respecting the standards of quality and efficiency within a healthy, functional and completely safe environment.

Otherwise, the UNI EN 15221 - 1:2007 standard defines facility management as *the integration of processes within an organisation to maintain and develop agreed services that support and improve the effectiveness of its primary activities.*

This process encompasses many activities including:

- Management of space within the property
- Management of equipment and facilities
- Maintenance management
- Resource management
- Economic and financial management
- Identification and procurement of services (commodities, utilities and others)
- Supplier management
- Planning of activities and technical interventions
- Stock and spare parts management
- Data analysis

Whereas Potkány [32] defined facility management as *“an effective form of support for enterprise activities management whose aim is to provide relevant, cost-effective services for main enterprise (core business) activities support and so enabling their optimization”. A*ccording to Potkany once again [33], FM *“should not only be understood as general building management connected with everyday building operation but it should also include long term planning and focus on its users.”*

The term "facility" encompasses a broader concept, in fact, it indicates the property where the work is carried out and all service activities. For this reason, the area of application of the discipline is broad, ranging from the strategic management of buildings to that of services.

Facility can be classified into three macro-areas: services to the building, to space and to people.

Services to the building is the macro-area that encompasses the activities aimed at maintaining the building and all its systems and facilities. These activities guarantee the continuity of the building's operation, in accordance with the regulations on hygiene in the workplace, safety and rational use of energy.

Space services are activities that aim to create and maintain a workspace that is a useful support for the company in order to facilitate the processes of value creation and communication. These activities require a high level of complexity from an organisational point of view.

Finally, personal services are the macro area that includes services such as catering, document management, reception, environmental hygiene, etc. These are all activities that have the purpose of creating value for the company. These are all activities that aim to increase productivity, the well-being of staff.

Currently, facility management is increasingly favouring the configuration of predictive maintenance models, abandoning the logic of threshold maintenance.

In fact, the intention of FM is to create a working environment that meets the needs of the profession and complies with health, safety and environmental standards. The quality of life in the workplace is a key element in improving employee performance.

This is possible, above all, thanks to the products of Industry 4.0 (including IoT, big data and machine learning) which allow the prediction of failures and the definition of useful life. In particular, the adoption of these technologies in the FM sector makes it possible to exploit both data and the knowledge of maintainers and experts to generate data-driven models that are useful for asset monitoring.

Predictive maintenance is therefore the optimal strategy for complex buildings and an opportunity for innovation in the FM area. Thanks to this predictive knowledge of the assets, traditional maintenance strategies can be innovated and directed towards condition-based maintenance strategies.

In this regard, Araszkiewicz [34] presented a case study of The Edge office building in Amsterdam to identify possible gaps of digitization in property management and its impact on construction engineering.

The main gaps are:

- Interoperability and enhancement of data integration.
- augmented knowledge management and enriched training and competence development for facility managers.

According to him, future research must focus *on "the integration of GIS, BIM and BEMS for more intuitive and effective facility management."*

Thanks to the versatility of FM, this discipline is applicable in many sectors even if the result of the study of Awang et al. [35] showed that the most important roles of a facility manager are operations and maintenance.

In conclusion, Potkány [32] identified the main areas of competence of the FM:

1. *Housing and premises services*
    - *strategic planning and premises management,*
    - *design and construction of future premises,*
    - *premises rent, renovation and refurbishment,*
    - *premises operation and maintenance.*

2. *Health, safety and protection*
    - *medical services,*
    - *safety management,*
    - *access systems, ID cards,*
    - *fire protection and precautions.*

3. *Workplace*
    - *design and ergonomic workplace,*
    - *selection of furniture, gadgets and equipment,*
    - *moving and change of furniture,*
    - *interior and exterior accessories,*
    - *tagging, decoration and premises division.*

4. *Maintenance of premises users*
    - *receptionist and secretary services*
    - *help desk services,*
    - *catering and automatic catering machines,*
    - *conference and special events organisation,*
    - *work uniforms, protective garments and gadgets.*

5. *Technical infrastructure*
    - *energy providers (water, electricity, gas, heating),*
    - *environmental management,*
    - *maintenance management system,*
    - *waste management (separation, disposal,...).*

6. *ICT*
    - *operation of data and telephone networks,*
    - *IT security, safety and maintenance*
    - *IT and telephone connections,*
    - *management of data centres, server operation.*

7. *Cleaning and tiding-up*
    - *sanitation services,*
    - *tidying-up workplaces, cleaning of machines and premises,*
    - *cleaning, washing and tidying-up buildings,*
    - *winter and summer maintenance of external environment.*

8. *In-company logistics*
    - *in-company and courier services,*
    - *document management and archiving,*
    - *transport and warehouse services,*
    - *travelling services and company fleet management,*
    - *reprographic services (xeroxing and printing).*

9. *Other premises and infrastructure*
    - *rent of measurement and specialised equipment,*
    - *interior work with special equipment.*

10. *Other people and organisations*
    - *bookkeeping, audits and financial statements,*

- *human resources management,*
- *legal services, contract management,*
- *project management, quality management.*

If facility management is carried out correctly, there are several benefits that extend the life cycle of resources, reduce management and operating costs and increase the company's profits. The benefits are:

- Reducing costs: this discipline not only deals with the selection of suppliers with the best value for money, but also seeks to reduce energy consumption, optimise resources and maintenance activities.
- Improving safety: this is a central aspect of facility management through the control of company security devices.
- Providing engaging and productive working environments: in addition to the physical management of spaces, the facility is also responsible for the cleaning of environments, maintenance of green areas and all those activities that can ensure a comfortable environment
- Extend the lifecycle of assets: efficient management of facilities and all their components reduces maintenance costs and extends their lifecycle.
- Improving customer satisfaction: FM manages lighting, escalators, cleaning, internal temperature.

2. Integration of BIM, IoT and DT for FM

This section presents the state of the art in the use of these technologies described above applied to manage predictive maintenance. According to a report of Politecnico di Torino*,* the aim of maintenance is *"to protect a building in its early stage and some major rationale for maintaining building are retaining its significance and value of investments, maintaining the building in a condition that it persists to accomplish its purpose and presenting a good outer shell."*

Thanks to the technological expansion of the 21st century, the AECO industry is also evolving towards increasingly integrated and digitized processes. According to Araszkiewicz, "*digital technology that supports FM, e.g. Internet of Things (IoT), Big Data management systems and advanced connectivity will affect the efficiency of facility managers and their clients."*

In the field of construction, in fact, IoT applications are growing significantly. This technology fits on different scales: from smart homes, smart buildings, to smart cities and smart mobility.

More specifically, the Internet of Things in Buildings (BIoT) means that the objects are connected to each other through the network. This system is concerned with improving the management of the building and the well-being of users.
The programming and control of the plants allows to optimize the performance of the building and to avoid waste of energy**.**
In addition, the connection between BIM and IoT, oriented to Facility Management or BIM 6D, allows technicians to use the data in real time to detect a failure, allowing an effective prevention activity, a reduction in costs but above all a significant reduction in the downtime of plants.
Another predictive maintenance solution is a Digital Twin that, starting from historical data and the history of faults, allows to anticipate the occurrence of faults. This gives you time to plan a maintenance operation before a critical break.

In the literature, there are many examples of application of these technologies such as IoT, DT or BIM to FM.

Araszkiewicz [34] studied the possibility of using the BIM methodology to integrate the model with the data to obtain information and decision support for facility management maintenance.

Furthermore, Naticchia et al. [36] presented a methodology to support the management of information during the life cycle of a building with the aim of increasing the level of efficiency. The study focused on the combination of three tools such as: " *the BIM methodology for information management, a cloud-based system for managing information flows, and MR allowing the continuous interaction among operators, the digital model of the building, and information flow*." This study also highlighted the fact that, although these tools help operators, they cause the lowering of the number of interventions on the site and consequently also the numbers of the operators.

Instead, Pärn et al. [37] identified three challenges on BIM-FM integration to overcome: personnel training on technologies, understanding the useful data required during the building's life cycle and the BIM technologies since FM is not fully used for the decision support knowledge.

And also, [38] enumerates the benefits using BIM-FM integration expected to be achieved by facility managers that are:

1. Effective operational cost
2. Shorter time for decision making
3. Resource for decision making
4. Better documentation system
5. Collaboration and work flexibility
6. Updated information and clash detection

On the other hand, [39] proposed a method for digitising and integrating information from the MEP system with the as-build model. This was aimed at generating a cross-platform O&M management system to run routine O & M tasks. Hu et al. reached three conclusions:

1. the model must contain geometrical, construction and engineering information.
2. The management of the MEP system has improved thanks to the cross-platform.
3. They have created the basis for further studies on the digitisation of MEP systems.

In addition, Potkany et al. [33] analysed the possibilities to use FM to manage the investment and operating costs of buildings, taking into consideration the environmental management principle, throughout their life cycle. They have established that "*Within the construction building preparation a facility manager should give requirements for suitable building envelope with suitable heat resistance, which will prevent heat losses and so will contribute to lowering the costs for heating*."

[40] showed a new methodology for detecting fouls in large building plants, focusing on the faults in the Variable Air Volume (VAV) boxes. The research began by analysing commercial buildings and Narayanaswamy et al. noticed that, every day, more than 10000 foul warnings were received in the HVAC system from the Building Management System (BMS) system. Such warnings were detected by simple sensing instruments such as individual sensors. In order to overcome this gap, they developed an algorithm that did not require a large amount of historical data and knowledge of the distribution of the specific plant: Model Cluster Compare (MCC).

Instead, Lauro et al. [41] presented "*a hybrid statistical, clustering and rule-based approach in order to diagnostic abnormal electric consumptions of fan coils caused* *by improper use by the employees*" and have established that future researches are needed on meteorological data and thermal energy consumption related to fan coils. On the other hand, [42] showed the performances of machine learning algorithms to identify the faults of the air conditioning system on coefficient of performance (COP).

They conducted three types of analyses using three types of algorithms:

- support vector machine (SVM)
- multi-layer perceptron (MLP)
- deep learning.

They have established that *"the simulation results show that the MLP has the best accuracy and precision up to 99.4% than SVM and deep learning. The second most accurate classifier was SVM which correctly classified the data up to 97%."*

Another example of the use of algorithms to identify the faults is provided by Granderson et al. [43] that created a dataset with ground-truth data on the presence and absence of building faults.

However, Kazado et al. [44] analysed "*three different approaches for integration of the building sensor technology and the BIM process to create a common data platform for the visualization of indoor environmental parameters (e.g., temperature and CO2) that would enable facility operators to obtain the required information*".

The three approaches examined and then discussed are:

1. Sensor-Revit integration with built-in functions of Revit software.
2. Sensor-Revit-Navisworks integration with built-in functions of Navisworks.
3. Sensor-Revit-Navisworks-API integration with add-in developed.

The first approach has many limitations because it only allows the visualization of 2D data, otherwise, the second one, although it allows 3D visualization, does not allow the analysis of historical data. On the other hand, the third approach overcomes the limitations of the two previous approaches allowing 3D visualization and the visualization of historical data.

Instead, [45] presented a study focused on "*calibration and test campaigns of an IoT camera-based sensor system to monitor occupancy, as part of an ongoing research project aiming at defining a Building Management System (BMS) for facility management based on an occupancy-oriented Digital Twin (DT)."*

The purpose of the research was to improve the operational phase of the building through monitoring and data analysis. Important aspects emerged during the study that should be considered in subsequent studies:

- it is necessary to consider human behaviour.
- A multi-stage test and calibration campaign is important for setting the sensor system.

- It is essential to set the boundary conditions of the system (e.g. width and height of the corridors).

Also, Xie et al. [46] showed an DT-FM integration for detecting fouls demonstrating that "*supported by the data management capability provided by digital twin, the proposed framework realizes a continuous condition monitoring and anomaly detection."*

Another technology, named machine to machine (M2M), allows automatic transfer of information with limited or no human interaction and enhances automating business processes.
In this regard, the paper of Krishnamurthy et al. [47] developed "*an M2M middleware from ground up, in order to assist SMEs in overcoming the hurdles and complexities involved in enabling seamless interaction between diverse M2M technologies that are relevant to the facility management domain".* They showed that their middleware is capable of scalably and reliably handling concurrent events generated by different types of M2M devices.

An additional technology analysed is the wireless sensor networks (WSN). In 2008, Malatra et al. [48] proposed an integration of wireless sensor networks (WSN) in an overall facilities management enterprise architecture. Although, they observed a reduction in cost, flexibility and agility to respond to dynamic conditions, future research would be needed to improve this technology.

On this matter, Mannino et al. [49] showed an integration BIM-IoT for FM identifying WSN as the IoT solution to collect the data needed to control and monitor the building. They also found two main problems in the use of WSNs: signal transmission and powering devices.

Furthermore, Stojanovic et al. [50] developed a *service-oriented platform for generation of semantically rich 3D point cloud representations of indoor environments* with a focus on visualisation and representation of the internal environment. In fact, this last aspect is fundamental to increase the collaboration between these technologies and stakeholders.

In order to overcome the limitation of detailed visual information about a built facility and the maintenance, Valinejadshoubi et al. [51] investigated the BIM's capability in sensor information management using cloud services in smart IoT environments during a building's operational phase enhancing:

- the decision-making for building facility managers.
- communication between the building facility manager and the IoT company
- data extraction and transfer to the cloud
- disruption to monitoring services.

Ultimately, Suriyarachchi et al. [52] investigated the relationship between BIM and IoT in smart buildings located in Sri Lanka and Martí et al. [53] "*proposed a combination of yet another segmentation algorithm (YASA), a novel fast and high quality* *segmentation algorithm, with a one-class support vector machine approach for efficient anomaly detection in turbomachines"*

In conclusion, in the field of AECO sector, FM applications are increasing and Nidhi and Ali [54] summarised these positive impacts:

1. *Machines and equipment are properly maintained and always user ready.*
2. *Occupants engaged in business operation can concentrate on core business activities.*
3. *Safety and security of men and machines are taken cared of by specialised people.*
4. *Supporting services are not part of the core business operations particularly for IT business.*
5. *Operational excellence can be achieved by better utilisation of the facility.*
6. *Reduction in energy bill by way of better energy usage.*
7. *Positive impact on the bottom line particularly for the company running the business operations from the facility.*
8. *FM as a new business opportunity can be enhanced further if energy saving is incorporated into the FM activities.*
9. *Positive impact on the environment due to reduction in energy consumption in operation.*

Despite the many positive aspects, it must be highlighted that there are still gaps to be filled such as data exchange and interoperability, 3D modelling of the building, collected real-time data or problems related to the sensors.

The following table shows the future challenges that should concern FM and its integrations with BIM, IoT and DT.

BIM for FM	BIM - IoT for FM	DT for FM
• Enhance interoperability • Improve the exchange of data • Collect data in real time	•Enhance cloud computing •Standardised a way to integrate data •Standardised a way to manage data •improve other tecnologies (MR)	•Visualizing sensor data •Increase applications

Figure 8: Future challenges for BIM for FM, BIM-IoT for FM and DT for FM

2.1. Italian legislative framework

The European Directive 98/34/EC of 22 June 1998 defines a standard as a technical specification approved by a recognised body to carry out standardisation activities for repeated or continuous application, compliance with which is not compulsory.

A standard may belong to one or more of the following categories

- international standard (ISO)
- European standard (EN)
- national standard (UNI).

UNI stands for Ente Nazionale Italiano di Unificazione.It is a private association that draws up technical standards for all industrial, commercial and service sectors. Technical standards are prescriptions that may concern the dimensional and performance characteristics of a product, a production process or a service. They become mandatory if they are included in official documents.

The abbreviation EN, on the other hand, applies to standards drawn up by CEN (Comité Européen de Normalisation).These standards are mandatory for member countries with the aim of standardising legislation at European level. For this reason, when the standard is adopted in Italy, it has the initials UNI EN.

The acronym ISO identifies the rules drawn up by the International Organization for Standardization. These standards have worldwide validity and different countries can decide whether to adopt them or not.

In Italy, the application of these standards will be recognisable by the acronym UNI ISO, or UNI EN ISO if this standard has also been adopted in Europe.

In sum, the standard bearing the acronym UNI EN ISO is a standard issued at international level, adopted in Europe and in Italy. In the case of the acronym UNI EN, it will be a UNI standard applied according to European legislation. On the other hand, a standard with only the acronym UNI will be part of the Italian standard.

Below is a list of the Italian standards consulted in order to identify the most useful ones for the drafting of the thesis.

- UNI 10723:1998 – Processo edilizio -Classificazione e definizione delle fasi processuali degli interventi edilizi di nuova costruzione

The standard defines and classifies the phases of the building process and applies to new interventions for any purpose of use of the building.

- UNI 7867-1:1978 - Edilizia. Terminologia per requisiti e prestazioni. Nozioni di requisito e di prestazione.

- UNI 11151:2005 - Processo edilizio - Definizione delle fasi processuali per gli interventi sul costruito

The standard indicates the regulatory support elements for the definition of the programme of a building intervention on the built environment. In particular, it is specifically applied whenever the conformity of the project of the work to the needs of the client must be formally documented, through the drawing up of the programme of the individual intervention.

- UNI 11150-1:2005 - Edilizia - Qualificazione e controllo del progetto edilizio per gli interventi sul costruito - Parte 1: Criteri generali, terminologia e definizione del documento preliminare alla progettazione

The standard defines the phases of the building process of intervention on the built environment, highlighting the specificities, the temporal sequences, the relations and the characteristic constraints and also defines the parameters for assessing the effectiveness/efficiency of the relative project.

- UNI 11150-2:2005 - Edilizia - Qualificazione e controllo del progetto edilizio per gli interventi sul costruito - Parte 2: Pianificazione della progettazione

The standard indicates the support elements for the definition of the preliminary design of a building intervention on the built environment. It can be used when the client intends to document the aims, the constraints and the requirements assumed as the basis for the design direction and to allow the qualification of the project through the carrying out of conformity checks on the preliminary design of each individual intervention.

- UNI 11150-3:2005 - Edilizia - Qualificazione e controllo del progetto edilizio per gli interventi sul costruito - Parte 3: Attività analitiche ai fini degli interventi sul costruito

The standard indicates the criteria for the development of diagnostic activities to support the preliminary design of a building intervention on the built environment.

- UNI 11150-4:2005 - Edilizia - Qualificazione e controllo del progetto edilizio per gli interventi sul costruito - Parte 4: Sviluppo e controllo della progettazione degli interventi di riqualificazione

The standard provides the client, the designer and any third party organisations and bodies with guidance for the development and control of the built environment rehabilitation project.

- UNI 11337-1:2017: Edilizia e opere di ingegneria civile – Gestione digitale dei processi informativi delle costruzioni - Parte 1: Modelli, elaborati e oggetti informativi per prodotti e processi

This standard covers the general aspects of the digital management of the information process in the construction sector, such as:

- the structure of the information vehicles
- the information structure of the process;
- the information structure of the product.

This standard is applicable to any type of (resulting) product in the sector, be it a building or an infrastructure, and to any type of process: design, production or operation. Whether they are aimed at new construction, conservation and/or rehabilitation of the environment or of the built heritage.

- UNI 11337-7:2018: Edilizia e opere di ingegneria civile – Gestione digitale dei processi informativi delle costruzioni - Parte 7: Requisiti di conoscenza, abilità e competenza delle figure coinvolte nella gestione e nella modellazione informativa

The standard sets out the requirements for the professional activity of figures involved in information management and modelling. These requirements are identified by dividing the specific tasks and activities performed by the professional figure in terms of knowledge, skills and competence according to the European Qualifications Framework (EQF). The requirements are indicated both to enable the assessment of informal and non-formal learning outcomes and for competence conformity assessment purposes.

- UNI 10144:2006 – Classificazione dei servizi di manutenzione

The purpose of the standard is to classify maintenance services in the following respects: type of service, specialisation of service, method of service, scope of service, in order to have a single reference for all the rules governing maintenance contracts.

- UNI 10146:2007 - Criteri per la formulazione di un contratto per la fornitura di servizi finalizzati alla manutenzione

The purpose of the standard is to indicate appropriate conduct to facilitate and protect the parties in the drafting of contracts for the provision of maintenance services. The standard provides the typical criteria for a negotiated contract. It is also applicable to public administration, within the framework of the formalised practices in use.

- UNI 10147:2013 – Manutenzione – Termini aggiuntivi alla UNI EN 13306 e definizioni

The standard defines the most used terms in the Maintenance sector, which should be read in combination with those used in EN 13306.

- UNI 10148:2077 – Manutenzione – Gestione di un contratto di manutenzione

The standard aims to facilitate the application of the maintenance contract by indicating the technical, organisational and administrative criteria for its operational management.

- UNI 10224:2007 – Manutenzione – Processo, sottoprocessi e attività principali – Principi fondamentali

The standard provides principles, criteria and methods for establishing, organising, managing and improving an organisation's maintenance process.

- UNI 10652:2009 - Manutenzione – Valutazione e valorizzazione dello stato dei beni

The standard specifies a quantitative and qualitative method for analysing and estimating the condition of an asset in order to value and assess it. It applies to data that can be collected within the maintenance function in the context of its own activities and its relations with other functions.

- UNI 11063:2017 – Manutenzione – Definizione di manutenzione ordinaria e straordinaria

The standard defines the criteria for classifying maintenance activities, distinguishing between ordinary and extraordinary maintenance, in order to provide a reference framework to standardise the behaviour of users in managing and accounting for the resources used, according to the criteria of industrial and general accounting, in a coherent and significant manner also in terms of organisation and operations. It applies to all sectors for which maintenance is required.

- UNI 10685:2007 – Manutenzione – Criteri per la formulazione di un contratto di manutenzione basato sui risultati

The standard provides criteria for drawing up a performance-based maintenance contract. It is intended to provide the parties with a basis for defining a performance-based maintenance contract and the related acts. It is also intended to standardise market behaviour, to define the essential requirements of the contract and to guide the formulation of acts that are as complete as possible.

- UNI 10749 – 1:2017 - Manutenzione – Guida per la gestione dei materiali per la manutenzione – Aspetti generali e problematiche organizzative

The standard illustrates general aspects in the management of maintenance materials and gives examples of the place of the function "management of technical materials" in a company organisation chart and its possible links with other functions, in order to guide a choice.

- UNI 10749 – 2:2017 - Manutenzione – Guida per la gestione dei materiali per la manutenzione – Criteri, codifica e unificazione

The standard provides classification, codification and unification criteria to allow homogeneous grouping of objects or entities and their analysis.

- UNI 10749 – 3:2017 - Manutenzione – Guida per la gestione dei materiali per la manutenzione – Criteri per la selezione dei materiali da gestire

The standard provides guidance on criteria for the selection of materials to be handled for maintenance and illustrates the internal and external factors influencing these criteria.

- UNI 10749 – 4:2017 - Manutenzione – Guida per la gestione dei materiali per la manutenzione – Criteri di gestione operativa

The standard provides guidance on the management criteria for maintenance materials and the methods that can be used to define the management parameters that contribute to determining the stock levels.

- UNI 10749 – 5:2017 - Manutenzione – Guida per la gestione dei materiali per la manutenzione – Criteri di acquisizione, controllo e collaudo

The standard provides guidance for the provision, control and testing of technical materials for maintenance.

- UNI 10749 – 6:2003 - Manutenzione – Guida per la gestione dei materiali per la manutenzione – Criteri amministrativi

The standard provides guidance on the methods and criteria that may be used to determine unit values for loading, unloading and storage of materials in stock. In addition, it provides guidance for identifying costs that are usually associated with the availability of materials.

- UNI 11454:2012 – La manutenzione nella progettazione di un bene fisico

The standard specifies the principles, criteria, methodologies and methods, as well as the information elements and indicators of order and maintenance content, which must be considered and included in the design processes of a finished product in order to ensure the expected characteristics, performance levels and duration during its life cycle, and which must be included in the contractual specifications and in the related documentation.

- UNI 10992:2002 – Previsione tecnica ed economica delle attività di manutenzione (budget di manutenzione) di aziende produttrici di beni e servizi – Criteri per la definizione, approvazione, gestione e controllo

The standard provides guidelines for the technical and economic forecasting (budgeting) of maintenance activities. Technical and economic prediction is not separated from effectiveness, which is not verified by the standard.

- UNI EN 13629:2016 – Manutenzione – Linee guida per la preparazione dei contratti di manutenzione

The standard offers guidance for the preparation of contracts for maintenance works.

- UNI EN 13306:2018 – Manutenzione – Terminologia di manutenzione

The standard specifies generic terms and their definitions for the technical, administrative and management areas of maintenance. It does not apply to terms used exclusively for the maintenance of computer programmes.

- UNI EN 13460:2009 – Manutenzione – Documenti per la manutenzione

This standard is the official Italian version of the European standard EN 13460 (May 2002 edition). The standard provides general guidelines for:

- the technical documentation to be attached to an asset, prior to its commissioning, to support maintenance requirements.
- the documentation of information to be established during the operational phase of an asset to support maintenance requirements.

- UNI EN 15341:2007 – Manutenzione – Indicatori di prestazione della manutenzione (KPI)

This standard is the official Italian version of the European standard EN 15341 (March 2007 edition). The standard describes a system for the management of maintenance indicators to measure performance in the context of influencing factors such as economic, technical and organisational aspects, to assess and improve its efficiency and effectiveness in order to achieve excellence in the maintenance of technical assets.

- UNI EN 11414:2011 – Linee guida per la qualificazione del sistema di manutenzione

The standard provides guidelines for qualifying the maintenance system by measuring and evaluating all stages of the process, verifying the conformity of the methods and tools adopted with the context in which it operates.

- UNI EN 15628:2014 – Manutenzione – Qualificazione del personale di manutenzione

This standard is the official version of the European standard EN 15628 (August 2015 edition) and replaces UNI 11420. The standard specifies the qualification of personnel in relation to the tasks to be performed in the context of maintenance of facilities, infrastructure and production systems.In this standard, maintenance of plants and buildings is included in terms of technical aspects of services. The standard deals with the following professional figures in the maintenance organisation:

- Maintenance Technician Specialist;
- Maintenance supervisor and/or maintenance engineer;
- Maintenance manager (Head of the maintenance service or function).

The standard does not specify the verification criteria nor the specialised training of personnel, which is related to the specific product area.

- UNI EN 16646:2015 – Manutenzione – Manutenzione nella gestione dei beni fisici

This standard is the official version of European Standard EN 16646 (December 2014 edition). The standard establishes the role of maintenance in the management of physical assets. It shall also establish the relationship between the strategic organisational plan and the maintenance system and describe the interrelationships between the maintenance process and all physical asset management processes. It addresses the role and importance of maintenance within the physical asset management system throughout the life cycle of an asset.

- UNI EN 15628:2014 - Manutenzione - Qualifica del personale di manutenzione

The standard specifies the qualification of personnel in relation to the tasks to be performed in the context of the maintenance of facilities, infrastructure and production systems. In this standard, the maintenance of installations and buildings is included in terms of the technical aspects of the services. It constitutes a guide to define the knowledge, skills and competences required for the qualification of maintenance personnel. The standard deals with the following professional figures in the maintenance organisation:

- Maintenance technician specialist;
- Maintenance supervisor and/or maintenance engineer;
- Maintenance manager (Head of the maintenance service or function).

The standard does not specify the verification criteria nor the specialised training of personnel, which is related to the specific sector.

- UNI EN 13460:2009 - Manutenzione - Documentazione per la manutenzione

This standard is the official version of the European standard EN 13460 (April 2009 edition). The standard specifies general guidelines for:- the technical documentation to be attached to an asset, prior to its commissioning, to support its maintenance;- the information documentation to be established during the operational phase of an asset, to support maintenance requirements.

2.2. English legislative framework

In this chapter, as in the previous one, the English regulations consulted for this thesis work have been listed. These standards may have the acronym BS or PAS.

The British Standards Institution (or BSI Group or BSI) is a British standards organisation, a member of the International Organisation for Standardisation (ISO).

PAS stands for Publicly Available Specification and is a standardisation document similar to a technical standard in structure and form, but is intended to speed up the standardisation process. PAS are produced in response to an urgent market need.

- PAS 1192-2:2013

The standard provides specification for information management for the capital/delivery phase of construction projects using building information modelling

- PAS 1192-5:2015

The standard provides specification for security-minded building information modelling, digital built environments and smart asset management

- PAS 1192-6:2018

The standard provides specification for collaborative sharing and use of structured Health and Safety information using BIM

- BS 1192:2007+A2:2016

The standard illustrates a collaborative production of architectural, engineering and construction information. Code of practice

- BS 1192-4:2014

Collaborative production of information. Fulfilling employer’s information exchange requirements using COBie. Code of practice

- BS 8536-1:2015

Briefing for design and construction. Code of practice for facilities management (Buildings infrastructure)

- BS 8536-2:2016

The standard provides a briefing for design and construction. Code of practice for asset management (Linear and geographical infrastructure)

2.3. The construction process according to Italian standards

The aim of this chapter is to define and present the phases of the building process from the definition of needs to the phases and levels of design, construction and maintenance of the building through Italian standards.

With reference to the historical UNI 7867, the building process is defined as "*the organized sequence of operational phases that lead from the detection of needs to their satisfaction in terms of construction production*". However, the contemporary building process is evolving from this representation, where collaboration between the different actors and actions of the process is missing in many operational realities and in many innovative process models.

The UNI 10723:1998 standard places the design at the centre of the production process and not the object of the process. In this way, the design activity is no longer considered a phase of the process but becomes the object of the process itself.

In fact, the building process must be seen as a coordinated sequence of phases that starting from the general planning of the interventions, arrives at the implementation of the same and ends with the management of what is achieved. The development of the building process is not linear but has many interdependencies.

The standard UNI 10723:1998 makes explicit this process through several explicit phases according to an ordered chronological sequence, which allows the definition and analysis of each of the essential phases through which it is implemented:

1. general programming;
2. the location of interventions;
3. specific programming (technical-financial);
4. architectural design;
5. the award of the works;
6. the execution of the work;
7. the acceptance procedure;
8. management and maintenance.

The three phases of the building process are:

- The Decision-Making Process (il Processo Decisionale);
- The Executive Process (il Processo Esecutivo);
- The Management Process (il Processo Gestionale).

The Decision-Making Process is the structured set of procedural phases that precede the implementation of the intervention and define its objectives, meta-project development, design development and programming. This process is further articulated in stages: those of meta-design and those of design. In order to best deal with the design, planning and management of a building intervention, in the stages of meta-design it’s possible to collect and correlate the objectives to be achieved, the means available and the specific conditions of the territorial and regulatory environment in which it operates. Otherwise, the planning phases identify the interventions necessary for the definition of the project and the operational, management and economic planning for the implementation of the intervention.

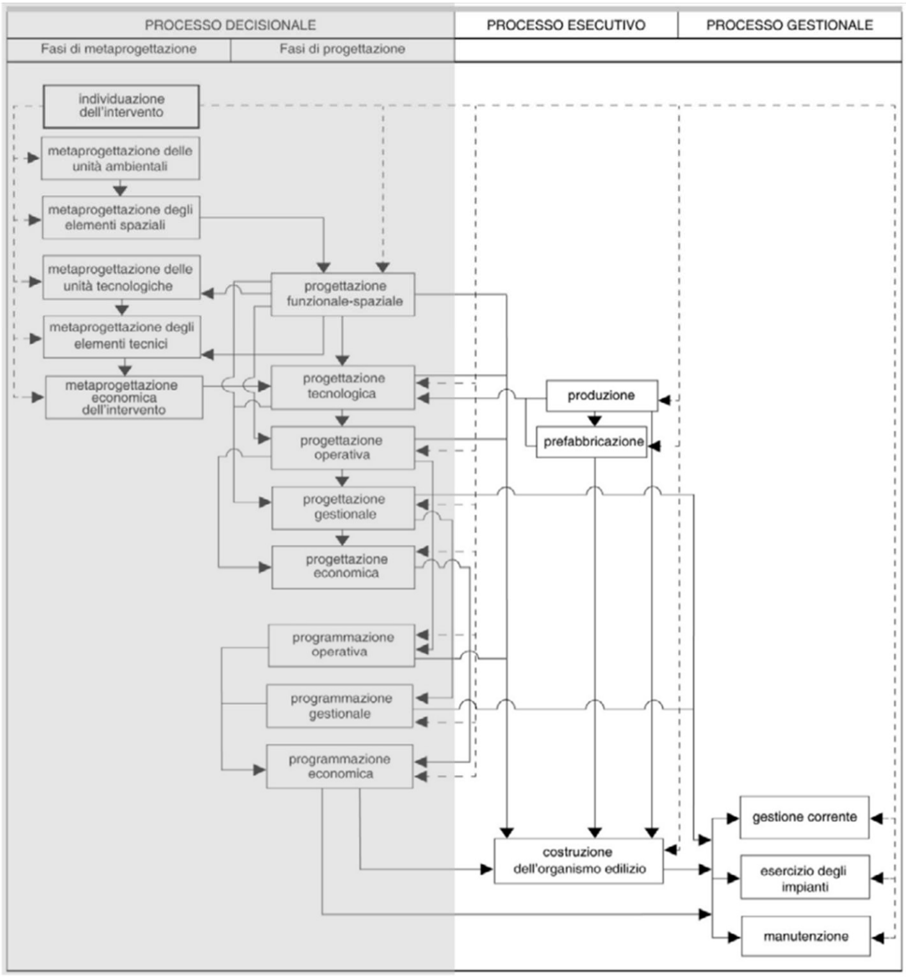


Figure 9: The Decision-making stages according to UNI 10723:1998

The Executive Process is the set of operational phases that lead to the realization of the building intervention according to what is defined in the previous phases.

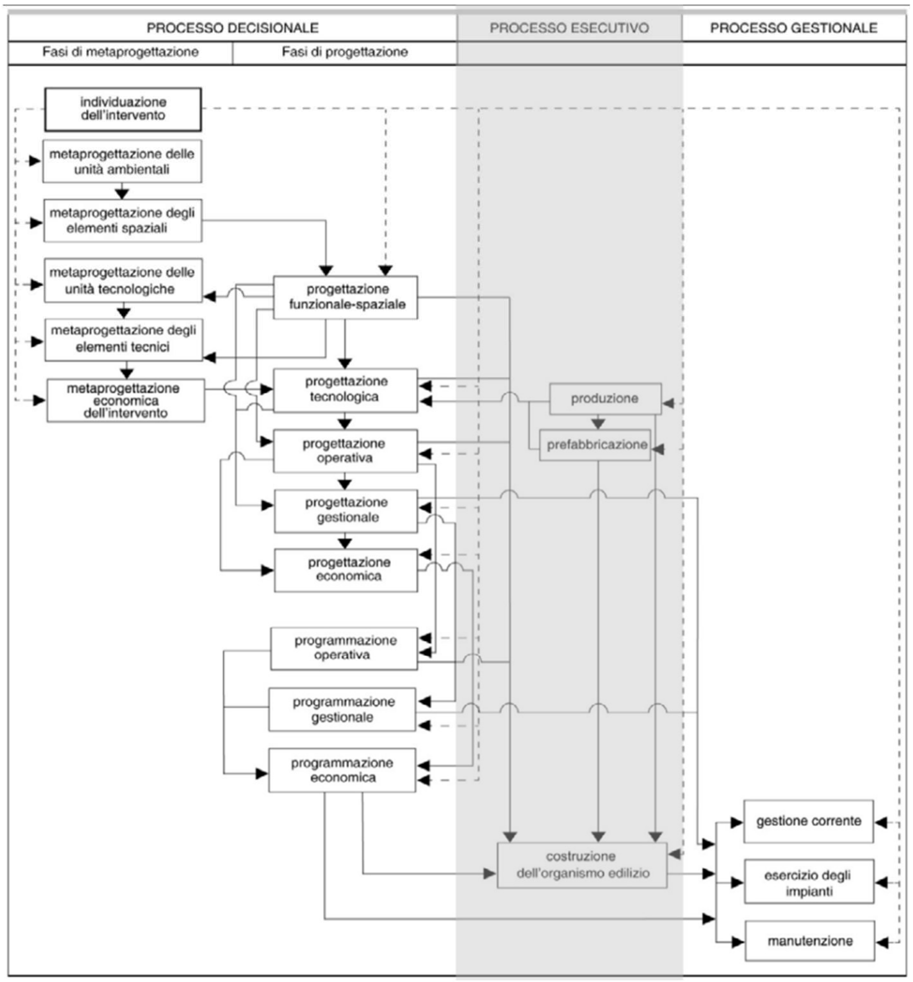


Figure 10:The Executive stages according to UNI 10723:1998

Lastly, the Management Process is the set of operational phases that, starting from the entry into service of the building body, follow each other, in order to ensure its functioning until the exhaustion of its functional and economic life cycle

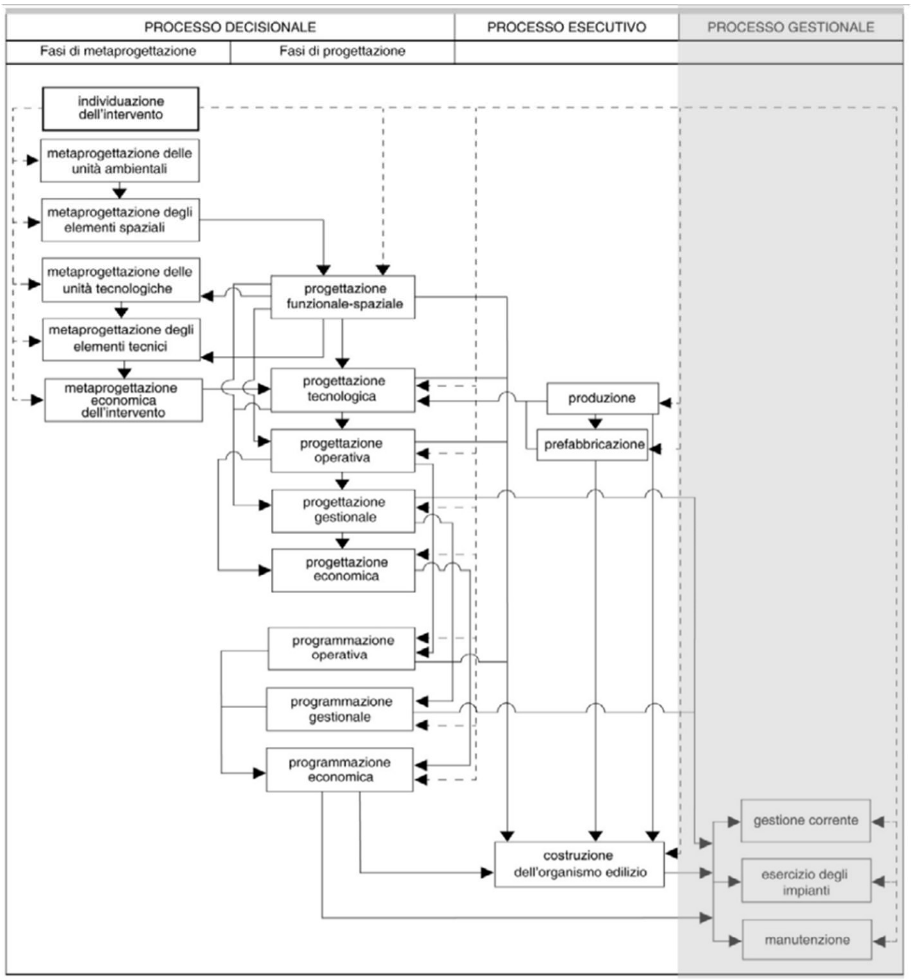


Figure 11: The Management stages according to UNI 10723:1998

In the entire building process operates a series of Operators to each of which is attributed, in the different phases, a role and specific tasks:

- Planning Entities, which are responsible for the choices of background and programming at the various levels;

- Regulatory authorities, which are responsible for issuing and updating the rules concerning the process,

- Decision-making and Control authorities responsible for the control of the building process as regards both the decision-making responsibilities and the verification of compliance of the process with the regulations;

- Implementing authorities responsible for the implementation of the interventions;

- Entities of Research, Design, which are responsible for research and design related to the residential system and the building product;

- Performance and Production Entities responsible for the production of the product

In addition to all these entities there is the User who is responsible for the use of the final goods and to which each entity must or should refer continuously. He/she intervenes in the various phases with a different weight configuring itself as Main Subject, if he/she operates as a client, the user also becomes one of the main Actuator Entities present in the process.

The customer is the principal figure of any operation. During the design phase, the professionals get involved as its delegates, both for design and for safety. Instead, the control of the project is the task of the bodies responsible for the application of the current legislation. In the executive phase, alongside professionals and supervisory bodies, the Company intervenes, which is entrusted with the task of carrying out the work.
The path towards the digitisation of the construction sector and, in particular, the adoption of BIM methodology takes place in different ways in different international contexts. In fact, in the past 5 years, like the UK, Italy has introduced the use of BIM in the public and private markets.

The reference standard for BIM methodology is the UNI 11337 technical standard that analyses the whole world of construction referring to any type of product (building or infrastructure), to each process phase and to each type of intervention.

The first part of UNI 11337 defines a scheme for characterising information, the means by which it is exchanged, the product and the building process.

Firstly, the standard clarifies how data can be exchanged to achieve 'process digitisation'.

The data exchanged are:

- Electronically structured: structured data means a system for encoding data in order to generate information content organised as in a database.
- Electronically processed: the data must also be usable by those who have not produced them by electronic means.
- Electronically related: Electronically structured data must be organised according to logical relationships.
- Fixed on digital media and written in open format to maximise the usability of the data regardless of the tools use.

These data can be exchanged through information vehicles which can be distinguished in information works and information models.

The information works provide a representation of reality (this is the documentation on which the traditional building process is based). Differently, the information models provide a virtualisation of reality, a digital copy of it. Information models consist of objects and it is always possible to extract one or more information works from them.

In the digital construction process, information models and deliverables are gathered in a common data environment (CDE) called in Italian ACDat (Ambiente di Condivisione dei Dati).

Subsequently, in the first section of the UNI 11337:2016 standard, the product and construction process information structure is described in 4 stages and 8 phases. There are 2 main stages: development and operation. The first stage is then further divided into 3 sub-stages: planning, design and production. Subsequently, stages are identified for each stage:

1. Requirement
2. Feasibility - sustainability
3. Functional-spatial
4. Authorisation
5. Technological
6. Executive
7. Testing and delivery
8. Operation and Maintenance

Each stage can start even when the previous one has not yet ended, otherwise a stage only starts if the previous one has started.

At present, there is no direct correspondence between the stages and phases foreseen by UNI 11337-1 and those defined by the public works regulatory framework, although it is possible to establish relationships:

- the feasibility project may correspond to the functional spatial information phase

- the final design may correspond to the authorisation information phase

- the executive project may correspond to the technological information phase.

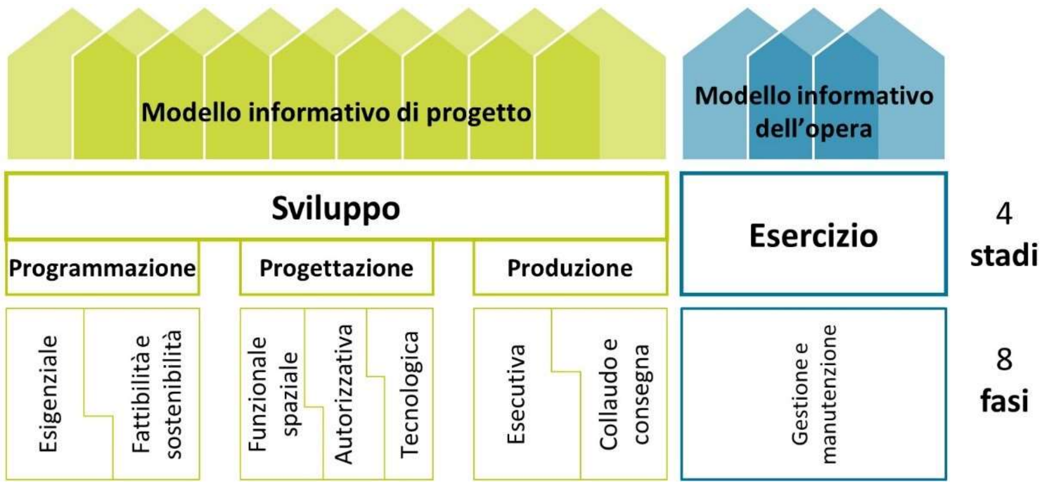


Figure 12:The subdivision of the process according to UNI 11337-1- credits: https://news.wuerth.it/

On the other hand, part 5 of the UNI 11337 standard defines the roles, tools and methods for managing the information flows necessary to enable the production, management and transmission of information within the BIM methodology.

It introduces a precise scheme for the formulation by the Customer of the requirements for the information management of the contract and for their subsequent acceptance by the contractor by identifying three policy documents. Finally, following the definition of the characteristics of the ACDat, the standard identifies the new professional figures related to the implementation of a digital construction process.

These figures are the subject of an in-depth study in part 7 of the standard.

Figure 13:The professional figures introduced by UNI 11337-7- credits: https://news.wuerth.it/

The standard identifies three management figures that are the information flow manager, the information manager and the information coordinator and an operational figure, i.e. the information modeller.

The ACDat information flow manager (CDE Manager) is in charge of managing the shared environment, its use and the data it contains. The figure of the CDE Manager is juxtaposed to that of the BIM Manager; this figure is required to master data science in order to govern an entire digital ecosystem.

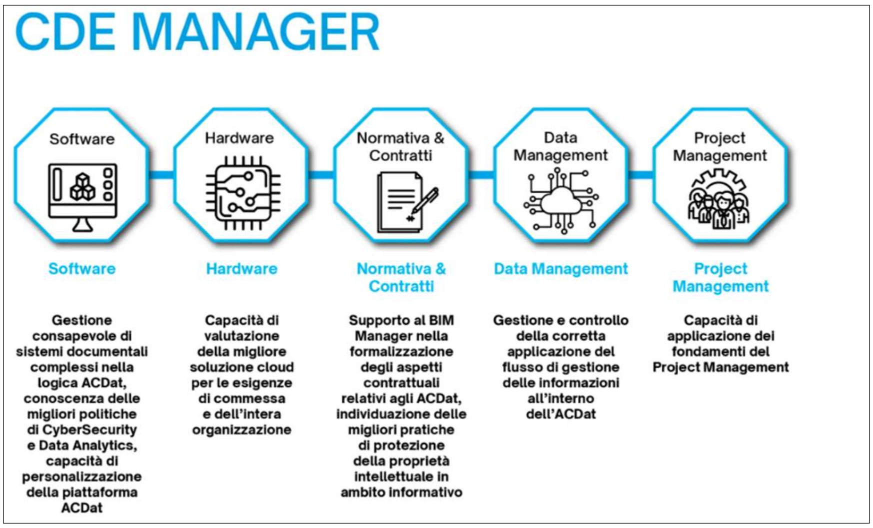


Figure 14: The competences of the CDE Manager – credits: https://adhox.it/professioni-metodo-bim-certificazioni/

The information manager (BIM manager) who manages the general information rules of the organisation, resource management and contracts. The profile of the BIM Manager emerges as a manager of the digital processes of the organisation for which he or she acts. In fact, he or she must be able to carry out periodic assessments of the degree of digital maturity of the organisation. The BIM Manager is responsible for overseeing the configuration of proprietary guidelines and their updating through inspections but can also assist top management in determining investment and training policies.

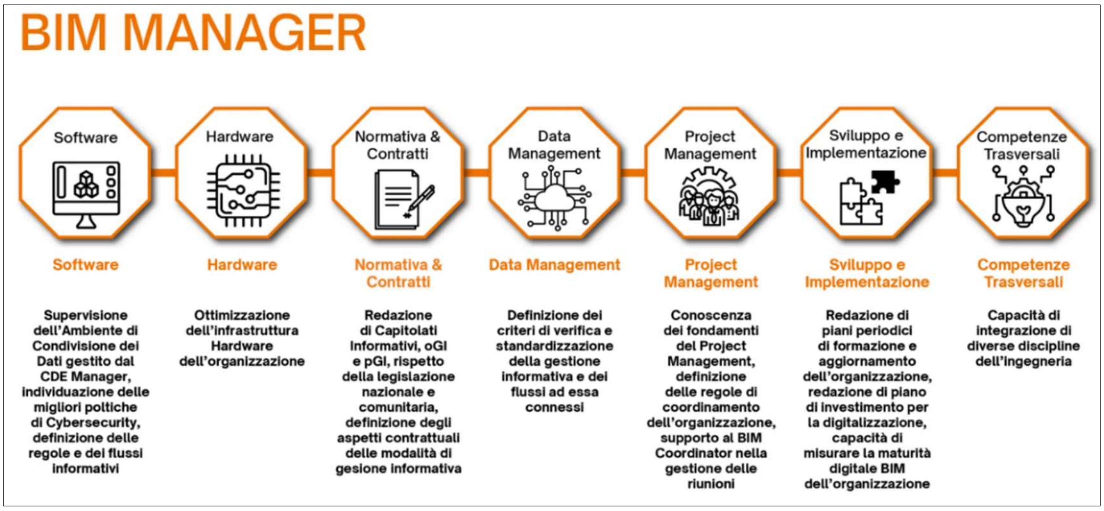


Figure 15: The competences of the BIM Manager– credits: https://adhox.it/professioni-metodo-bim-certificazioni/

The information coordinator (BIM coordinator) has control over the application of the information rules of the process. The figure of the BIM Coordinator aims to link the BIM Specialist and the BIM Manager, assuming a fundamental role in coordinating activities and ensuring continuity between calculation and modelling environments. This professional figure is a key figure in the design phase, but also for the planning phase, monitoring and control of works, in the execution phase, or in the maintenance phase, in forecasting interventions and managing work orders.

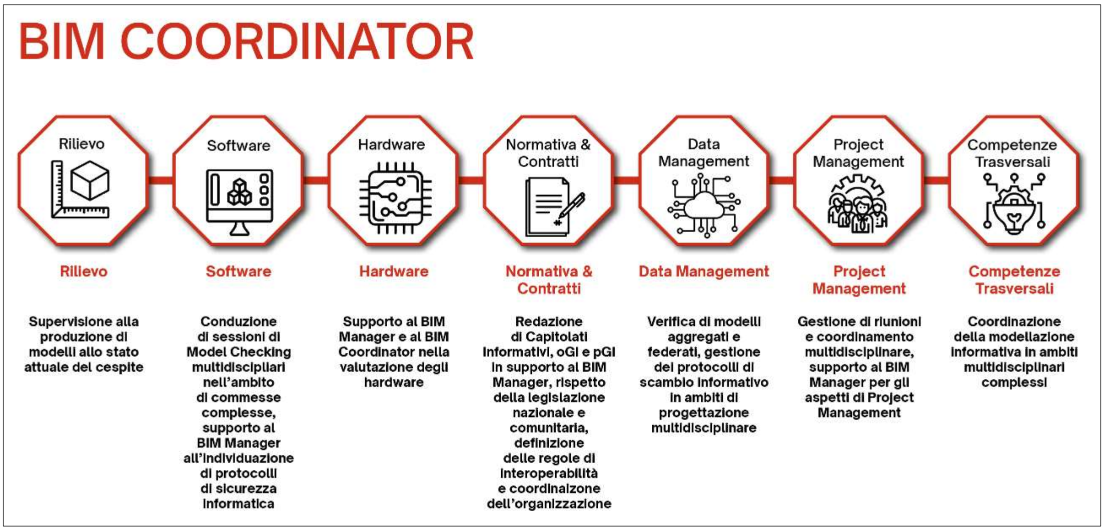


Figure 16:The competences of the BIM Coordinator– credits: https://adhox.it/professioni-metodo-bim-certificazioni/

Finally, the information modeller (BIM Specialist) is in charge of the realisation of the models and the application of the information rules of the process. In fact, the BIM Specialist is the operative subject technologically involved in the information modelling and endowed with awareness of the cultural, legal, managerial and organisational implications. He or she shall possess a profound knowledge of the applications for the production of information models and an adequate mastery of the relative disciplinary knowledge, as well as an awareness of the criteria with which the software has been conceived from the point of view of information engineering and databases.

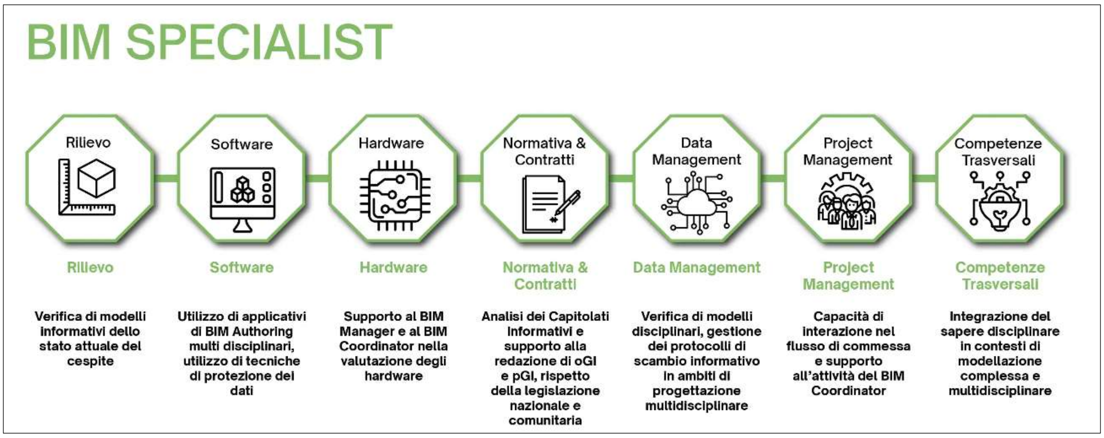


Figure 17:The competences of the BIM Specialist– credits: https://adhox.it/professioni-metodo-bim-certificazioni/

The building process is structured according to the contents of the Digital Plan of Work designed by the UK Government to provide a system to make it easier for Clients to access, plan and control BIM projects. This topic will be addressed in the next chapter.

2.4. The construction process according to English standards

The code of Practice for Facilities Management (Building Infrastructure) BS 8536-1:2015 provides recommendations for design and construction briefing to outline the expected performance of a building in use.

BS 8536-1 and 2 wants to involve the operator, the operations team and the relevant supply chain from the very beginning of the process and to include post-care operations in this supply chain.

The new version of BS 8536-1 includes briefing requirements for soft landings, building information modelling (BIM) and post-occupancy evaluation (POE).

According to the standard BS ISO 22263 a building process is *a process that normally occurs several times in the life-cycle of a construction entity, from its initiation to its termination, Each project adapts the construction process to meet specific goals within a frame of time, cost and quality.*

Although, in 2014, the UK government wanted to provide clients with a clear and simple system for accessing, planning and controlling projects by creating the Plan of Work.

In fact, in the same year, the UK government commissioned the NBS (National Building Specification), a subsidiary of the RIBA (Royal Institute of British Architects) organisation, to produce a free, simple and accessible online tool to provide the type of information to be provided to the BIM project team.

The Plan of work is a document that describes in a quantitative and qualitative way the future strategies and actions to be taken explaining how to create, build and manage an asset.

Particularly*, the plan of work is a framework to ensure that the deliverables of all contributors are identified and appropriate to the decisions required at each work stage and should be adopted by the owner as the basis for delivering and operating the asset/facility.* (Standard BS 8536-1:2015)

The benefits of using a Digital Plan of Work are many.

- There is an informed, consistent decision-making framework for all members of the design team, including the clients. Furthermore, at each stage of the work, you are able to provide the client with the progress of the work in a consistent and agreed manner.

- This is a system that encourages collaboration between the contributing parties at each stage of the project. This approach makes each figure aware of his or her obligations and makes the results to be achieved clearer.

- Ultimately, the Plan of Work identifies and clarifies the responsibilities of each individual, providing clarity and creating a project that is constantly monitored and updated from the beginning.

The PoW phases are eight and they must aim to meet the client's requirements.

1. *0 Stategy*- defines the owner's business case for the project, including required outcomes and other core consideration.

2. *1 Brief* – develops project objectives, including project outcomes and required performance for the asset/facility.

3. *2 Concept* – prepares the concept design, including outline proposals for the structural design and building services engineering systems.

4. *3 Definition* – develops the design, including outline proposals for the structural design and building services engineering systems.

5. *4 Design* – prepares technicaal design, including coordinated and updated proposals for structural and building services engineering information, cost and detailed operational data.

6. *5 Build and Commission* – plans, organizes and coordinates off-site manufacturing with on-site construction, including assembly, testing and commissioning.

7. *6 Handover and close-out* – training of the operations team and selected end-users, handover of the asset/facility to the operator and start-up of operations.

8. *7 Operation and End of Life* – steady-state operation, aftercare, post-occupancy evaluation, fine-tuning (POE), benchmarking and feedback.

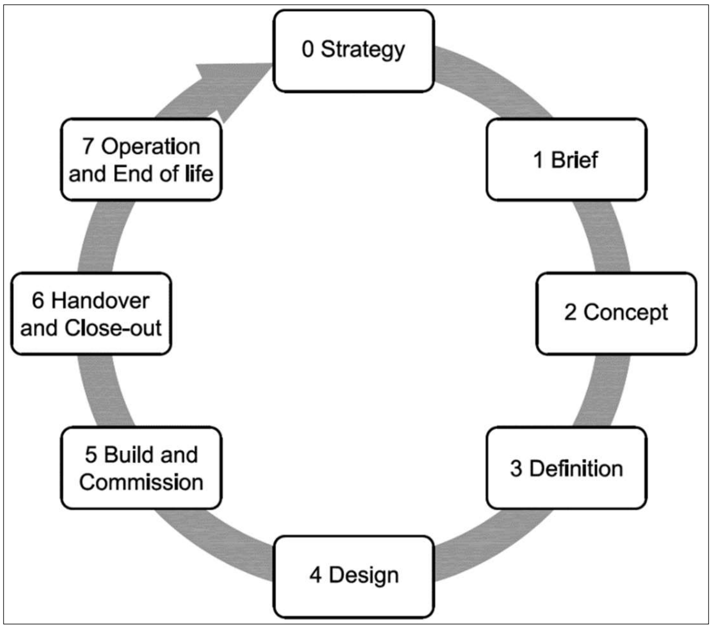


Figure 18: Work stages according to BS 8536-1:2015

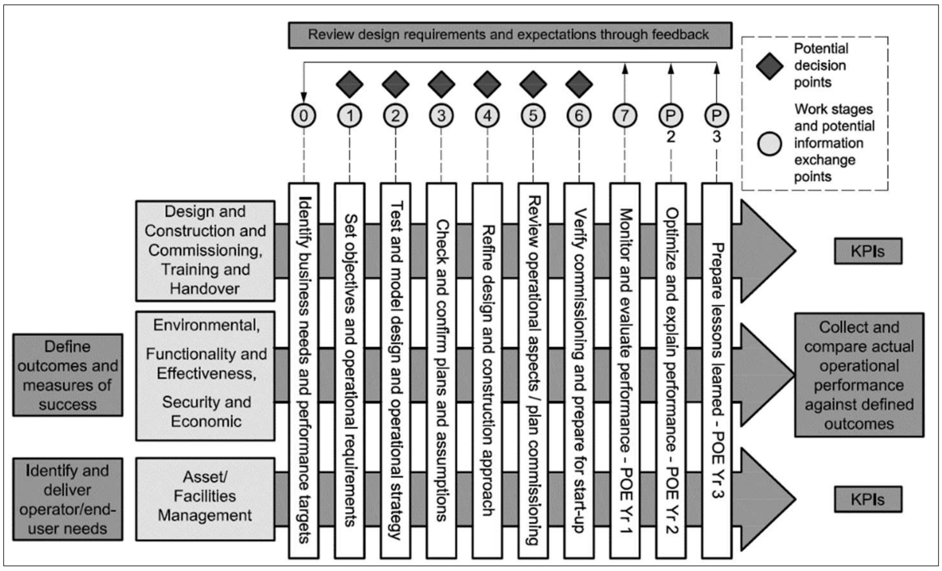


Figure 19: Overall approach highlighting the importance of performance reviews and feedback according to BS 8536-1:2015

This PoW complements the RIBA Plan of work which provides a framework for the project team for design, construction and operational processes whether a BIM approach is adopted or not.

The RIBA Plan of Work 2020 is a map that organizes the process of consultation, design, construction, maintenance, operation and use of projects in a series of key phases. The details and objectives of each phase may vary or overlap to meet the specific needs of the project. The RIBA Plan of Work 2020 consists of eight phases ranging from number 0 to 7. Each stage is briefly described below.

1. Stage 0 - is about determining the best means of achieving the client's requirements. (RIBA Plan of work, page 19)

2. Stage 1 - is about the detail of the brief and making sure that everything needed for the design process in in place before. (RIBA Plan of work, page 20)

3. Stage 2 - is about getting the design concept right and making sure that the look and feel of the building is proceeding in line with the client's vision, brief and budget. (RIBA Plan of work, page 22).

4. The purpose of Stage 3 is to spatially coordinate the design before the focus turns to preparing the detailed information required for manufacturing and constructing the building. (RIBA Plan of work, page 24).

5. Stage 4 is about developing the information required to manufacture and construct the building. (RIBA Plan of work, page 26).

6. Stage 5 is when the building is manufactured and constructed.

7. In Stage 6 the building will be in use and the emphasis of the project team will have switched to closing out any defects and completing the tasks required to conclude the Building Contract. (RIBA Plan of work, page 29).

8. Stage 7 is the period when the building is in use, lasting until the building reaches the end of its life. (RIBA Plan of work, page 30).

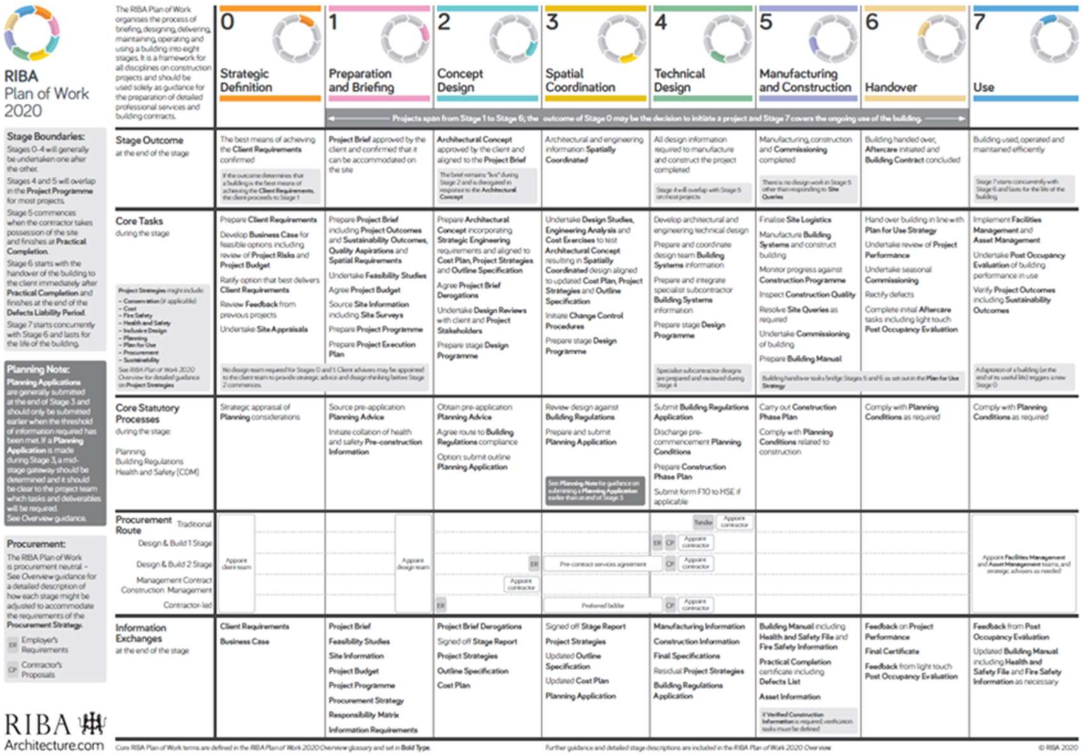


Figure 20: RIBA Plan of work template

This is followed by a further description clarifying how the RIBA Plan of work is intended as a guiding document. Its strength is its adaptability to any type of project and any design programme (CAD or BIM).

The first stage (stage 0) of the RIBA Plan of Work outlines a project brief and identifies your project definition criteria, personal priorities and design ambitions. This stage gives the client the opportunity to understand what the architect has to offer by assessing their experience and portfolio.

In stage 1 an initial project summary is prepared using the information gathered in the previous phase. There are also feasibility studies, site/building surveys, and an initial risk and cost assessment of the project. Each phase of the RIBA Work Plan incorporates sustainability checkpoints. This checkpoint was introduced in 2020 with the aim of reducing carbon emissions to zero by 2030. This phase helps guide the design of subsequent phases.

The following stages, especially 2, 3 and 4, are the main design phases of the RIBA work plan.

In particular, stage 2 is the phase in which the client receives the first visualisations or drawings of the design ideas developed from the project brief.This design also includes a proposal for structural design, construction services and specifications. These proposals will be useful in defining the costs associated with the project.This is also a useful stage for research and development of innovative materials or new solutions that can improve the design.

In the next stage (stage 3) the project is elaborated in a more detailed and clear way and develops the structural design, construction services and a costing exercise defining detailed elements. This project will be enhanced in stage 4 where the drawings and documentation required for the tender will be prepared and completed at the end of this stage.

Stage 5 is the start of construction. The project is complete. In some cases, stages 4 and 5 overlap or proceed simultaneously in order to speed up the start of work but create price uncertainty due to unresolved design details. A compromise must be found for the client between speed and price certainty.
Stage 6 concludes all aspects of the construction contract, such as the correction of any defects, the production of the final certificate by the contract administrator, or commissioning, to ensure the proper functioning of the building.After delivery of the building, the Defect Liability Period (or Rectification Period) begins, normally lasting between 6 months and one year. The Contractor undertakes to report and remedy any defects found within this period.

The RIBA Work Plan stage 7 exists as a form of customer service including requests for constructed drawings or discussions for future modifications or additional work, or advice which may relate to the maintenance or general management of the installations. These services are decided and described in the initial appointment agreement.

Further to the definition of the work stages, the BS 8536-1:2005 standard defines the roles and responsibilities, identifying several figures:

- Owner.
- Owner's representative.
- Operator, operations team and facility manager.
- End-users.
- Design and construction team.
- Subcontractors, specialist suppliers and manufacturers.

For each role, an extract from the norm is given in order to provide a comprehensive explanation of the duties and obligations of each of them.

The owner should ensecure that there is a clear governance structure with defined roles and responsibilities that are resourced by personnel with the appropriate level of competence, skills and experience. […]

The owner should appoint a person whose principal task is to ensure that design and construction is planned and controlled to enable a smooth transition into operation and for the defined periods of aftercare.

The owner's representative should be appointed by the owner for the whole period from the Strategy and into the Operation and End of life work stage to provide continuity of purpose and consistency. […]

The role should include regular reference to the schedules or equivalent documentation that identify the work activities of the design and construction team with their associated information requirements and deliverables. The owner's representative should facilitate input from the operator, operations team or facility manager, as appropriate, and end-users to the work of the design team with their associated information requirements and deliverables.

The operator, operations team and facility manager, as appropriate, should be given authority by the owner to contribute information and data concerning the operational strategy and operational requirements, including performance outcomes and targets, operational costs and budgets, and the procurement of facility-related services where appropriate.

The users of asset/facility are a key stakeholder group and can include occupants, visitors and external customers among others. They are collectively referred to as "end-users", because they are generally the ultimate beneficiaries of the services provided by the asset/facility in operation.

The design and construction team should support the role of the owner's representative in pursuing an operational asset/facility that meets agreed performance outcomes and targets. The design and construction team should nominate a person from within its body to be responsible for coordinating all transition-related activities with the owner's representative.

As far as practicable, subcontractors, suppliers and manufacturers should adopt an approach that supports the key principles throughout all work stages in which they are involved.

2.5. Summary of the Italian and English standards

The construction sector, in the first decade of the 21st century, has faced a very critical moment in the application of BIM and in the transition from the traditional approach that does not reason by objects but by projects. This approach, in fact, is based on project progress levels, which are at the basis, as in Italy, of the entire apparatus for measuring contracts, performance/services and fees. A level of progress contractually required by the client is not trivially modifiable according to BIM.

With the use of 3D modelling tools, the measurement of project progress is transferred from the "project" to the "objects" it contains (systems and components). In fact, BIM has introduced the LOD Level Of Development/Detail/Definition (information system; graphic and non-graphic).

In 2007, the RIBA (Royal Institute of British Architects) has a well-established system of design advancement in the UK on which contracts run. The current system, as described above, is based on 8 stages that represent the entire construction process.

In 2013, when defining PAS 1192-2, the RIBA underlined this topic. In fact, in PAS 1192-2 the LODs are not referred to the "objects" but referred to the "model": Level of - model - Definition (or Detail).

The LODs of the model, according to PAS do not have a numbering and are defined according to the phases: Brief; Concept; Design; Definition; Build and Commission; Handover and close-out; Operation and in-use. The assignment of LODs to "objects" in the UK system was introduced in the BIM Toolkit in the following two years.

It should be noted that the British system is linked to the process stages, while the Italian system (UNI11337-1:2017) the development of the object takes on a character of its own, freeing it from the stages and phases of the process. LODs are classified through a letter and a designation: A-symbolic, B-generic, C-defined, D-detailed, E-specific, F-executed, G-updated.

In the Italian standard, UNI 11337-1:2017, moreover, the problem of the development of the "objects" and that of the development of the "project/model" of the models is addressed providing an answer to the criticalities (at the level of objects and at the level of projects/models) completing the work of the PAS. In order to do this, in part 1 of the UNI, the Stages and Phases of the construction information process are defined which allow, precisely, to specify the objectives and uses (measure of the model/project), and the LOD (measure of the objects).

The definition of the information stages of the process does not yet have a clear correspondence with the traditional design levels on which the mandatory legislation on public works is based. For this reason, in the annex to part 4 (UNI 11337-4; annex I) the design levels/models have been referred to the development levels foreseen by the procurement code to which specific LODs have been made to correspond.

In conclusion, for an easier reading of the reference panorama, an overall framework of comparison of the two standards is given below.

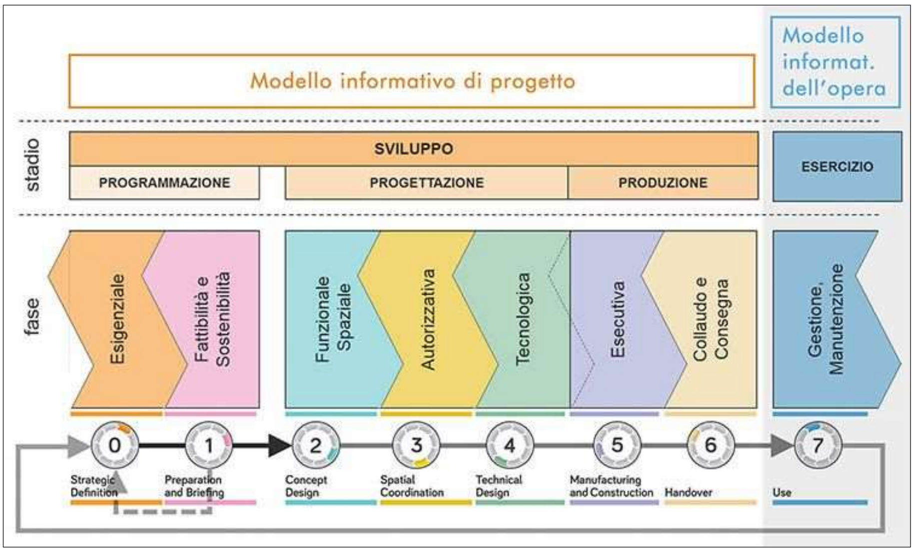


Figure 21:Comparison of standards – credits: https://www.infobuild.it/

2.6. COBie protocol analysis

In the construction sector, the collection and preparation of the information needed to manage a project have always been neglected.

As the professor at the Politecnico di Milano Cinzia Talano says *"The analysis of current practices highlights how the operations and maintenance phase, being the final stage of the building process, is mainly influenced by the problems connected with a not effective organization of information, occurred in the previous phases."*

One element that needs to be clarified with regard to digitisation concerns the actual possibility for operators to exchange data through digital models that are accessible to all, regardless of the software used.

IFC files, over time, have been used as a data structure of continuous and bidirectional interchange between programmes during work phases. This data exchange is fundamental, as the different disciplines complement each other by following a coordinated workflow. Facility management is the area where this criticality manifests itself most, because data is often missing or redundant.

In an attempt to coordinate the flow of information by focusing more attention on the content and not on the digital format, a military initiative by the U.S. Army in 2007 gave rise to the COBie protocols. The Construction Operations Building Information Exchange (COBie) protocol is a process representation to reduce costs and increase the quality of the project in terms of satisfying organised criteria. This protocol was then modified and expanded over time into the National BIM Standard by the National Institute of Building Sciences in the United States to optimise and limit resources, costs and time.

COBie avoids the problems of different formats by theorising about an information representation that exists outside the geometric digital model. However, one of the critical points is that the information cannot be transferred solely by means of alphanumeric data and the bi-directional character is lost by having to manually update the geometric model in its original format.

In concrete terms, the COBie protocol is a spreadsheet in open .xml format, characterised by a specific structure made editable in every part.

This makes it possible to order and share data relating to a building and all its parts, ensuring that all the information and data shared by the various professionals involved are complete, compatible, and usable for the management of the building, from design to operation and maintenance of the facility.

Title	COBie	
Version	2	
Release	4	
Status	IFC2x3	
Region	en-US	
Purpose		This COBie spreadsheet is an example file that comes with the COBie Extension 1.0
Outline		Individual worksheets are organized by project phase as shown below
All Phases	Sheet	Contents
	Contact	People and Companies
Early Design Worksheets	Sheet	Contents
	Facility	Project, Site, and Facility
	Floor	Vertical levels and exterior areas
	Space	Spaces
	Zone	Sets of spaces sharing a specific attribute
	Type	Types of equipment, products, and materials
Detailed Design Worksheets	Sheet	Contents
	Component	Individually named or schedule items
	System	Sets of components providing a service
	Assembly	Constituents for Types, Components and others
	Connection	Logical connections between components
	Impact	Economic, Environmental and Social Impacts at various stages in the life cycle
Construction Worksheets	Sheet	Contents
		NOTE: Submittals and approvals added on 'Documents' worksheet
		NOTE: Manufacturer and model added on 'Type' worksheet
		NOTE: Serial and tag added on 'Component' worksheet
Operations and Maintenance Worksheets	Sheet	Contents
	Spare	Onsite and replacement parts
	Resource	Required materials, tools, and training
	Job	PM, Safety, and other job plans
		NOTE: Warranty information added on 'Type' worksheet
All Phases	Sheet	Contents
	Document	All applicable document references
	Attribute	Properties of referenced item
	Coordinate	Spatial locations in box, line, or point format
	Issue	Other issues remaining at handover.
Legend		
	Text	Required
	Text	Reference to other sheet or pick list
	Text	External reference
	Text	If specified as required
	Text	Secondary information when preparing product data
	Text	Regional, owner, or product-specific data
	Text	Not used

Figure 22: The organisation of an excel Cobie sheet.

M13 fx year

	Name	Description	Duration	DurationUnit	Start	TaskStartUnit	Frequency	FrequencyUnit	ExtSystem	ExtObject	ExtIdentifier	TaskNumber	Priors	ResourceNames
2	1810 x 2110mm Maintenance Schedule	1810 x 2110mm	0,25	hour	n/a	n/a	0,02	year		IfcTask		n/a	n/a	n/a
3	790 x 2110mm 3 Maintenance Schedule	790 x 2110mm 3	0,25	hour	n/a	n/a	0,02	year		IfcTask		n/a	n/a	n/a
4	Cell Bed family Maintenance Schedule	Cell Bed family	0,1	hour	n/a	n/a	0,02	year		IfcTask		n/a	n/a	n/a
5	Desk Whitewood Maintenance Schedule	Desk Whitewood	0,1	hour	n/a	n/a	0,02	year		IfcTask		n/a	n/a	n/a
6	Cell Locker Maintenance Schedule	Cell Locker	0,1	hour	n/a	n/a	0,02	year		IfcTask		n/a	n/a	n/a
7	Safer Seat Maintenance Schedule	Safer Seat	0,1	hour	n/a	n/a	0,02	year		IfcTask		n/a	n/a	n/a
8	1275x1200h Maintenance Schedule	1275x1200h	0,1	hour	n/a	n/a	0,02	year		IfcTask		n/a	n/a	n/a
9	TFT Monitor Maintenance Schedule	TFT Monitor	0,1	hour	n/a	n/a	0,02	year		IfcTask		n/a	n/a	n/a
10	Mirror Maintenance Schedule	Mirror	0,1	hour	n/a	n/a	0,02	year		IfcTask		n/a	n/a	n/a
11	Plumbing SVP 1 Maintenance Schedule	Plumbing SVP 1	0,5	hour	n/a	n/a	1	year		IfcTask		n/a	n/a	n/a
12	WC Pan 510 x 510mm Maintenance Schedule	1. Routine hygienic cleaning should consist of spraying the CWC with a	0,1	hour	n/a	n/a	0,02	year		IfcTask		n/a	n/a	n/a
13	Wallgate ALS180 Basin 470w x 300d Maintenance Schedule	affects the components in contact with water. If the unit is installed in a	0,1	hour	n/a	n/a	0,02	year		IfcTask		n/a	n/a	Wallgate ALS180 Basin DL7523

Instruction | Contact | Facility | Floor | Space | Zone | Type | Component | System | Assembly | Connection | Spare | Resource | Job | Impact | Document | Attribute | coordinate | Issue | PickLists | Sheet1

Figure 23: The COBie protocol "Job" form to be filled in Data Drop 4 "Operations and Maintenance Information

Before analysing in detail the information to be collected in the operation and maintenance phase, the protocol identifies a list of people involved in the whole process (from design to maintenance of an artefact)

4.2.1.2.2 Stakeholders List

Owners
Planners
Architects
Consulting Engineers
Construction Managers
Contractors
Sub-Contractors
Fabricators
Suppliers
Manufacturers
Commissioning Agents
Facility Operators
Facility Managers
Asset Managers
Software Developers
System Analysts
Systems Integrators

Figure 24: Paragraph 4.2.1.2.2 - COBie protocol

Furthermore, the protocol, in 'Table 4 Stakeholder Coverage Analysis', describes how the concerns of each COBie constituent are addressed through the COBie standard. As an example, an extract from the table is given below.

Consulting Engineers	Quality standards required by the COBie Guide ensure that designers create COBie data that matches the content of all scheduled assets. Merging rules described in this standard provide implementation support required.
Construction Managers	COBie business case analysis supports streamlining those activities that have non-value added operations.

Figure 25: An extract from the table 4 – Stakeholder Coverage Analysis

The protocol then identifies the information to be exchanged, depending on the role of the stakeholder and the phase in the life cycle of the artefact.

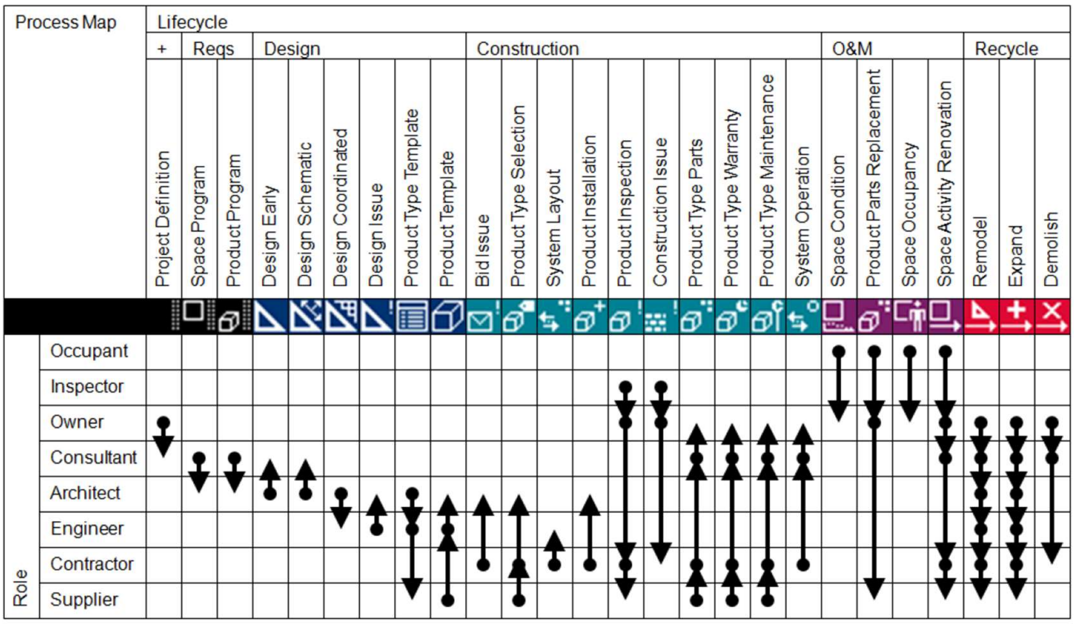


Figure 26: Stakeholder (Figure 30 - COBie protocol)

In addition, the standard provides the different entities that are required for each type of information exchange. These entities are summarised below.

4.2.6.2.1.22 O&M stage – space condition

This exchange includes reporting on the condition of spaces over time. In IFC4, all time-phased information is captured using performance-based properties on IfcPerformanceHistory. This allows for data to be recorded for multiple time periods (avoiding the single property set restriction), and to provide a uniform way of accessing and rendering time-phased data such that software applications need not be aware of particular properties. A property set should be defined for recording space conditions over time. Entities exported for this exchange include the following:

- IfcPropertySet: Properties may be specified to indicate condition details.

4.2.6.2.1.23 O&M stage – product parts replacement

This exchange includes reporting on the replacement of product parts over time. In IFC4, the process and resource model has been formalized, such that replacement of parts may be considered as a MAINTENANCE task with assigned resources for materials, labor, equipment, products, crews, subcontracts. Entities exported for this exchange include the following:

- IfcTask: Report parts replacement over time.
- IfcConstructionResource: Report parts replacement resources.
- IfcPropertySet: Properties may be specified to indicate details.

4.2.6.2.1.24 O&M stage – space occupancy

This exchange includes scheduling occupancy of spaces over time. Entities exported for this exchange include the following:

- IfcOccupant: Indicate occupants.
- IfcTask: Indicate scheduled occupancy periods.
- IfcSubContractResource: Indicate leases for space occupancy.
- IfcRelAssignsToActor: Indicate current owner(s) and/or occupant(s) of a space.
- IfcRelAssignsToProduct: Indicate occupancy periods of spaces.
- IfcRelAssignsToProcess: Indicate resources assigned to space occupancy periods.
- IfcPropertySet: Properties may be specified to indicate details.

4.2.6.2.1.25 O&M stage – space activity renovation

This exchange includes scheduling reconfiguration of spaces over time. Entities exported for this exchange include the following:

- IfcTask: Indicate renovation tasks.
- IfcConstructionResource: Indicate renovation resources.
- IfcRelAssignsToProduct: Indicate elements to be renovated.
- IfcRelAssignsToProcess: Indicate resources assigned to tasks.
- IfcPropertySet: Properties may be specified to indicate details.

Figure 27: An extract from COBie protocol

2.7. The cycle of information: PAS 1192-2

PAS 1192-2 (Specification for Information Management for the capital/delivery phase of construction projects using Building Information Modelling), is the reference standard for level 2 of the English maturity model which will be explained in the next chapter.

All stakeholders in the UK construction industry have identified a process for managing information during the different phases of work leading up to the delivery of a building/installation/infrastructure.

The standard is of great importance because it is now the starting point for the new ISO standard that an international working group is already working on. This would mean foreign orders calibrated to this process, so it becomes strategically important to begin to understand the concept behind this new process.

The standard is based on a fundamental concept: the information in a building is an asset for the client and all the actors involved in the process work together to deliver this information. The method used is Building Information Modelling (BIM), and the standard defines a standardised process for achieving clear and well-defined objectives and milestones.

The following diagram schematises the information delivery cycle with the relevant moments of information exchange, i.e. data. The standard then goes into more detail, and this work will do the same in future sections.

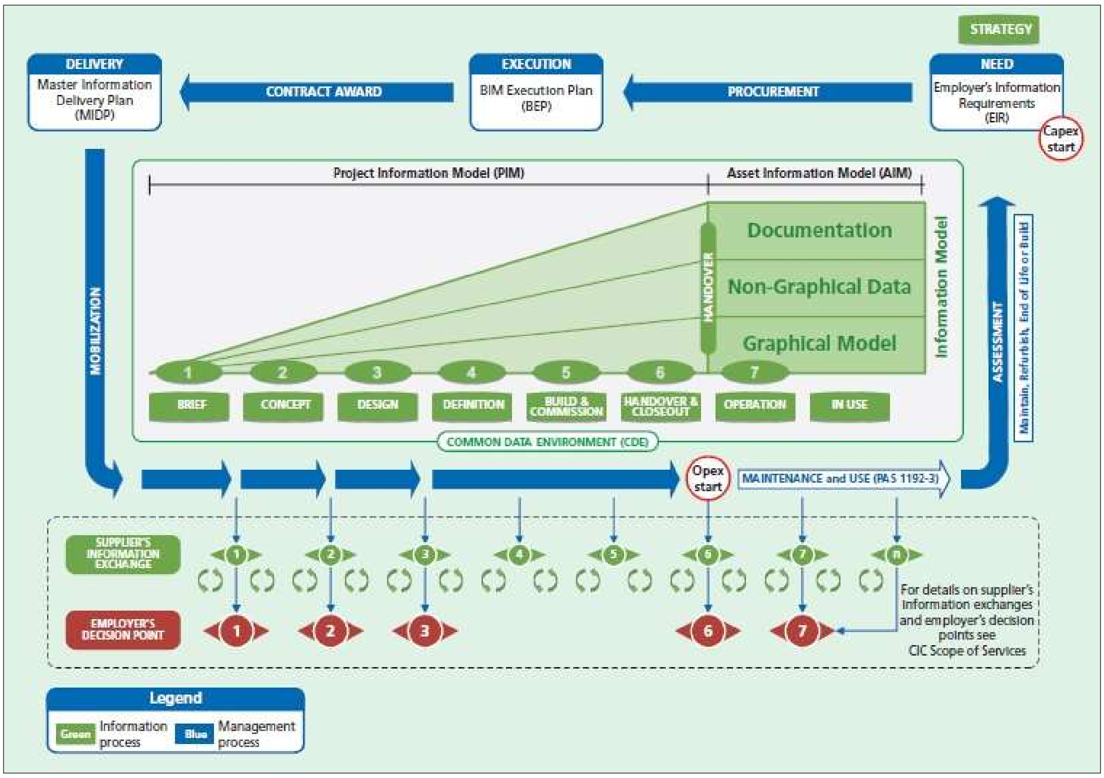


Figure 28: The cycle of information – PAS 1192-2

The reading starts from the top right of the figure, where there is the first moment in which decisions are taken on the information requested by the client. Following this, the requests are received by the team. This team, in turn, defines a plan of action by defining the method of information exchange.

Afterwards, the design from a project idea is started. In these phases, an intensive exchange of information takes place, which is managed and controlled at certain defined moments. At the moment of delivery, the virtual building, the Building or Asset Information Model, is also delivered. This model must be maintained to always reflect the real characteristics of the building as they change over time.

2.8. BIM maturity levels

In 2011, an industry strategy began in the UK with the aim of reducing costs throughout the building lifecycle (planning, design, construction, maintenance, demolition) and reducing CO_2 emissions from the building stock.

The whole industry will have to move from a collaborative process based on 2D models to one based on parametric 3D models, i.e., a Building Information Modeling methodology. The triangle diagram represents the steps that the industry as a whole needs to take in order to operate in OpenBIM.

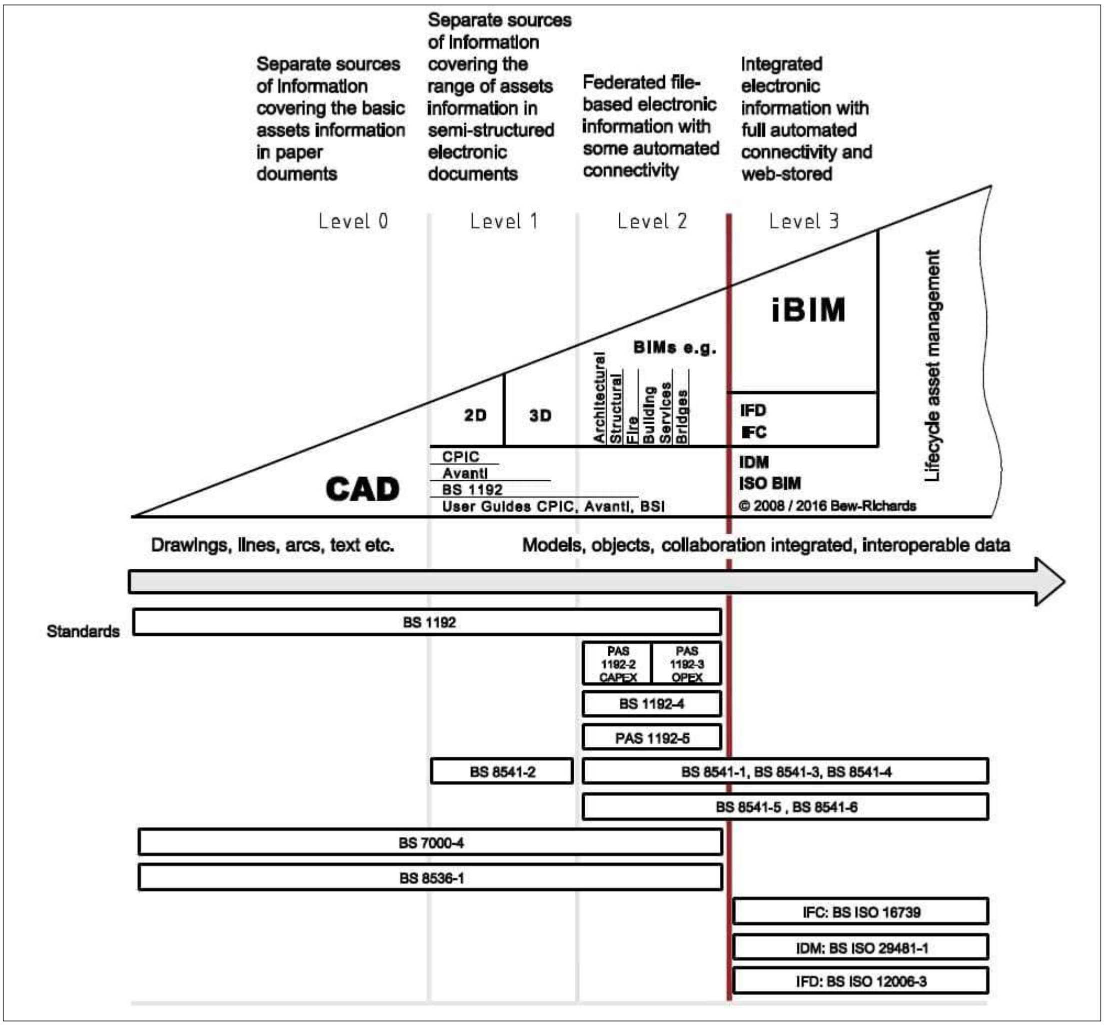


Figure 29: BIM maturity levels – credits: https://bim.acca.it/bim-e-interoperabilita-dei-software/

The 4 steps, called "levels", are described below.

- BIM level 0

In level 0 there is no collaboration between the stakeholders, a CAD system is used with only the use of 2D drawing and a mechanism of data exchange in paper or electronic form.

- BIM level 1

There is a use of 3D CAD for the architectural design in the conceptual development phase and 2D CAD for documents useful for legal approvals and for the transition to the construction site. Electronic data sharing takes place in a common environment: the Common Data Environment (CDE) even if there is no collaboration between the different disciplines, each publishing and modifying its own data.

- BIM level 2

This level is characterised by collaborative working. There is a use of BIM systems that develop BIM models, managed for each discipline, with data associated with the objects represented. Not necessarily all parties work on a single shared model but at least in federated models. Each must export to one of the most common file formats such as IFC (Industry Foundation Class) or COBie (Construction Operations Building Information Exchange). The approach can develop 4D models (3D and time scheduling) or 5D models (4D and cost constraints).

- BIM level 3

Level 3 represents full collaboration between all disciplines through a single, shared project model stored in a centralised repository. This is Open BIM. The process is completely open with data integration enabled through IFC/IFD. Everything is managed by a server. This level could be considered as iBIM or as integrated BIM and potentially used in simultaneous engineering processes.

Copyright and risk-sharing issues need to be resolved. The former can be solved probably through the use of contracts and the latter through shared risk procurement paths between the different partners.

3. Role and Responsibilities in CM: Stakeholder management

The analysis of the construction process according to the Italian standard and the English standard allowed an in-depth analysis of the various phases, roles and responsibilities in order to identify a process that is as optimised as possible and in which all the professional figures are present, from the point of view of the client and from the point of view of the designers and contractors.

The starting point was to define the phases that compose this process. From a legislative point of view, the phases identified by the English standard (BS 8536-1) and the Italian standard (UNI 11137:2017) are similar to those in the RIBA Plan of Work. For this reason, the entire construction process examined will follow the time cadence present in the RIBA.

Secondly, the stakeholders are analysed by first identifying a macro-category and then identifying individual roles. These structures have been hypothesised by considering a process that exploits BIM tools from the design phase to the maintenance phase and also assuming a maintenance control of the installations carried out by means of the most modern sensor technologies, such as those belonging to the IoT world.

Macro-categories were identified in order to identify all the figures involved in the process, starting from the Italian standard UNI 10723 and the English standard BS 8536-1.

From the point of view of the clients, the first macro-category identified is that of the decision-making authorities to which the owners of the property to be realised to belong. Assuming that the building to be realised belongs to the tertiary sector, this client will be composed of various complementary figures: the owner who may be supported by a representative and the asset managers. The owner is the one who has decision-making and spending power and relies on professional figures to manage and optimise resources. A new professional figure is increasingly emerging, namely the asset manager, whose task is to manage the savings entrusted to him, ensuring their profitability over time with the aim of maximising their value by defining investment strategies.

As regards the design phase, there will be a project team made up of traditional professionals, who will be joined by new professionals: those who will manage the models and the virtual work environment and those who will design and test the sensors.

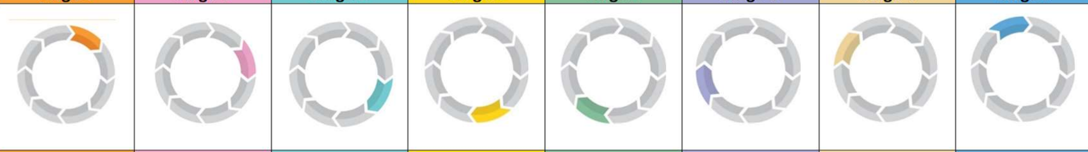
In the construction phase there will be the contractors, sub-contractors, suppliers and manufactures.

On the other hand, from the point of view of the company's internal organisation, there are two macro-categories: end users and the team of operators. The former are those who use the spaces and immediately detect the presence of defects or malfunctions in the building. The latter are those who physically maintain the building, carrying out scheduled or unscheduled maintenance. Within the team of operators there will be a facility manager who has the task of coordinating the activities and the operators.

As far as the plant system is concerned, being the system more subject to checks during use and assuming a maintenance carried out with the support of the sensors, there will be two professional figures: software operator and BIM operator. Initially, these figures will take care and check the correct functioning of the installed sensors and the model. Subsequently, they will train the operators in the correct use of the IoT system and enter the information in digital formats and no longer on paper.

Stakeholders management

Stage 0	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7



Decision making authorities							
Owner/Owner's representative	Owner/Owner's representative	Owner/Owner's representative	Owner/Owner's representative	Owner/Owner's representative	Owner/Owner's representative	Owner/Owner's representative	Owner/Owner's representative
Chief excecutive officer						Chief excecutive officer	Chief excecutive officer
						Chief Operating Officer	Chief Operating Officer
						Chief Information Officer	Chief Information Officer
						Chief Finance Officer	Chief Finance Officer
						Facility Mangers	Facility Mangers
Project team							
Project Lead	Project Lead	Project Lead	Project Lead	Project Lead	Project Lead	Project Lead	
Lead Designer	Lead Designer	Lead Designer	Lead Designer	Lead Designer	Lead Designer	Lead Designer	
Architect	Architect	Architect	Architect	Architect	Architect		
	BIM Manger	BIM Manger	BIM Manger	BIM Manger	BIM Manger	BIM Manger	
	BIM Specialist	BIM Specialist	BIM Specialist	BIM Specialist	BIM Specialist	BIM Specialist	
	BIM Coordinator	BIM Coordinator	BIM Coordinator	BIM Coordinator	BIM Coordinator	BIM Coordinator	
	CDE Manager	CDE Manager	CDE Manager	CDE Manager	CDE Manager	CDE Manager	
			Building Services Engineer	Building Services Engineer	Building Services Engineer	Building Services Engineer	
			Civil & Structural Engineer	Civil & Structural Engineer	Civil & Structural Engineer	Civil & Structural Engineer	
			Cost consultant	Cost consultant			
			Software Developers	Software Developers	Software Developers	Software Developers	
			System Analysts				
Construction team							
					Construction leac	Construction lead	
					Contractors		
					Sub-contractors		
					Fabricators	Fabricators	
					Suppliers	Suppliers	
					Manufactures	Manufactures	
Operator team							
						Software operator	Software operator
						BIM operator	BIM operator
						Facility operators	Facility operators
							End-user

Figure 30: Stakeholder management

3.1. Stakeholder’s hierarchies

First of all, it is necessary to define the hierarchical structure of the various roles in order to better define the responsibilities and consequently the improvement measures. Business processes and organisation charts were studied in order to identify the hierarchy and the relationships between the various departments and to identify the interactions among people, responsibilities and roles.

A corporate position describes the role of an employee or manager within an organisation. Depending on the activity carried out and the company position, the responsibilities and tasks of each professional figure are determined. Employers classify the different positions within their organisation in order to create an organisation chart with the aim of defining the relationships between the figures. These company roles can be divided into executive, managerial and production roles.

Executive roles concern senior positions responsible for the functioning of a specific. They are required to achieve set objectives and to coordinate the figures in the managerial department.

Managers and supervisors are responsible for coordinating and managing the activities of the company by coordinating the productive area with the executive area.

The production department is characterised by the presence of work teams that deal with the same tasks and are responsible for the actual production of a product or service.

Below are the main company positions responsible for management and organisation in the various areas of the company: the chief executive officer (CEO), the chief operating officer (COO), the chief finance officer (CFO), the chief information officer (CIO) and facility manager (FM).

3.1.1. Chief executive officer (CEO)

The term CEO identifies the person delegated with the most responsibility for management and strategic decisions. In fact, the CEO takes the decisions that allow to shape the company organisation and its governance rules according to the set objectives, ensuring a proper management of human and economic resources and the growth of the company. This figure is the point of reference for the entire management, which is entrusted with the operational management of the company and is required to take decisions on company organisation, allocation of resources, investments, commercial collaboration agreements, evaluation of mergers or demergers.

3.1.2. Chief operating officer (COO)

The Chief Operating Officer is an executive who interfaces directly with the CEO and is responsible for coordinating and optimising a company's operational and project activities, making them more effective and functional. In fact, he/she implements the strategic guidelines defined by the CEO by establishing all the necessary operational activities in order to organise the different daily activities.

In practice, the COO plans the company's strategy and monitors the results by supervising all company departments, from the most operational to the most strategic ones. For this reason, the COO communicates with many other top-level figures, such as the CIO (chief information officer), CMO (chief marketing officer) or CFO (chief finance officer).

The main tasks of the COO can be divided into more operational activities such as:

- He/she coordinates the day-to-day operations of the company.
- He/she supports the CEO and replaces him/her in operational activities if necessary.
- He/she analyses and optimises resources
- He/she verifies the return for the company
- He/she monitors the internal company organisation and assesses awards or career moves.

and more strategic activities:

- He/she keeps all senior figures in the company up to date on its work.
- He/she plans and implements company objectives and strategy, communicating them to co-workers and employees.
- He/she co-ordinates and supervises structural organisational changes in the organisation.

3.1.3. Chief finance officer (CFO)

The role of the chief finance officer (CFO) is one of the most important management figures responsible for defining the company's financial strategy. The chief financial officer (CFO) is responsible for the overall management and planning of the company's financial activities, dealing with financial and monetary resources and supervising all business activities, directing the company's strategy in this area.

In fact, his main responsibility is to supervise the financial management of the company ensuring its stability The CFO is also in charge of planning, controlling and coordinating financial activities, investments and holdings interfacing with human resources.

3.1.4. Chief information officer (CIO)

In the era of digital transformation, the CIO holds a strategic position because he has to consider the incorporation of all new digital technologies in the company: analytics to extract information from big data, artificial intelligence for the automation of processes and so on.

In this context, the CIO works alongside the CEO and other managers such as the COO (chief operating officer) or the CFO (chief finance officer) in order to guide the company's digitalisation process in the best possible way.

The Chief Information Officer (CIO) is becoming increasingly important as the head of the company's information and communication technology function. His task is to lead the strategic direction of the company's information systems with the aim of improving and simplifying internal processes and maximising productivity.

The CIO is a business executive and reports directly to the Chief Executive Officer (CEO) and interfaces equally with the heads of other functions such as the Chief Finance Officer (CFO) and Chief Operating Officer (COO).

The Chief Information Officer oversees the operation of the machines but also makes decisions on the strategy of the organisational business processes by taking charge of the company's digital transformation path.

The main tasks of the CIO are:

- Contributing to the analysis and definition of business processes, gathering and rationalising the needs of the various departments.
- Defining, together with management, the company's objectives and the contribution of IT to achieving them.
- Defining and managing the Information Systems budget and coordinating the IT department.
- Be up to date on new technologies available and have in-depth knowledge of the cloud ecosystem and applications of Artificial Intelligence, Machine Learning and Blockchain.
- Use Big Data to transform it into simple and interpretable information.
- Have skills in the field of Data Science and Cyber Security.
- Be up-to-date on new regulations on Privacy and user data management, whose violations can have both civil and criminal implications.
- Participate in the definition of functional and architectural requirements of information tools to be introduced in the company.
- Contribute to change management following the introduction of new information tools; new CMS systems, software, updating and integration of old databases, digitisation of documents and paper archives.
- Designing and managing the day-to-day operation of information systems, optimising internal resources and contracts with external suppliers.
- Manage and organise the flow of information based on experience by facilitating the use of technology.

The advent of digital transformation and Industry 4.0 requires old devices to be replaced with the new tools of the Internet of Things (IoT) and such the role of the CIO becomes more and more being able to interpret the data collected by smart machines. The Chief Information Officer (CIO) is becoming increasingly important as the head of the company's information and communication technology (ICT) function. His task is to lead the strategic direction of the company's information systems with the aim of improving and simplifying internal processes and maximising productivity.

3.1.5. Facility manager (FM)

The definition EN 15221 - 4:2011 identifies the facility manager as "*the person responsible for facility management, who is the single point of contact at a strategic level, leading the facility management organisation, ensuring quality and continuous improvement of the company*".

The Facility Manager is responsible for managing the buildings and services that are instrumental to a company's activities: offices, factories, utilities, security, telecommunications, canteen services, defining the times and procedures for the maintenance of buildings and facilities and coordinating the staff in charge of services, taking into account budget constraints.

The aim of his activities is to ensure an efficient and professional working environment, capable of meeting needs at the lowest possible cost.

The general services covered by a Facility Manager can be divided into two types:

- Services related to infrastructure such as heating and air conditioning systems, electrical, water and fire-fighting systems, and everything related to the maintenance of structures, windows and doors, office furniture.
- Services that make the place better, such as cleaning and waste management services, reception and concierge services, security, mail and internal logistics.

The facility manager carries out these activities with the aim of:

- designing, planning and delivering services to support the company
- increasing the effectiveness of the company and its productivity
- adapting the company to the market

The Facility Manager analyses the company's needs and plans the management of the resources available to everyone.

The facility manager operates in three different areas:

1. strategic by identifying the best services to achieve business objectives
2. analytical by understanding the needs of individual workers to improve the company's operations and productivity.
3. managerial-operational by managing the various services in order to improve them. He defines the maintenance plans for the company's spaces, facilities and installations, establishing operational procedures and making sure they are followed. He also coordinates the activities of maintenance staff and technicians.

Additionally, the Facility Manager analyses the operating results both to account for his work to management and to assess deviations between the estimated budget and actual budgets.

Ultimately, the Facility Manager must know how to manage numbers and budgets and resources, but he must also be able to interpret the company's strategies, identify present and future needs in order to use the best tools and the most suitable control methodology for business choices that drive change. He must therefore intervene in the context of business development with the ability to involve and integrate people, resources and structures.

3.1.6. Maintenance team

Facility operators are those who make up the maintenance team and ensure that the flow of activities is smooth. In order to organise an efficient maintenance department, it is necessary to identify the purpose of maintenance, to define the objectives and to set up the maintenance team. The main purpose of each facility operator is to ensure reliability and optimal performance of the assets in alignment with the needs and objectives of the company.

In order to guarantee all the activities necessary to manage a facility, depending on the size of the space and the number of people and resources that need to be managed, the FM departments have their own separate working teams. A work team that deals with the maintenance of the facility focusing on heating or lighting systems.

In Italy, the national standard UNI 11420 "Maintenance - Qualification of maintenance personnel" and the subsequent publication of the European standard UNI EN 15628 were born with the aim of defining, in the field of maintenance, what are the knowledge, skills, competences and training requirements necessary for the professional qualification that covers a role in the maintenance organisation.

The standard identifies three professional figures:

1. the maintenance specialist;
2. the maintenance supervisor and/or maintenance engineer;
3. the manager of the maintenance service or function.

- Maintenance manager

The maintenance manager must ensure that daily operations run smoothly and are consistent with the strategic objectives of the company. He coordinates and supervises repair, maintenance and improvement work on installations and machines. He supervises the personnel assigned to him, ensuring compliance with general and specific safety rules and measures. In practice, he is the person who checks that the mechanics' report is filled in correctly for both preventive and extraordinary work on machines and installations, he has malfunctioning machinery and devices repaired, regularly organises preventive checks to safeguard the machinery and coordinates inspections and the recording of these checks. In addition, he/she must ensure that all maintenance technicians have the necessary tools to work efficiently by making sure that all operations are within budget and must communicate the needs of your department with management.

Ultimately, the responsibilities of the maintenance manager are:

- Keeping the executive updated on the progress of the work
- Ensure that the recording by employees or external companies of the time that maintenance work is carried out is correct; if not, he or she must ascertain the causes of variation from the scheduled dates and times
- Ensure that the equipment available is correct for quicker and more efficient execution of the work.
- Maintain relations with the control bodies for any periodic overhauls of the installations
- Set up a preventive maintenance and overhaul plan for all the company's machines and installations
- Observing and enforcing the safety standards and measures and the specific requirements for carrying out the work
- Ensuring the constant presence of mechanics during the production process
- Assigning work to staff, giving instructions to return on the dates and times set, and requesting the materials needed to carry out the work entrusted to them
- Keeping abreast of the progress of the work, intervening in those of major importance and instructing staff in overcoming any difficulties

In order to summarise, the seven key competences for the maintenance manager outlined in the standard UNI ENE 15628 are listed below.

- *C.1: to define and develop maintenance policies according to company strategies;*

- *C.2: to define processes and tools to support maintenance tasks;*

- *C.3: to define, manage and develop the organizational model of maintenance;*

- *C.4: to ensure the levels of availability, reliability, maintainability, supportability, safety and quality required for the entire useful life of assets;*

- *C.5: to ensure appropriate management and continuous improvement of maintenance;*

- *C.6: to ensure and control the compliance with maintenance and company budget, the respect of the planned maintenance tasks and the proper condition of assets;*

- *C.7: to define strategies, policies and criteria for performance management of contractors and for the definition of maintenance materials requirements.*

Below is an excerpt from table 3 which highlights for the main skills, competences and knowledge for maintenance manager.

	Competences	Minimum skills	Essential knowledge
C.1	To define and develop maintenance policies according to company strategies	a) To define strategies, policies, guidelines and objectives, controlling the implementation; b) To ensure compliance with legislation, technical standards and company strategies, objectives and procedures on safety, health, environmental protection and quality; c) To develop the maintenance budget in accordance with business strategies, company strategies, objectives and procedures and according to the current state of assets and their life cycle; d) To operate with respect to business strategy, availability target of assets and seek continuous cost optimization; e) To promote process re-engineering analysis and studies for maintenance and logistics with the aim to ensure the improvement of availability, reliability and maintainability and to optimize maintenance costs; f) To follow the development of the relationships with technical organizations, institutes and associations for the issues concerning the area of maintenance.	a) Relevant company procedures; b) Relevant business and company strategies, targets and business processes; c) Legislation, technical standards, management system for safety, health, environment and quality, company's and external specialist resources; d) Fundamentals of business administration and economy; e) Communication techniques; f) Principles, logic and parameters of operation and utilization of items and assets; g) Criteria, logic, methodologies and tools for maintenance management; h) Professional leadership; i) Management of working groups j) Industrial relations; k) To seek relevant industry best practices and aim to implement locally.

Figure 31: Extract from table 3 of the UNI EN standard 15628

If we distinguish between the two figures of the FM and the MM, the former is mainly concerned with facility management and the latter with correcting faults on the facilities.

Although in smaller facilities, the figure of the facility manager and that of the maintenance manager collapse into a single figure

- Maintenance supervisor and/or maintenance engineer

Maintenance supervisors are a key role in ensuring the operational continuity of the different daily maintenance operations. They act as a link between the management ones and the rest of the maintenance team. They are the ones who organise, supervise and direct maintenance workers. For this reason, maintenance supervisors play a more managerial role than maintenance technicians and mechanics. In practice, supervisors lead the team and delegate different tasks and report to a maintenance manager or a facility manager.

The standard UNI EN 15628 defines this professional figure as follows: *the maintenance supervisor or maintenance engineer coordinates the maintenance tasks according to the annual budget, related maintenance plans and unplanned maintenance tasks.*

The key competences are:

- *B.1: to ensure the implementation of maintenance strategies and polices;*
- *B.2: to plan the maintenance tasks within his area of responsibility, defining and organizing the necessary resources;*
- *B.3: to organize, manage and develop the maintenance resources, personnel, materials and equipment;*
- *B.4: to ensure compliance with regulations and procedures related to safety, health and environment;*
- *B.5. to ensure technical and economic efficiency and effectiveness of maintenance tasks based on current state of technology;*
- *B.6: to participate in the technical aspects of contracts and procurement process and manage the performance of the contractors;*
- *B.7: to communicate to all necessary partners such as staff, contractors, customers and suppliers.*

The standard also highlights two competences that are exclusively entrusted to the maintenance engineer in case the maintenance supervisor and the engineer are two separate persons:

- *B.8: to use their technical/engineering knowledge and the organizational tools to improve maintenance tasks and plant efficiency in terms of availability and reliability;*
- *B.9: to fulfil organizational and economical obligations in the field of his undertaken tasks.*

Below is an excerpt from table 2 which highlights for the main skills, competences and knowledge for maintenance supervisor and/or maintenance engineer.

	Competences	Minimum skills	Essential knowledge
B.1	To ensure the implementation of maintenance strategies and policies	a) To contribute to the development of the maintenance budget according to business objectives; b) To cooperate in the development of annual and perennial maintenance plans; c) To define criteria, methods and frequency of maintenance tasks; d) To provide within his area of responsibility, the necessary information to the maintenance manager for the definition of investment proposals relating to assets according to their status; e) To control costs, progress and quality of services; f) To provide essential key performance indicators of maintenance process; g) To develop and propose insourcing/outsourcing concepts to meet the maintenance strategy.	a) Maintenance strategies and policies, methods and technologies; b) Methods and techniques of organization and planning; c) Principles, logic and parameters of operation and utilization of asset and item in combination with wear and damage mechanisms; d) Procedures; e) Business job descriptions and roles; f) Maintenance and diagnostic techniques; g) Principles and techniques of design, construction and maintainability; h) Communication techniques; i) Business objectives.
B.2	To plan the maintenance tasks within his area of responsibility, defining and organizing the necessary resources	a) To negotiate the program of required maintenance works with the physical asset owner/operating manager; b) To define the organizational arrangements for the execution of maintenance tasks; c) To plan maintenance tasks falling under his area of responsibility, define the necessary resources and control the tasks organization and the reporting; d) To coordinate maintenance works performed by	a) Communication techniques; b) Methods and techniques of organization, planning and project management; c) Principles, logic and parameters of operation and utilization of asset and item; d) Standards and operational methods of work.

Figure 32:Extract from table 2 of the UNI EN standard 15628

- Maintenance technician specialist

The job of a maintenance technician is to repair and maintain the facility in which they work. They are those who deal with general maintenance tasks that do not require specialised training. The two most common job types are industrial maintenance technician and building maintenance technician.

Industrial maintenance technicians are responsible for solving mechanical, electrical, and hydraulic issues or reading, analysing technical procedures. Instead, building maintenance technicians are responsible for evaluating, repairing and maintaining plumbing, electrical and HVAC systems in the building. In addition, the company may have a figure who that takes care of all types of maintenance equipment by focusing mainly on machines and perform machine-related maintenance tasks.

The standard UNI EN 15628 provides a list of the competences of this role. *Based on the maintenance objectives, the competences of the maintenance technician specialist consists in the independent execution of maintenance tasks, including the following key competences:*

- *A.1 : to perform or ensure in case of failure the safe execution of the maintenance plans according to business strategies ;*

- *A.2: to act promptly in case of failure or malfunction, ensuring the effectiveness of the restoration;*

- *A.3: to perform or ensure the proper execution according to rules and procedures relating to safety, health and environmental protection;*

- *A.4: to ensure the availability of materials, tools and equipment necessary for the execution of maintenance tasks;*

- *A.5: to coordinate and/or supervise on-site maintenance tasks;*

- *A.6: to ensure the quality of the maintenance tasks:*

- *A.7: to use and ensure the use of the ICT (Information and communication technology) systems.*

Below is an excerpt from table 1 which highlights for the main skills, competences and knowledge for maintenance technician specialist.

	Competences	Minimum skills	Essential knowledge
A.1	To perform or ensure the safe execution of the maintenance plans according to business strategies	a) To perform planned task according to the maintenance plans; b) To perform the inspection tasks in order to highlight and prevent the item degradation; c) To identify and propose actions or projects to improve reliability, availability and maintainability of assets; d) To take care, within the limits of his responsibility, organization and discipline of operating personnel; e) To use the machines, equipment and tools necessary for the execution of maintenance tasks; f) To comply with the required procedures, standards and operational methods of work; g) To apply the diagnostic techniques (failure analysis and troubleshooting techniques) and the on condition maintenance.	a) Maintenance plans, standards and operational methods of work; b) Technical documentation and maintenance manuals; c) Procedures; d) Business job descriptions and roles; e) Risk assessment tools/methodologies; f) Principles and techniques distinctive of the individual profession; g) Principles, logic and parameters of operation and utilization of asset and item; h) Maintenance objectives.
A.2	To act promptly in case of failure or malfunction, ensuring the effectiveness of the restoration	a) To interpret the first signs of failures and use fault diagnosis methods; b) To detect promptly the failure causes and determine appropriate corrective actions; c) To work according to quality and safety principles; d) To perform restoration tasks in accordance	a) Standards and operational methods of work; b) Technical documentation and maintenance manuals; c) Procedures; d) Business job descriptions and roles; e) Risk assessment tools/methodologies; f) Processes and work cycles; g) Principles and techniques distinctive of the profession; h) Principles, logic and parameters of

Figure 33: Extract from table 1 of the UNI EN standard 15628

In conclusion, the hierarchical diagram of the roles of the maintenance department and the management figures is given.

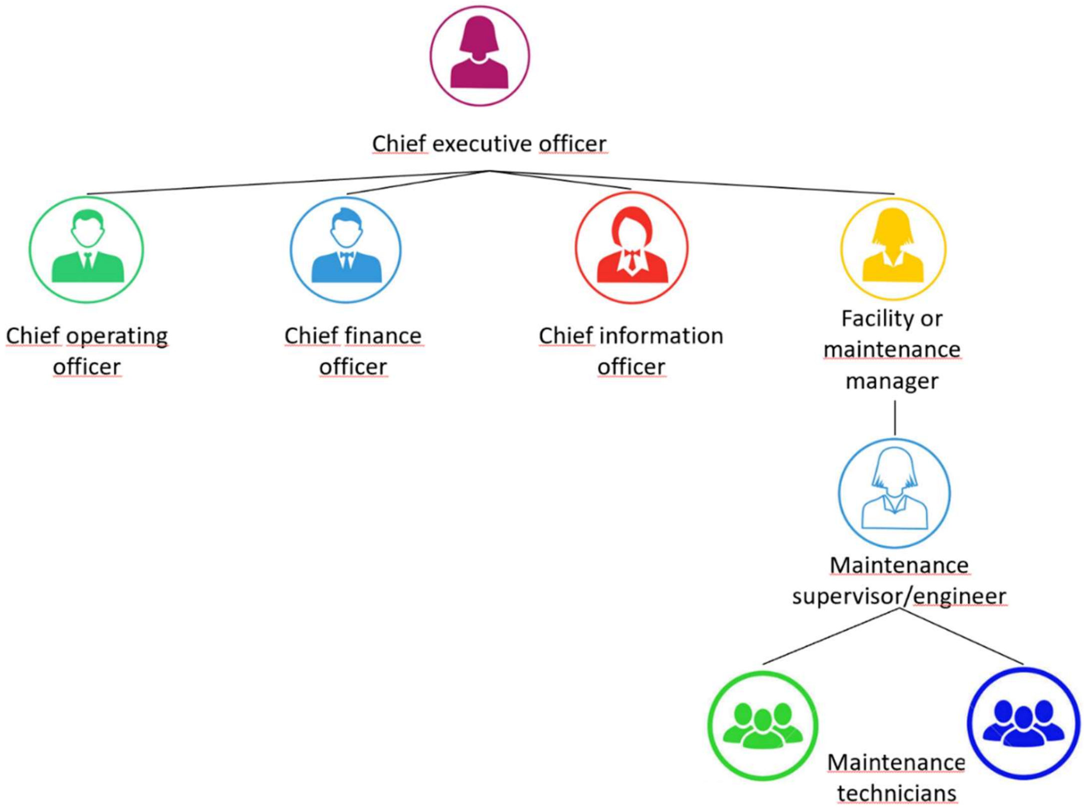


Figure 34: Hierarchical scheme (supervisor and engineer coincide)

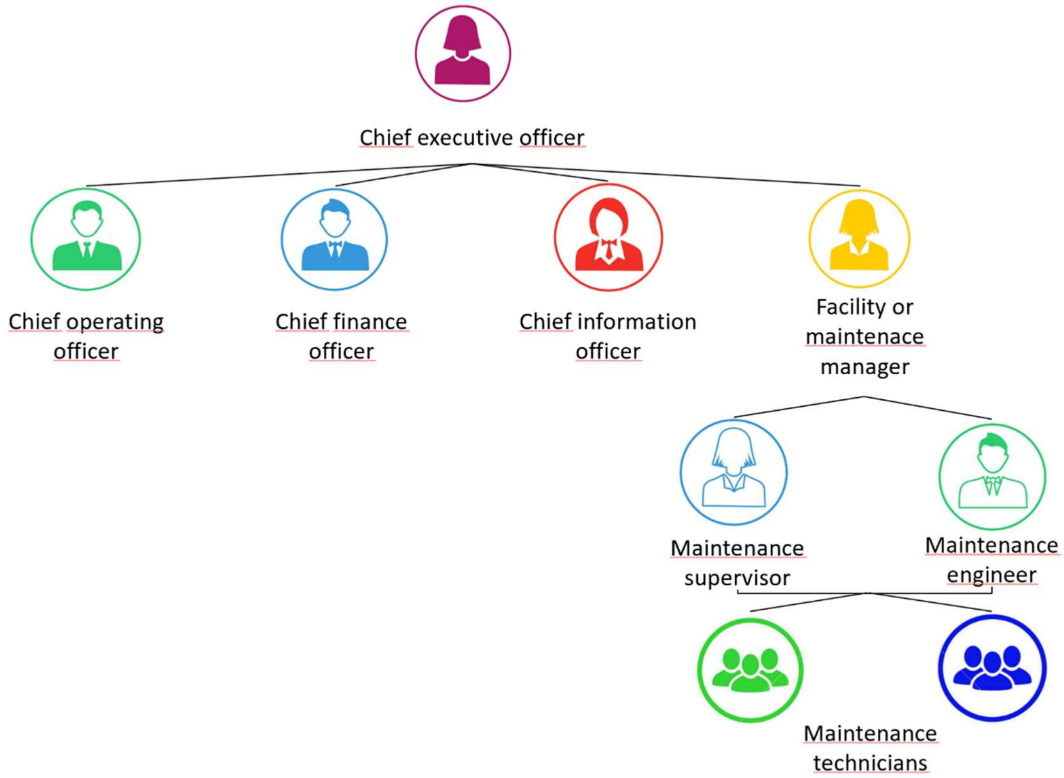


Figure 35: Hierarchical scheme (supervisor and engineer do not coincide)

4. Operation and Maintenance phase

This chapter aims to give a complete picture of the last two phases of the construction process as described in the English regulations. The Italian regulations have been deliberately left out as they lack a detailed description of the activities, roles, documents and responsibilities involved in these two phases. The importance of creating an innovative process characterised by the maximum collaboration of the different figures and of generating a close link between the design, construction and use phases of the asset is highlighted. The maintenance phase must be seen as a process whose aim is to maintain or improve the performance requirements identified in the design phase. Reference will only be made to the use of BIM methodologies, which allow to create this close relationship between the phases and the different professional figures such as the designers or the team of operators. The documents, in this case, become a tool supporting the staff by helping the management of the asset. Finally, BIM methodologies force a close collaboration between the different professional figures with the sole purpose of obtaining the best possible management of the building.

4.1. Stage 6: Handover

The handover stage describes the activities associated with the handover of the constructed asset including the updating of the constructed information, commissioning and training. In addition, the employer will be informed and trained on the operational requirements of the contract.

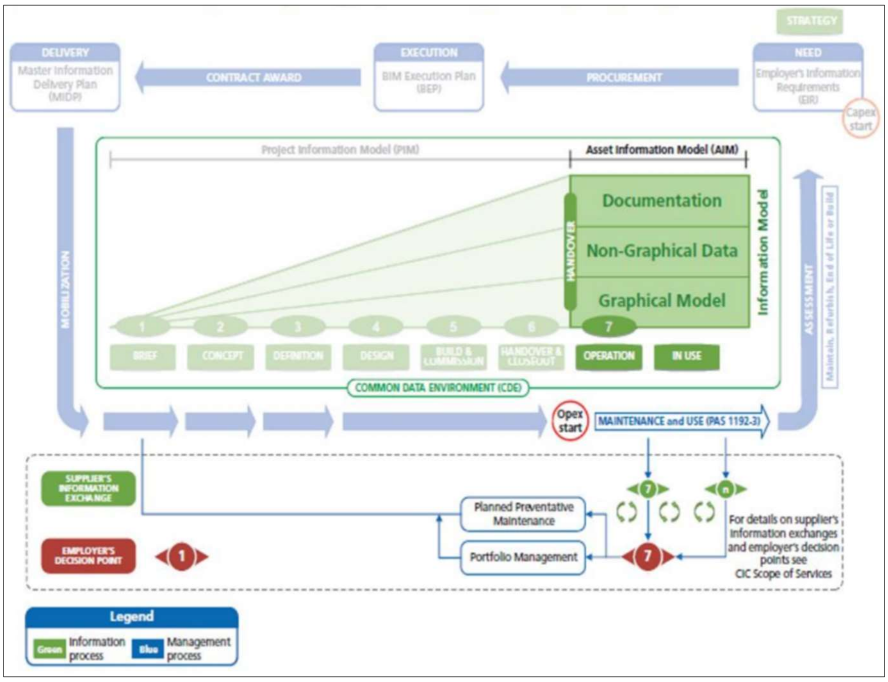


Figure 36: The handover and close-out stage – credits: https://bimportal.scottishfuturestrust.org.uk/

All information was previously prescribed in the Employer Information Requirements (EIR) and created during the evolution of the Project Information Model (PIM), it is now transmitted to the Asset Information Model (AIM) in the required formats. Models must be checked for completeness, including laser scanning surveys and point cloud analysis. Data requirements for the transfer process and associated activities are documented in PAS 1192-3.

The transition from the construction phase to the operational phase and the related transfer of structured information to the life cycle phases is of considerable value.

Organisations will require, as part of their BIM strategy, the ability to transfer data from the Project Information Model (PIM) to the Asset Information Model (AIM) and software platforms which may be a Computer Assisted Facilities Management (CAFM) or Asset Management System (AMS).

For efficient transfer, these processes are documented in the Employer Information Requirements (EIR). The EIR defines the structure, process and content of the information to be exchanged during the project.

The employer must adequately define formats for the exchange of information, such as COBie, although in some cases this does not meet the requirements and it is therefore necessary to apply another scheme in the Employer Information Requirements [EIR].

At this phase it is essential to involve the operational team from the first creation of Asset Information Requirements (AIR) in the soft landings process to ensure success in defining the information requirements and transferring the data to AIM.

The BS 8536-1 describes soft landings as *a process for the graduated handover of new or refurbished asset/facility, where a defined period of aftercare by the design and construction team is an owner's requirement that is planned and developed from outset of the project.*

Soft landings are not just a matter of coexistence but become a commitment of the design team, through construction and operation that aims to improve operational readiness and in-use performance. The aim of this commitment is to achieve better results for the assets through active involvement of the operations team. BSRIA's soft landing diagram is shown below.

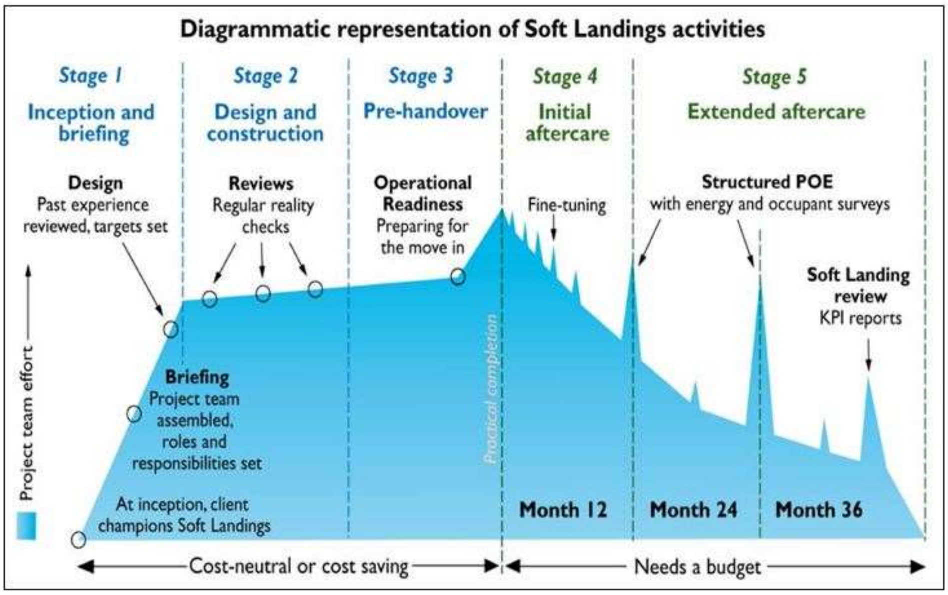


Figure 37: Soft landing approach – credits: https://bimportal.scottishfuturestrust.org.uk/

In addition, the owner has an obligation to identify the people who will be responsible for consultation and reporting, including technical people and staff involved in the management and operation of the building.

It is important to emphasise that in this case, the contribution of suppliers and subcontractors is also crucial to the performance of the building, and they must be involved in the initial discussions. Those who should be included are the designer or controls engineer, the lighting controls supplier and IT suppliers.

A Soft Landings approach is supported by BS 8536-1:2015 providing recommendations ensuring design and construction are consistent with the operational and performance requirements of owners, operators and end-users.

To understand the soft-landing approach, it is necessary to understand the key areas:

1. Role and responsibilities

The client/owner has a fundamental and active role in the whole process of developing roles and responsibilities. These roles include client representatives, all design professionals and the supply chain.

2. Focus on outcomes

The client and the project team make a clear and explicit commitment to continue with Soft's activities for three years after completion by achieving the performance targets agreed in the design phase.

3. Aftercare and post occupancy evaluation

Soft Landings determines targets to be achieved year by year until the conclusion of the 3-year period. Within the first year, the building's performance should stabilise. Within the second year, the data is reviewed with the aim of improving performance. The second year involves a structured post-occupancy evaluation (POE). Finally, during the last year, the service team will analyse the results of the POE and make the necessary interventions by monitoring the building's performance.

4. Performance management

The frequency of visits decreases with time until monitoring becomes a routine activity. The post-maintenance process ends with a final POE that measures and reports on performance against the objectives set and required by the customer.

5. Contacts and procurement

Soft Landings do not affect procurement procedures but offer guidance by defining needs prior to procurement by setting objectives and requirements In summary, Soft Landings procurement is inherent and integrated through collaboration with process maps and guidance documents. I

In conclusion, the standard defines activities for the design and construction team and for the operations team. These activities are set out below.

The design and construction team should prepare for handover of the asset/facility based on the following work activities:

a) *Summarize the changes that have been incorporated and advise on whether or not their implications have been brought to the attention of the owner and the operator, operations team or facility manager, as appropriate, and the representative(s) of end-users;*
b) *Verify the commissioning information provided by the suppliers in accordance with the methods identified in the commissioning specification;*
c) *Prepare a schedule for coordinating on-site activities and the witnessing of balancing, regulating and performance testing by the owner's representative and the operator, operations team or facility manager, as appropriate;*
d) *Record all equipment and system settings and outputs from commissioning and inform the owner and the operator, operations team or facility manager, as appropriate;*
e) *Identify where any operational details and performance targets have been adjusted to reflect commissioning results;*
f) *Finalize the plan for environmental and energy metering;*
g) *Prepare a plan to identify the responsibilities and scope of energy use reviews;*
h) *Determine how non-technical users will know how to operate the asset/facility efficiently;*
i) *Extract data from building information model o upadate the building logbook and/or the asset information model (AIM), as appropriate;*
j) *Review the update operational information provided by the operator, operations team or facility manager, as appropriate;*
k) *Prepare the forecast of final capital cost;*
l) *Prepare a detailed cost analysis of the final capital cost.*

The operator, operations team or facility manager should undertake the following activities, as a minimum:

1) *Provide updated operational information to the design and construction team;*
2) *Review and comment on all operation and maintenance information;*
3) *Review and comment an all commissioning and handover-related information;*
4) *Update the estimate of operational cost;*
5) *Contribute to the building logbook and/or asset information model (AIM), as appropriate;*
6) *Update the schedule of assets to be maintained, including a responsibility assignment matrix;*
7) *Prepare a cost breakdown of the asset/facility for management accounting purposes.*

4.2. Stage 7: Use

This phase is the operational phase where asset management services will begin.In this phase the asset information model (AIM) helps to manage, maintain and operate the asset through the asset data and information aligning with the organisation's asset management system.

According to PAS1192-3 the purpose of the AIM is to be the sole source of approved and validated asset information. This includes asset data and geometry, performance data and all supporting information such as specifications, operations and maintenance manual, and health and safety information.

It is necessary to update the AIM during the operational phase considering the available resources, skills and software systems. Post-occupancy evaluations are needed to compare actual performance with planned performance to assess the results and to check if changes need to be made to improve performance.

The Asset Information Model (AIM) resides within a common data environment (CDE) during the operational phase.The processes for maintaining the AIM are set out in PAS1192-3.

Changes are made following a planned or unplanned event as illustrated in the PAS extract below. In some cases it is only necessary to update the data.

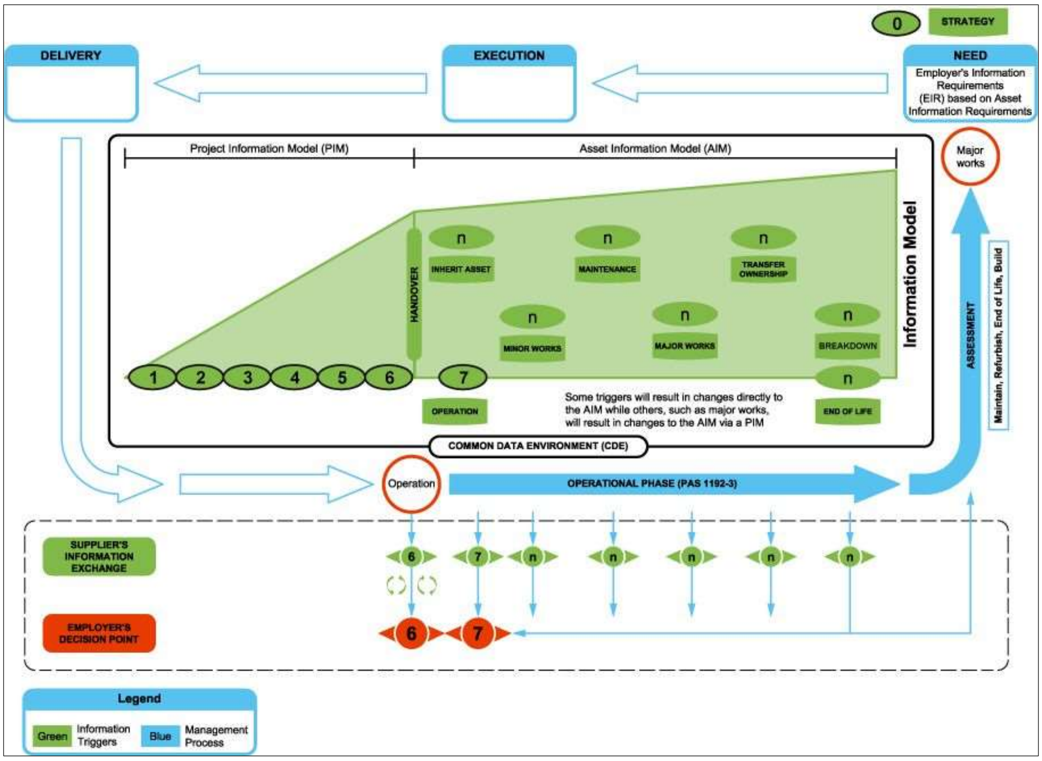


Figure 38: The use and operation stage through PAS 1192

To ensure the quality of information and data, it is necessary to establish roles, responsibilities and authorities for maintaining AIM and for managing organisational needs. The organisation establishes, documents, implements and updates an information management process (IMP). The IMP covers the operational life cycle of the asset, from design to maintenance and demolition.

An example of the roles and responsibilities can be found in Appendix D of the standard, this table is shown below.

Trigger or 1related event	Owner	Operator	Maintainer	Other (specified)
Undertaking a project operating to PAS 1192-2	Update AIM from information received from the major works design and contractor leads Make AIM available to the Operator	Receive access to AIM from the Owner Make AIM available to the Maintainer	Receive access to AIM from the Operator	Major works design and contractor leads: Supply information to the Owner
Developing an AIM for an existing asset	Create or commission the creation of the AIM Make AIM available to the Operator	Receive access to AIM from the Owner Make AIM available to the Maintainer	Receive access to AIM from the Operator	
Day-to-day operation of an asset	Update the AIM with operational data and information	Update the AIM with operational data and information	Supply information to the Operator or Owner for updating	
Planned and reactive maintenance of an asset	Update the AIM with data and information provided by the Maintainer (for assets managed by the Owner)	Update the AIM with data and information provided by the Maintainer (for assets managed by the Operator)	Provide data and information related to maintenance activities to the Owner or Operator as appropriate	
Carrying out minor works on an asset	Update the AIM with data and information provided by the works contractor (for assets managed by the Owner)	Update the AIM with data and information provided by the works contractor (for assets managed by the Operator)		Works contractor: Provide data and information for the AIM to the Owner or Operator as appropriate
Carrying out major works on an asset	Update the AIM with information provided by the design lead and/or contractor lead for the works (for assets managed by the Owner)	Update the AIM with information provided by the design lead and/or contractor lead for the works (for assets managed by the Operator)		Design lead and/ or contractor lead: Provide data and information from the works
End-of-life of an asset	Update the AIM with data and information related to the end-of-life Make AIM available to the Operator if the Operator still has an interest in the asset portfolio	Receive access to updated AIM if the Operator still has interest in the asset portfolio		End-of-life contractor: Provide data and information to the Owner
Realigning the AIM	Update the AIM with information related to all events since the last alignment	Update the AIM with information related to all events since the last alignment		

Figure 39: Stakeholders and roles – appendix D of PAS 1192

As previously stated, Soft Landings aims to help deliver sustainable and functional assets that meet the needs of End Users and provides a framework for the delivery team to understand the asset being built by assisting occupants in the early months of operation. Operational issues need to be identified as early as possible to develop an action plan.

BS 8536 (5.8.2.2) emphasises the need for an aftercare team, identified by the design and construction team to manage post-delivery tasks for the initial period.

This team helps the team of operators to become familiar with the asset/plant by providing training and technical support.

If performance deviations from expected performance are identified, these deviations shall be communicated within the respective teams. Troubleshooting must be carried out through collaboration between the design and construction team and the operations team or plant operator.

BS8536 Figure 3 illustrates the connection between the project information model (PIM) and the asset information model (AIM) by highlighting the relationship between this British standard and the standards that support "Level 2 BIM", namely PAS 1192-2 and PAS 1192-3. PAS 1192-5. It is necessary to capture the results of projects in order to optimise asset/facility management.

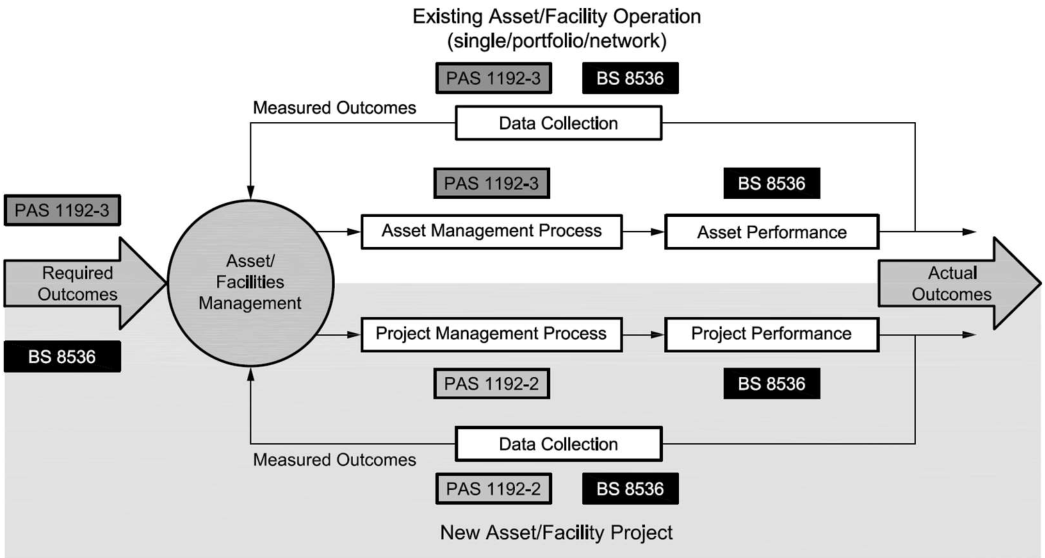


Figure 40: BS 8536 figure 3 - Asset-project model and feedback

In conclusion, also at this stage, the standard defines activities for the design and construction team and for the operations team. These activities are set out below.

The design and construction team should prepare for operation of the asset/facility, including the initial and extended periods of aftercare, based on the following work activities:

a) Conduct aftercare review meetings and workshops as planned;
b) Record user comments related to functionality and effectiveness;
c) Maintain records of walkabouts to detect emerging issues;
d) Fine-tune the building services engineering systems;
e) Fine-tune the structural monitoring and control systems, where applicable;
f) Record and feed back details of all fine-tuning;
g) Update the asset information model (AIM);
h) Update the facility handbook, as appropriate;
i) Update the facility user guida, as appropriate.

The operator, operations team or facility manager, as appropriate, should prepare for operation of the asset/facility, including the initial and extended periods of aftercare, based on the following activities:

1) Record and review early energy usage for comparison with predictions;
2) Review and record building management system (BMS) monitoring of environmental conditions to detect any emerging problems;

3) *Set up a helpdesk with physical presence, at least initially;*
4) *Prepare and circulate newsletters or utilize other media for communicating directly with end-users.*

4.3. Maintenance

In Italy, maintenance activities have undergone important transformations, with an increasingly important affirmation thanks also to the development of industrial production. Historically, maintenance was perceived as a "science of conservation" but over time maintenance has also taken on an "evolutionary" character. Thus, it is moving from an activity characterised by corrective interventions such as simple asset repair activities, to an activity governed by statistical-predictive techniques applied to the economic management of the project and to the entire life cycle of the asset.

Until the beginning of the 1990s, maintenance policies were based on the criterion of necessity: action was only taken after faults had occurred. In addition, maintenance operations, their organisation and the identification of the necessary resources were tackled without any systematic approach, especially in the absence of specific reference standards.

In recent years, however, the approach to conservation issues is changing and maintenance is seen as an 'evolution' of the system, adapting it to new needs. Similarly, regulations have begun to provide support and operational instructions aimed at building maintenance. The activities are those related to planning, organisation and execution work oriented towards the object of maintenance aimed at restoring the level of functionality that characterises it, comprising two important processes: maintenance and restoration.

Maintenance activities have to consider several aspects, such as safety and efficiency, aimed at not affecting the proper functioning of the services and activities taking place inside the building. Maintenance is therefore a programmed strategy to achieve an end result that can lead to an improvement in the performance of the building itself. In fact, through replacements, improvements can be achieved at a higher level.

It is also important to emphasise that it is needed to separate the concept of maintenance from the concept of upgrading, which aims to improve the functionality of an entire building by equipping it with equipment not previously present. This distinction is particularly relevant when deciding on the level of expenditure required for the maintenance of a building, which could be reduced as early as the design phase by devising a more accurate initial design that takes into account the possible interventions that may occur throughout the life cycle of the building.

The concept of maintenance was defined by the UNI 9910 standard as *the combination of all technical and administrative actions, including supervisory actions, aimed at maintaining or restoring an entity to a state in which it can perform the required function.* This definition emphasises that it is necessary to integrate different activities with the objective of maintaining functionality, which is achieved through different policies and strategies, which the standard helps to define.

Standard UNI 11063 is supplemented by UNI 10147:2013 and provides a classification of maintenance activities. It distinguishes these activities into "ordinary maintenance" and "extraordinary maintenance". It also integrates the terminology described in UNI EN 13306, and UNI 10147, in use in maintenance.

UNI 10147 identify three different maintenance policies:

- Corrective (or breakdown) maintenance.
- Preventive maintenance.
- Proactive maintenance.

Preventive maintenance is in turn divided into:

- condition-based maintenance (it is based on monitoring the current health status of a component assessed through a threshold value, above which (or below which) the component has a high probability of failure)

- periodic maintenance (it is carried out at fixed time intervals but without an investigation of the condition of the entity)

- predictive maintenance (it is carried out following the identification of parameters that are measured and processed with the use of mathematical models in order to predict the failure).

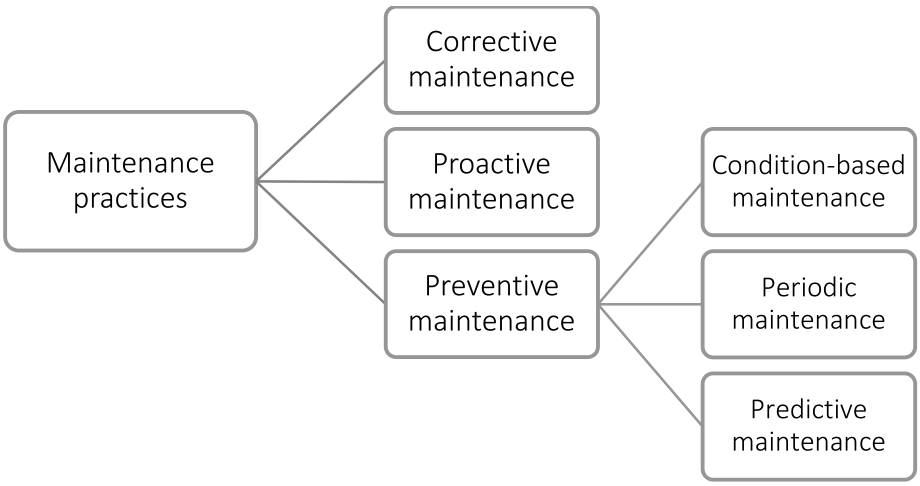


Figure 41: Division of maintenance practices

4.4. Corrective maintenance

The UNI standard defines corrective maintenance as *maintenance carried out following a failure and aimed at restoring an entity to the state in which it can perform the required function*. In this type of maintenance, action is taken only after the occurrence of a malfunction. This type of maintenance entails very high costs for various reasons such as loss of production and repair of the machine itself. Positive and negative factors can be identified with this approach.

The positive factors are:

- zero maintenance cost until the system is operational
- zero cost of downtime until the system is operational.

Negative factors are

- high loss of revenue due to downtime due to failure
- unpredictability of intervention
- generally high repair costs. In addition, a failure in one component can damage other components.

The corrective strategy is the most traditional approach to maintenance and generally applies to single systems that can be easily replaced by similar systems without much disruption.

4.5. Preventive maintenance

Preventive maintenance is defined as maintenance carried out at predetermined intervals or in accordance with prescribed criteria and aimed at reducing the probability of failure or degradation in the operation of an entity.

Unlike corrective maintenance, preventive maintenance tends to prevent taste, intervening when the system is still providing satisfactory performance, but the operation is unsatisfactory. Preventive maintenance is divided into periodic maintenance and condition-based maintenance.

Periodic maintenance is performed by identifying deadlines in terms of time or hours of operation in which to operate independently of the condition of the object. It is an activity that involves replacing parts that have a limited life by identifying the parts of the machine that are most likely to fail. This strategy is therefore based on the planned replacement of a machine component in order to prevent uncontrolled failure.

Condition-based maintenance is a type of preventive maintenance based on identifying the current state of health of a component. Condition-based maintenance is carried out following a campaign of periodic measurement of technical parameters that provide an indication of performance. The replacement intervals, therefore, are determined based on the machine's history.

A major limitation of preventive maintenance stems from the fact that it is not possible, for reasons of time and money, to cyclically replace all mechanical components at risk. Moreover, replacing components at the end of their "expected life" does not guarantee a certain reduction in the number of breakdowns or malfunctions. To sum up, in the case of preventive maintenance, the risk is to intervene on perfectly functioning machinery or, on the contrary, on machinery in which the taste has been reached before the time set for maintenance.

4.6. Predictive maintenance

The UNI 10147 standard also defines predictive maintenance as maintenance carried out following the identification and measurement of one or more parameters and extrapolation according to appropriate models in the time remaining before failure. It consists of the constant monitoring of the condition of a system through the installation of IoT sensors to monitor and transfer the detected data in real time. The latter are processed and elaborated through mathematical models and are used to predict a maintenance action with the aim of preventing failures and breakdowns. In order to generate a predictive maintenance plan, some preliminary steps are necessary:

1. Establish the conditions under which action is to be taken.
2. Installation of IoT sensors
3. Connecting the sensors
4. Creating and planning an intervention

A predictive maintenance policy can improve the quality of maintenance activities by increasing productivity and optimising resources.

The advantages of this methodology are:

- the reduction of faults,
- the possibility of planning maintenance on the basis of the real efficiency situation and the residual life forecast of the equipment,
- optimisation of the maintenance plan on the basis of the behaviour observed over time.

Results of Predictive Maintenance:

- Continuity of operation of production processes not burdened by excessive and costly reserves/stocks;
- Reduction in production losses due to accidental stoppages;
- Increased residual life of machine components;
- Reduction of unnecessary interventions;
- Improvement of environmental factors (noise, pollution, energy consumption);
- Reduction in maintenance costs compared to the periodic or time-based maintenance method.

4.7. Proactive maintenance

Proactive maintenance is the set of improvement or minor modification actions that do not aim to increase the asset value of the entity, but are aimed at providing management economies or organisational improvements such as improved environmental well-being, space usability and energy savings.

4.8. Ordinary maintenance and extraordinary maintenance

According to a systemic vision of the building, the building represents the whole of its parts and the performance must be defined and declared to allow for the correct operation throughout the useful life of the building.

The standard identifies two different levels of action

- a prescriptive level that refers to the operating conditions of the building with the aim of guaranteeing the maintenance of the operating conditions, with respect to phenomena of degradation or failure;
- a technical-normative level that refers to criteria for assessing in advance the behaviour of the building as an organism over time.

It is possible to interpret maintenance as a set of activities aimed at maintaining or restoring an entity to its functionality and it’s likely to distinguish two categories of maintenance: ordinary and extraordinary.

Ordinary maintenance is the set of interventions aimed at repairing, innovating or replacing building components in order to maintain the level of efficiency.

Extraordinary maintenance, on the other hand, is the set of works and modifications necessary to renovate and/or replace and/or integrate parts of buildings, including structural parts, without altering their volumes or changing their intended use.

5. Case study

Automated data acquisition (DAQ) technology has undergone significant advances in hardware and software in recent years, even the available technologies are still expensive and not open source, In addition, it is impossible to freely access and store data without purchasing specific software. In order to overcome the limitations listed above, studies were conducted to develop a customised design of automated data acquisition systems within the IoT and BIM integration methodology based on open-source technologies.

The case study is located at the Polytechnic of Turin in the DISEG Laboratory. The following figure shows the case study building and its representation in the BIM model of the Revit software.

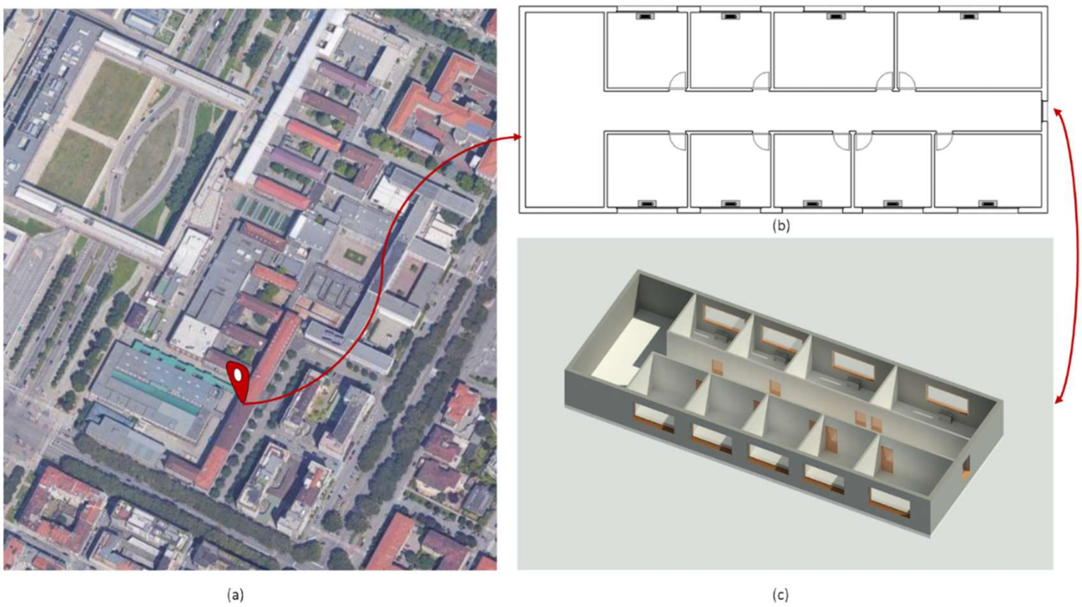


Figure 42:Case study building: (a) geolocation on the maps.google.it, (b) 2D view of the case study room and the location of the fan coils and (c) rendering of the study case

In all the rooms, the fan coils are located under the windows. The fan-coil motor of the case study is manufactured by EuroMotors Italia, type FC83M- 2014/1 with 4 possible speeds. The FC motor rotates counter clockwise at 1100 revolutions per minute (RPM) at maximum speed. In addition, the fan coil has a cooling or heating coil and a filter. Below are the fan coil specifications:

- Model number: FC 83M-2014/1
- 230-240 V
- 50 Hz
- 0,23 A
- Num. Speeds:4
- Power: 14/53 W
- RPM: 1100

The architecture of the IoT and BIM integration system is structured in four interlinked parts:

- Building facilities IoT sensors installation;
- Hardware and networking;
- IoT Sensor Node Dashboard;
- IoT and BIM model Dashboards.

In order to capture the data in real time and store it on the server, all the installed sensors are hosted by a microcontrollers (Arduino based ones: ESP8266 and RPIZCT4V3T2) and a Raspberry Pi single-board computer connected by Wi-Fi. In addition, the data collected is processed to monitor and detect anomalies in the operation of the building's facilities. The stored data is then connected to a digital twin in order to implement a dashboard to visualise the data trend, the BIM model is used to visualise the position of the components and to get an overview of the building.
The overall IoT architecture integrated in the BIM shows how IoT sensors continuously send data to nodes.The raw data from the nodes are processed by the microcontroller of the sensor-nodes and become readable. The processed data is then sent to the server connected to the gateway.
Through this gateway, users access the dashboards of the local and cloud sensor nodes in order to view the data and fault detection functions. In the last section of the architecture, combined IoT-BIM data are displayed on the dashboard.

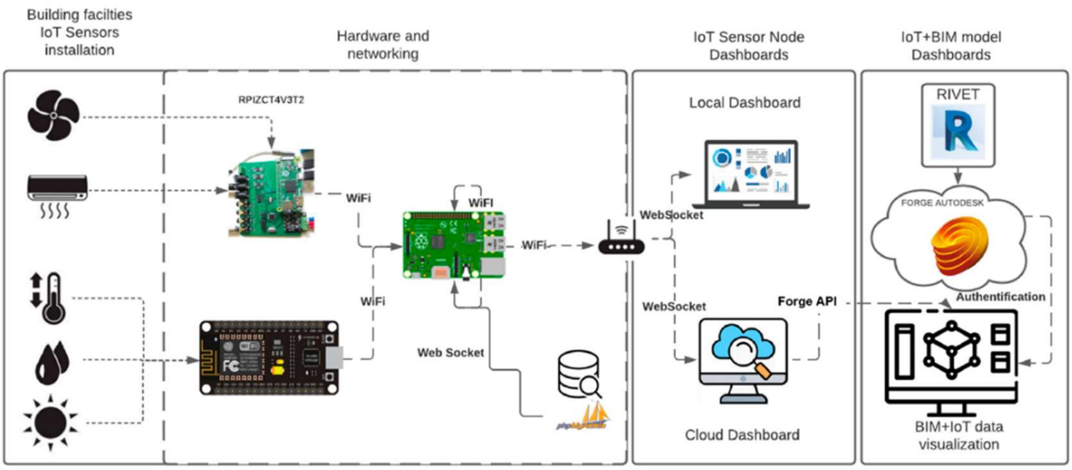


Figure 43: IoT and BIM integration system architecture.- credits: *[55]*

The proposed IoT system is based on open-source tools and market components. Physical parameters are acquired to monitor the internal conditions of the room and to control the operation of the fan coil. For this, sensors are placed in the room and connected to their sensor boards.
The following figure shows the characteristics of the individual sensors installed and their respective sensor board.

Sensor Board	Sensor Name	Accuracy	Measuring Ranges	Units
RPIZCT4V3T2	Current (SCT-013-000)	±3	0–100 A	Ampere (A)
	Voltage (EU: 77DE-06-09)	±5	0–230 (50 Hz)	Volt (V)
	Temperature (DS18B20)	±0.5	0–90 °C	Celsius (C)
	Temperature (PT100)	±0.05	−200 to 550 °C	Celsius (C)
ESP8266	Ambient temperature (DHT22)	±0.5	−40 to 80 °C	Celsius (C)
	Humidity (DHT22)	±2	0–100% RH	Relative Humidity (%RH)
	Photoresistor (LDR)	Resistant dependent	0–1 MΩ	lx

Figure 44: Applied sensors with technical specifications – credits: *[55]*

(a) (b) (c) (d)

Figure 45: Case study sensor nodes placement to the room and FC: (a) FC battery sensor, (b) temperature sensor, (c) motor with temperature sensor, and (d) room equipped sensor node.

The Rpi3B motherboard connects to the sensor nodes of the two ESP8266 and RPIZCT4V3T2 microcontrollers and simultaneously captures data and records them in the database

Subsequently, the collected IoT data and the 3D building model can be viewed together on via a static URL and port.

The following figure shows the general schematic diagram of the locations of the fan coil sensors, sensor boards and data acquisition system of the BIM model.

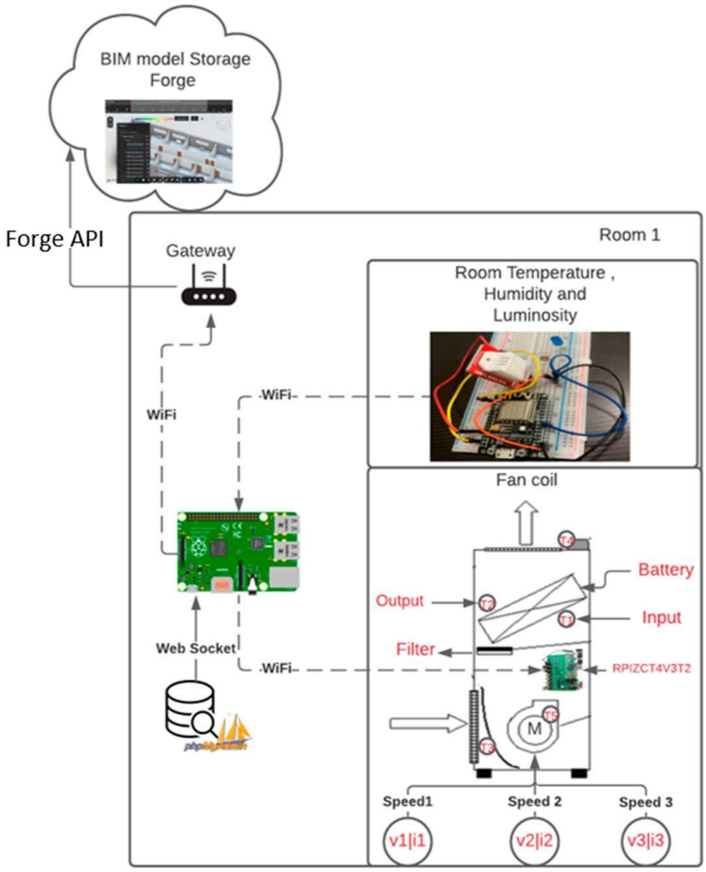


Figure 46:Sensors' location in the fan coil and building facilities - credits: *[55]*

Based on the types of anomalies and the data collected by the sensors, a fancoil condition monitoring system is implemented. In addition, the centrally collected data can be used to inform the maintenance team about the condition of any fancoil and provide preventive maintenance services.

The maintenance alarm system consists of three main sections:

- the sensors installed on the FC
- the management and monitoring system of the FC components;
- alerting maintenance team when a fault occurs.

The three voltage sensors acquire the data of the three motor speeds (v1, v2, v3); three current sensors acquire the data (i1, i2, i3) of the three speeds; and temperature sensors monitor T1 (supply water temperature), T2 (return water temperature), and T4 (outlet air temperature) in the range 0-90 ◦C and T3 (inlet air temperature) in the range 0-50 ◦C. T5 (engine case temperature) is monitored with a temperature sensor in the range 0-200 ◦C. On the sensor board controller, the algorithm for managing and monitoring each FC component is implemented. The algorithm makes decisions according to the signal values of the sensors with respect to the installation conditions

Each sensor, i different positions, has various data collection intervals which are summarised below:

Sensors	Frequency	Sensor Allocation	Note
T1	180″	delivery pipe	every 1800″ send to the server the average detected values in the interval in which one of the values is at least 200 volts
T2	180″	return pipe	every 1800″ send to the server the average detected values in the interval in which one of the values is at least 200 volts
T3	180″	air inlet	every 1800″ send to the server the average detected values in the interval in which one of the values is at least 200 volts
T4	180″	air outlet	every 1800″ send to the server the average detected values in the interval in which one of the values is at least 200 volts
T5	10″	motor case	every 1800″ send to the server the average detected values in the interval in which one of the values is at least 200 volts
v1	0.1″	motor voltage	send voltage value to the server only if for at least 180″ v1 is greater than 0 and less than 200 volts
v2	0.1″	motor voltage	send voltage value to the server only if for at least 180″ v1 is greater than 0 and less than 200 volts
v3	0.1″	motor voltage	send voltage value to the server only if for at least 180″ v1 is greater than 0 and less than 200 volts
i1	0.05″/3″	motor current	0.05″ for the first 10′ from v1 equal to at least 200 volts (anti-unbalance)/3″ in normal operation/no fields-on if v1 < 200 volts/send to the server the integral of i1 ×dt on the range where v1 is at least 200 volts (power consumption control)/send to alarm server if i1 > 1.5 × i1 rated for more than 6″
i2	0.05″/3″	motor current	0.05″ for the first 10′ from v2 equal to at least 200 volts (anti-unbalance)/3″ in normal operation/no fields-on if v2 < 200 volts/send to the server the integral of i1 × dt on the range where v2 is at least 200 volts (power consumption control)/send to alarm server if i2 > 1.5 × i2 rated for more than 6″
i3	0.05″/3″	motor current	0.05″ for the first 10′ from v3 equal to at least 200 volts (anti-unbalance)/3″ in normal operation/no fields-on if v3 < 200 volts/send to the server the integral of i3 × dt on the range where v3 is at least 200 volts (power consumption control)/send to alarm server if i3 > 1.5 × i1 rated for more than 6″

Figure 47:Sampling frequency and FC sensor allocation - credits: [55]

Figure 47:Sampling frequency and FC sensor allocation - credits: [55]

In order to detect anomalies, an algorithm was created and the alarm system was implemented on the sensor board.

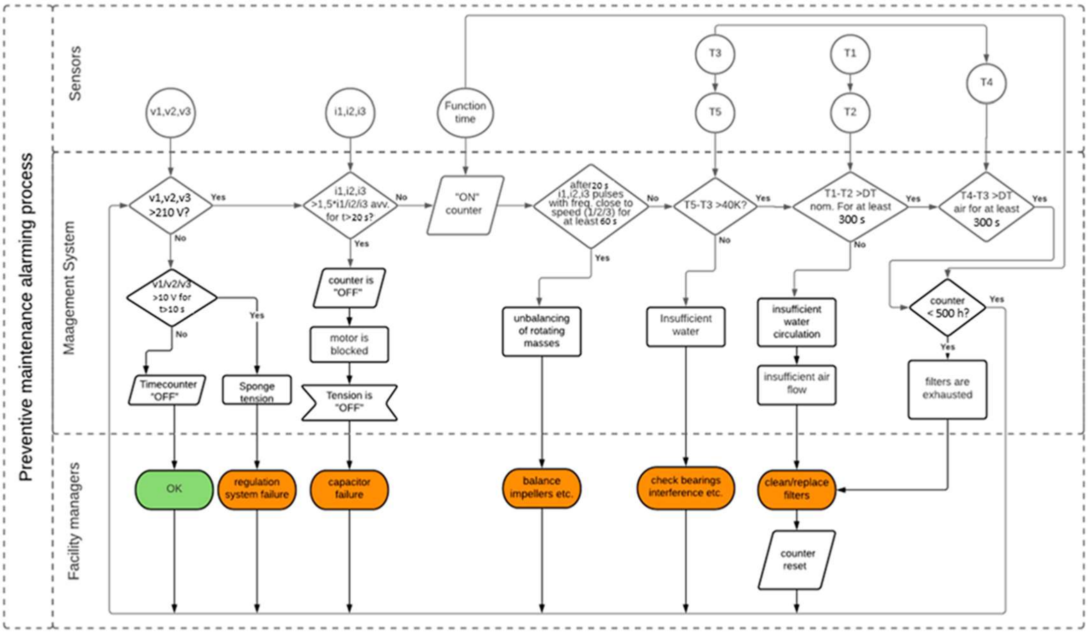


Figure 48:Integrated anomaly detection flow chart-credits: [55]

5.1. Facility information management

In order to achieve an efficient maintenance department, it is necessary to have a clear organisation of roles and responsibilities within the team, as well as a clear, fast and intuitive passage of information. In fact, it is necessary to ensure this information flow for fast and efficient plant maintenance by solving common problems such as duplicate requests or loss of information. The objective of this flow optimisation is to simplify and speed up maintenance activities. To optimise the flow of information, it is necessary to improve the sharing of this information between maintenance team members and company management. It must then be organised within the process to ensure targeted and timely interventions.

To identify the most efficient information flow, it is necessary to illustrate the information structure of the maintenance team. European standard EN 13460 provides the maintenance workflow.

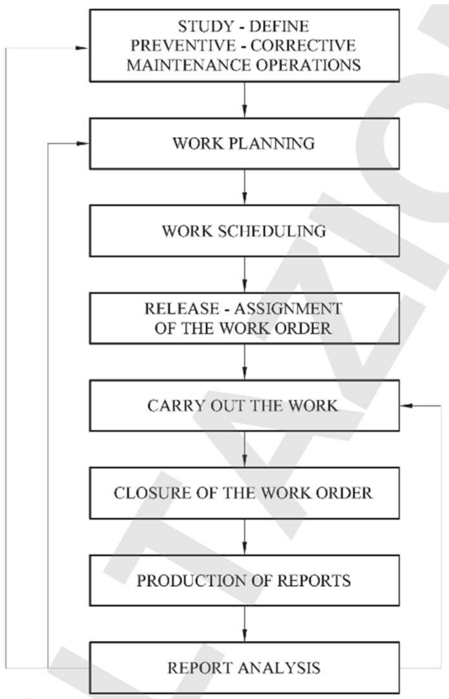


Figure 49: Maintenance flow (figure C.1 - UNI EN 13460:2009)

Scheduled and unscheduled maintenance activities are managed through a work order.

A work order is a digital (or paper) document providing all the information about a maintenance task. More specifically, according to EN 13460, a work order is *a document containing all the information related to a maintenance operation and the reference links to others documents necessary to carry out the maintenance work.*

For the purposes of clarification, Annex B of EN 13460 lists all the information that should be included in a work order.

Work order information	Information description
B.1 Number	Code assigned to a W.O. This code is unique for each W.O.
B.2 Petitioner	Name of the authorized person requesting the maintenance service.
B.3 Registration date	Date when the W.O. is issued.
B.4 Open date	Date when the W.O. is activated.
B.5 Close date	Date when the W.O. is completed. The corresponding work is finished.
B.6 Item code	Code assigned to the item within the physical structure of the plant. This code is unique for each piece of equipment.
B.7 Item location	Code corresponding to the geographical location of the item within the plant. It is normally attached to or is included in the item code.
B.8 Item running hours	Parameter by means of which, the utilization of the item can be recorded. The parameter can be different, such as number of operations, pieces, natural calendar.
B.9 Type of maintenance	Code referring to the nature of the maintenance activity (for example preventive, electrical, new installation, etc.). Usually, it is linked to the cost structure.
B.10 Priority	Code to give information about the necessary precedence among the W.O.s for its activation. Priority has in some cases to do with criticality.
B.11 Safety and environmental regulations	Link to the possible safety and environmental requirements to perform the maintenance work, either mandatory or recommendations.
B.12 Retention justification	The reason why an open W.O. is not running at the moment. Downtime for each retention should also be included.
B.13 Frequency	Time between maintenance services within cyclic operations.
B.14 Last operation time	Last date when a particular cyclic maintenance operation was performed.
B.15 Resources estimation	Amount of the different resources intended to be used to accomplish the W.O. in a cyclic operation.
B.16 Check list	Relation of points to inspect within a cyclic maintenance operation. Normally these should be first line maintenance activities.
B.17 Complaint	Reason why a W.O. is issued. Symptom of the failure, normally detected by the user of the item.
B.18 Failing part	Malfunctioned component of the item. The repair or substitution of this part in addition to the description of the actuation is the solution of the problem.
B.19 Cause of failure	Reason which determined the failure of the part, according to the maintenance technician criteria.
B.20 Technical procedure code	Link to the technical documentation which holds the information about the right actuation way. Tools required should be also included in that documentation.
B.21 Actuation description	Explanation of the carried out operations.
B.22 Labour amount	Working hours spent in carrying out the W.O; the sort of hours: normal, shift, night, extra, etc. should be specified.
B.23 Labour type	Personnel category or skills of those who carried out the W.O.
B.24 Personnel	List of all maintenance workers, who participated in carrying out the W.O.
B.25 Spare-parts reference	Code list of all spare-parts used within the W.O.
B.26 Spare-parts amount	Number of each spare-part type used within the W.O.
B.27 External labour	In the case of a contract with an external supplier of service for the W.O., list of all external workers, who participated in carrying out the W.O.
B.28 External spare-parts	In the case of a contract with an external supplier of service for the W.O., code list of all spare-parts used within the W.O.
B.29 Other external services	Services description, in the case of a contract with an external supplier of service for the W.O.
B.30 Acceptance	Maintenance work reception.

Figure 50: Table 1 - UNI EN 13460

It is necessary to regulate its management within the business process through a specific procedure. This is why the work order is included in the descriptions of maintenance processes that give rise to organisational procedures.

Predictive maintenance is based on the permanent connection between physical reality and immaterial reality, thanks to technological solutions such as IoT sensors with the aim of optimising the whole of the above maintenance process and reducing the time taken to transmit information.

The plant connected to the IoT system transmits a continuous cycle of data on the operation of the plant. Through the analysis and reprocessing of this data, it is possible to signal in real time whether a given fan coil is "working" according to standard or low operating parameters, allowing the early detection of anomalies and communication to the maintenance supervisor. The objective, therefore, is to understand in advance when a component is deteriorating and when to schedule maintenance by exploiting artificial intelligence, trying to reduce and/or eliminate the risk of a sudden failure of a system component.

The main activities to be regulated in the procedure for managing a Work Order are several, including:

- the preparation of the work;
- approval of the work;
- scheduling the work;
- issuing the work order;
- progress of the work;
- verification and acceptance of work;
- closure of the work.

In fact, each work order is assigned a priority level defined by the trend of the data collected by the sensors through the identification of thresholds that reflect the level of operation of the system.

The planning phase of the single intervention and the consequent management of the work orders are, as already mentioned, the result of the analysis of the trend of the data collected. Depending on the trend of the data, the maintenance supervisor identifies, for each fan coil, the scheduling of the maintenance activities defining the operations to be carried out, the resources, times and costs.

The scheduled work orders all have a low priority level. In addition, depending on the anomalies detected by the sensors (*figure 35*), other work orders are generated with different levels of priority depending on the type of anomaly.

The different faults shown in the flow chart have different priority levels depending on the context (e.g. a classroom or a hotel room).

The regulation system failure and capacitor failure are faults with a high priority level because they generate an interruption of the fan coil so the rotor is blocked and the motor is overheated. In different cases, a voltage interruption could be detected where it is not needed or the opposite case.

Hydraulic balancing and clean or replace filters are intervention with a medium priority level because they are faults that cause a decrease in performance. This decrease can be compensated for until the coldest hour of the coldest day by increasing operating times. These interventions are intended to extend the useful life of the fan coil.

Imbalance of the impellers (a problem that only causes noise) or checking of the bearings are low priority failures because they do not cause either a decrease in performance or the operation of the fan coil.

The following figure shows the priority levels assigned to each type of alarm.

Intervantion	Priority
Regulation system failure	HIGH
Capacitor failure	HIGH
Balance impellers	LOW
Check bearings interference	LOW
Clean/replace filters	MEDIUM

Figure 51: Level of priority

In order to make a maintenance process efficient within a company, it is necessary to correctly compile a work order and manage it before, during and after the intervention. A key step is its archiving to generate a history of a maintenance plan in order to be able to analyse the progress of the various maintenance activities, the adherence to the budget, the sufficiency of resources, the stock level and the forecast of future activities. A final aspect of using a sensor-based control system is the traceability of operations and personnel. Each professional figure in the team plays a key role in the correct execution of all operations in a precise, organised and optimised process.

The organisational process is divided into three specific moments: before the intervention, during the intervention and after the intervention. In addition, an intervention can also be divided into planned and unplanned.

In the case of planned maintenance, this is the final step of preliminary administrative decisions.
In what may be called the "pre-intervention" phase, the facility manager, following discussion with other management figures, assigns a budget for all maintenance activities. In addition, he defines the overall intervention strategy by accessing the aggregated data on which these choices are based by detecting anomalies that might be found and the checks that should be made throughout the year in order to achieve the best possible operation. In addition, he coordinates maintenance interventions by managing interferences, for example, between lessons and maintenance activities.

Then, all the identified activities will then be managed, organised and scheduled by the maintenance supervisor. In fact, the maintenance supervisor draws up a work order for each part of the system (e.g.fan coil), through which the intervention is planned, desining the maintenance activity, establishing the budget, the necessary resources and the time frame in which this activity must be carried out respecting the directives imposed by the facility manager.

Once the work orders are authorised, it is the maintenance supervisor who will manage and supervise the different activities by defining the personnel who will have to work and the resources that have been provided. During the intervention, it is the maintenance technician who performs the defined and planned activity, clarifies the resources actually used and compiles the work order, which is then returned to the supervisor and then to the facility manager.

After the intervention, the maintenance supervisor and the facility manager check the outcome of the intervention, whether the resources (materials and labour) were sufficient, whether the budget and timetable were respected. Afterwards, summary reports will be generated and used by the facility manager to take a snapshot of the maintenance department's performance in order to decide on future budgets and resources. On the other hand, the reports are important for the maintenance supervisor to see if the design is effective or if some operational changes are needed.

A key aspect of the "after action" phase is the archiving of data that will show the progress of all maintenance activities, the percentage of planned and unplanned activities, the progress of the inventory (whether or not replacements are needed), the adherence to the budget, the level of operation of the installation itself. This archiving is essential because it allows reasoned decisions to be made about future activities. For example, if a fan coil has undergone many planned interventions, it will be possible to decide whether to replace it definitively; if the budget made available is continually exceeded, it will be necessary to increase it in the future, etc.

The following is a simplified description of the decision-making process. This process begins with a strategic phase which is the result of the data trend and identification of the controls to be carried out. After this phase, there is the technical design phase of the maintenance, in which the maintenance supervisor goes on to define in detail the individual interventions which will be put into practice by the technicians. During execution, should there be any interference with other activities (even independent of maintenance activities), the facility manager will resolve such interference.

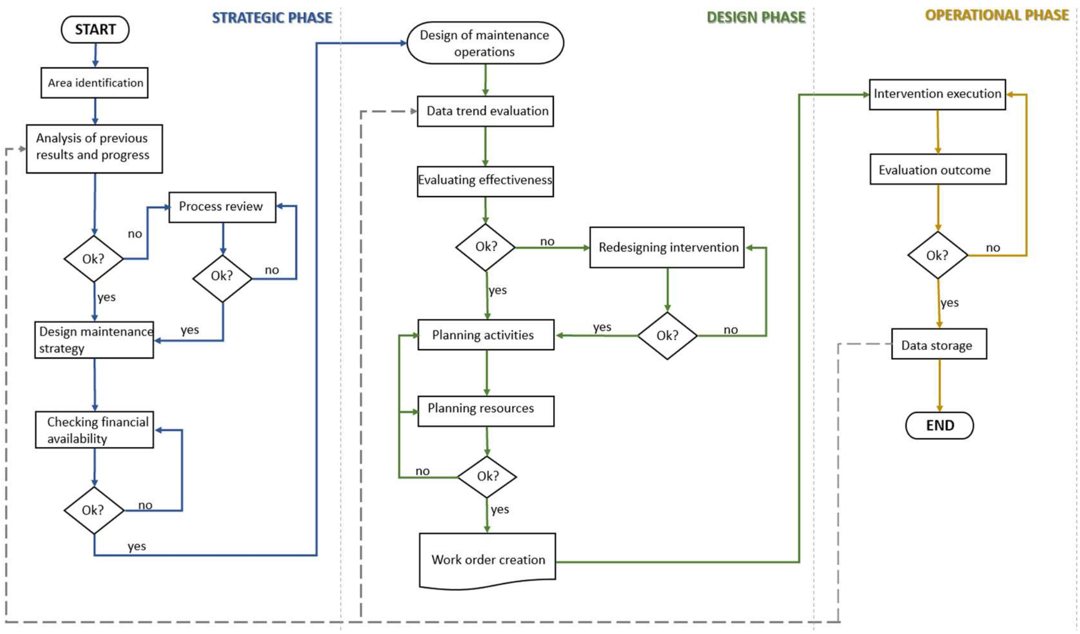


Figure 52:Decision-making process

Maintenance that the facility manager can identify are:
- Cleaning of condensate trays;
- Cleaning of exchange batteries;
- Cleaning of filters;
- Replacement of filters.

All timings can vary according to the data in order to avoid sudden and uncontrolled breakdowns.
In this case, nineteen information items have been identified that need to be managed among facility manager, maintenance supervisor and maintenance technicians.

A work order includes:

- Number of work order;
- Priority level;
- Name and surname of the person who authorised the work;
- Date of registration;
- Date of opening;
- Date of closing
- Which system it relates to;
- The location of the installation;
- Purpose of the intervention;
- Description of the problem;
- Type of intervention;
- Safety and environmental regulations;
- Name and surname of the technician to whom the intervention has been assigned;
- Cause of failure;
- Technical procedure;
- Description of implementation;
- Prerequisites for the completion of the objective such as expected spare parts or necessary tools;
- Expected budget;
- Actual budget.

According to the responsibilities of each stakeholder and according to the type of information, the person who transmits and receives this information was identified.

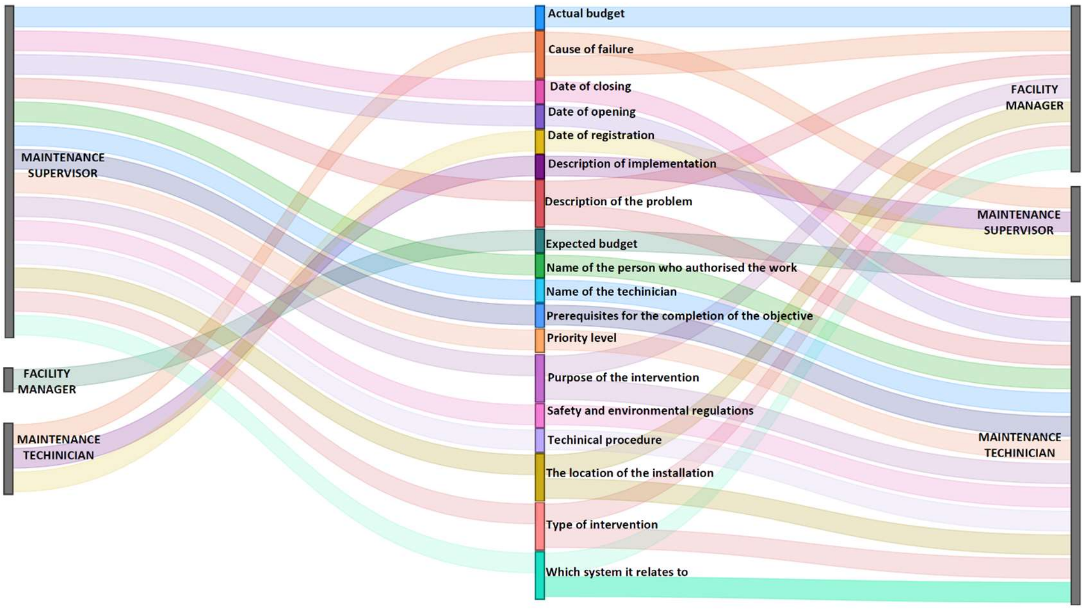


Figure 53: Information flow

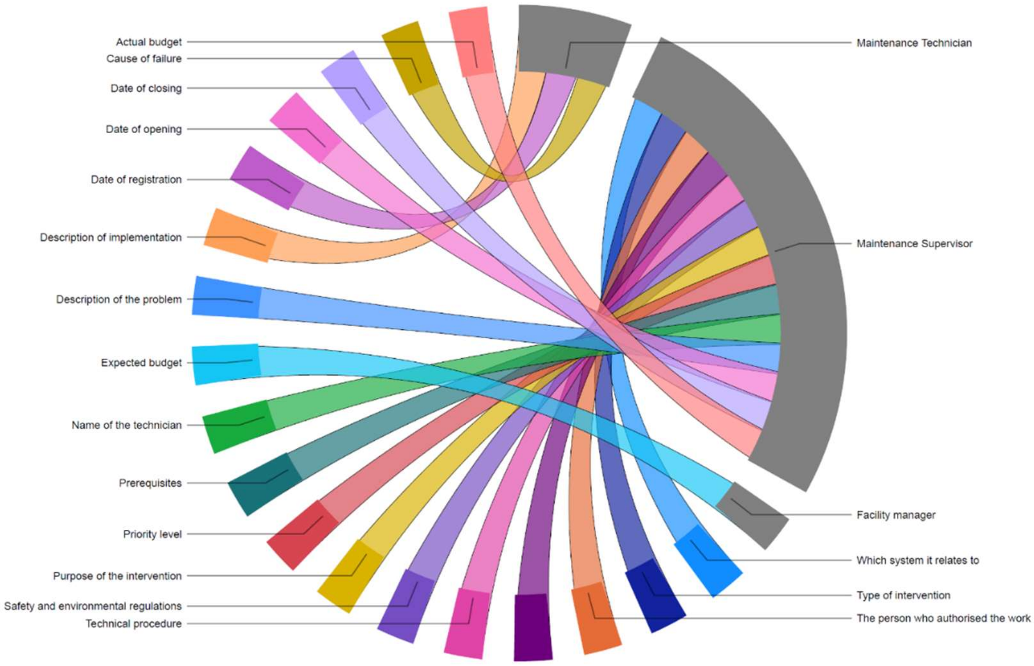


Figure 54: Who transmit the information

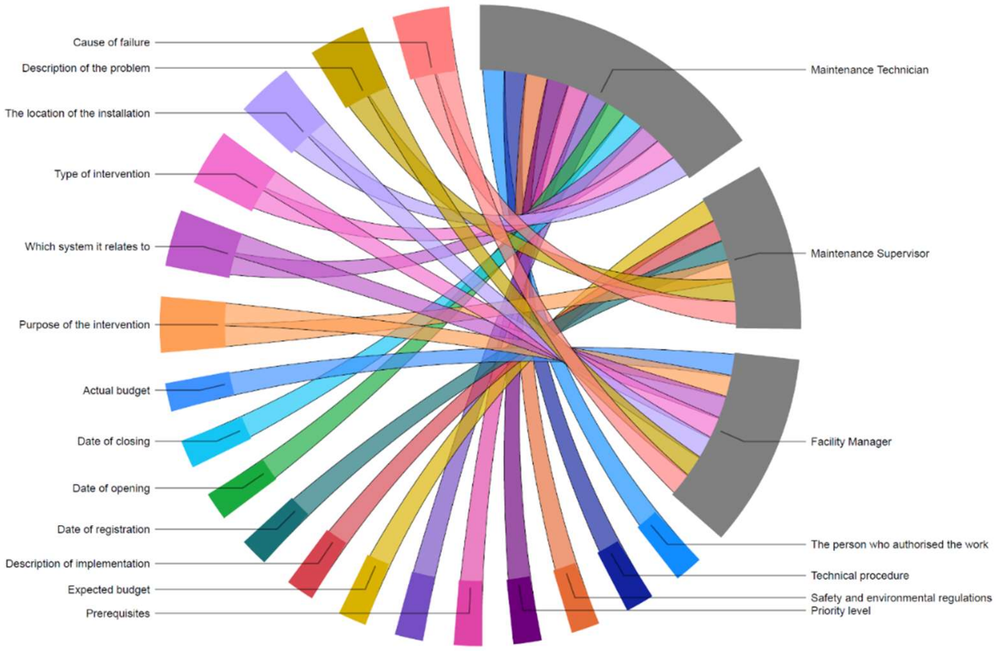


Figure 55: Who receivet he information

All information has been divided into macro-blocks according to the category of the individual data. In fact, the data are divided into spatial, general technical, maintenance and surveyed data.

The following figure shows the link between the different data, considering that the database (of the platform from which the dashboard data will be extracted) is the data collector.

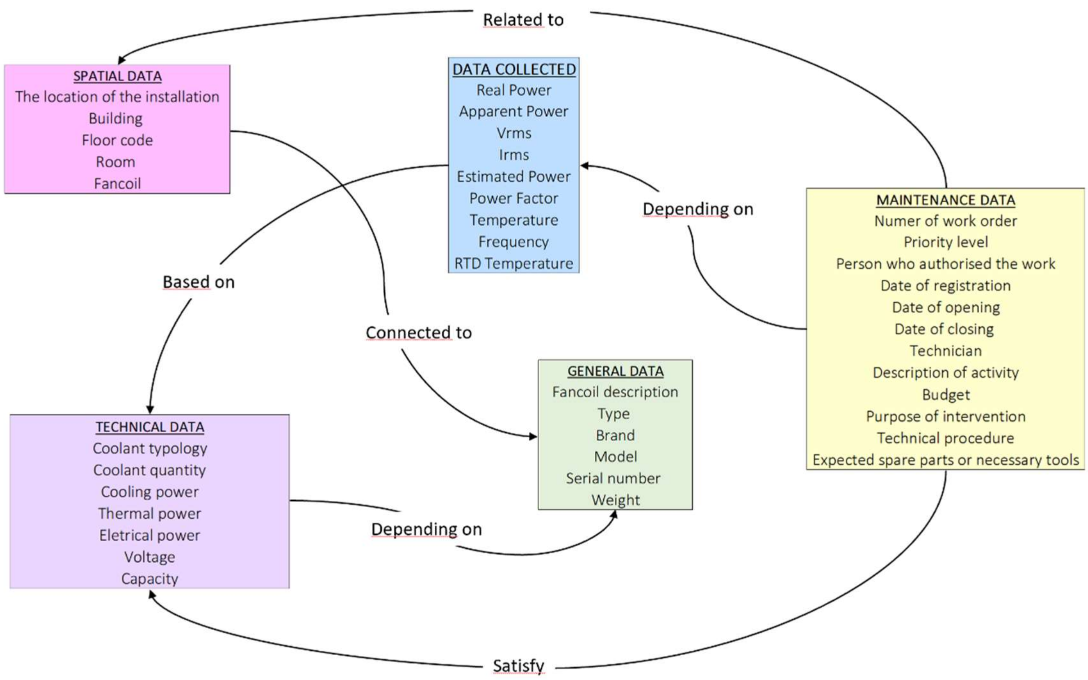


Figure 56:Data relationships

5.2. Data visualization: Dashboard

In this section, after explaining the decision process and identifying the information to be transmitted, the visualisation of all information from the platform itself, the sensors and the BIM model will be illustrated. Each stakeholder has its own interactive dashboard that should be seen as a useful tool for carrying out maintenance work in order to achieve process optimisation.

First, there is the dashboard that the facility manager will interface with. This dashboard is divided into four sections: "Interference management", "Data control", "Trend" and "WORK ORDERS Managed".

In the first section, the facility manager displays the work orders being executed in relation to the location of the intervention. On the dashboard, green "dots" will appear on a daily basis indicating, in relation to the building, the number of interventions being carried out. At the same time, a string will appear containing the reference classroom (with the coding used by the Polytechnic) and the number of the work order. Otherwise, in correspondence with two activities taking place at the same time and in the same place, a red dot will signal an interference. The platform alerts the FM in case of interference with other maintenance or university related activities. In fact, this stakeholder is responsible for managing the spaces and therefore for resolving any interference. The facility manager, in order to resolve the interference, may temporarily suspend the activity by notifying the maintenance supervisor.

To facilitate this resolution, in the lower part of this section it is possible to identify free classrooms by entering the date, time and building ID. (The building IDs are "CEN" or "CIT" and refer to “Sede Centrale” and “Cittadella” of Politecnico respectively.) Unoccupied classrooms in which the air conditioning system is normally functioning will appear. At this point, the FM can indicate the available classrooms to those responsible for moving activities to different classrooms. This double step makes it possible to limit environmental discomfort and to use access equipment without waste.

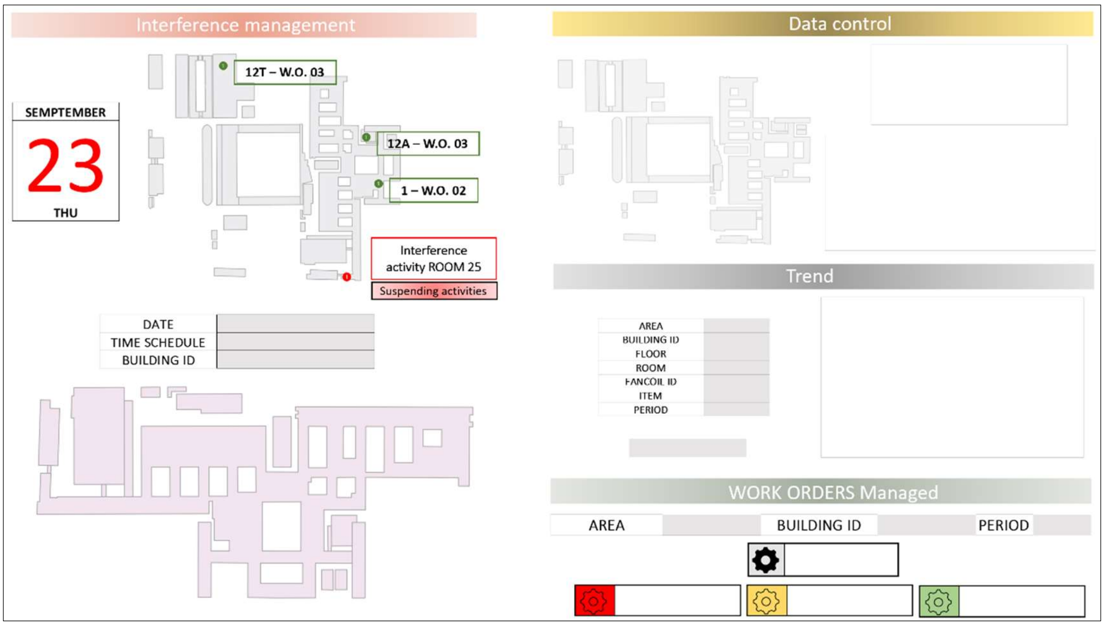


Figure 57: Displaying the FM dashboard

As shown in the figure 58, after selecting the date, time and ID, the portion of the building containing the free classrooms will appear on the map in green and the number corresponding to these free classrooms will appear on it too,

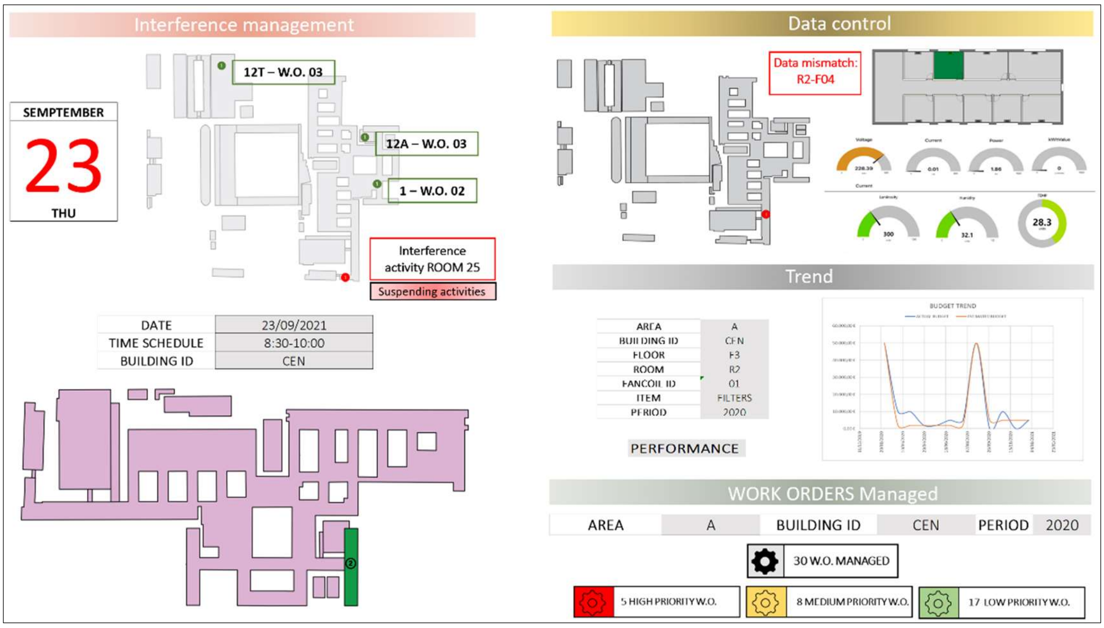


Figure 58:Subsequent display of FM dashboard

After clicking on the number that appears in the green area, it is possible to view the precise room and its location. A string will appear, corresponding to the actual location of the classroom, which contains the identifier of the room and the floor on which it is located.

Differently, on the right, there is a section in which the facility manager may notice discrepancies between the data detected by the sensors in the room and the sensors on the fan coil. The “Data control” section is very important because it allows the effective control in real time of the data that is collected by the IoT sensors positioned at the fan coil and placed in the room. In fact, in this section there is a reprocessing of the environmental data relating to the room and those of fan coil operation; there will be a display of inconsistency between the data which will be outside a range. For example, during summertime, if the fan coil is operating but the temperature or humidity in the room is too high, a warning will appear on the dashboard indicating this discrepancy. The map will show the room where the data inconsistency occurs and the corresponding room and fan coil code (codes used in maintenance work). These data discrepancies may not be caused by malfunctioning sensors, but this could be caused by external factors, such as opened windows. A visual check of the room will then be necessary. Visually, on the general map (which appears if inconsistencies between data are detected), a dot will indicate the location of the data. After clicking on the dot, a map of the building will appear at the top with the room and the fan coil highlighted, and at the bottom with the environmental and operating data recorded in real time by the sensors.

The other two sections are related to the management of maintenance strategies and the supervision of work orders, so that the facility manager can have a clear picture of the work carried out and its outcome. In this way, the FM can calibrate his decisions according to data trends. In the "Trend" section, depending on the data stored, it will be possible to view histories of the progress of maintenance work, replacements carried out, stock levels and the budget used. In this way, the FM can implement different strategies based on the actual results of previous strategies. Hence , he can assign a budget that is as consistent as possible for future maintenance work. This will allow cost reduction and a targeted use of all resources.
It is possible to view the trend over time in relation to the operation of the fan coil or even the trend in the budget or inventory. You must enter the reference area, the floor and the room ID consisting of the letter R and a progressive number, the fan coil ID also consisting of the letter F and a progressive number and finally, you enter the reference period. On the other hand, in the "WORK ORDERS Managed" section, by entering the area, the building ID and the period, it is possible to view the work orders executed according to their priority.

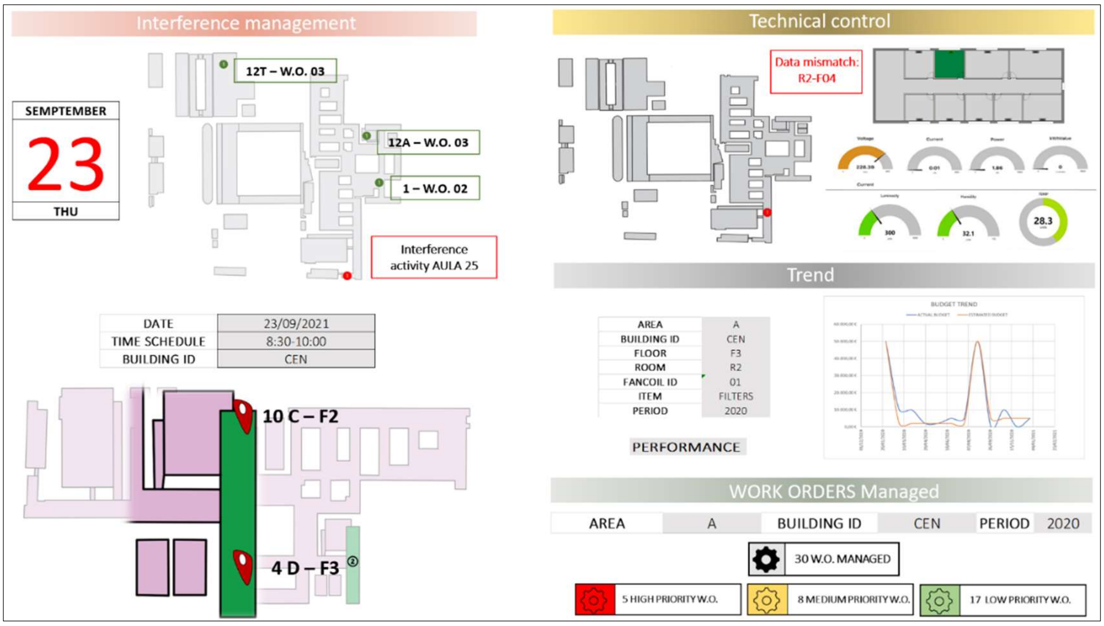


Figure 59:Full display of FM dashboard

The following figures show a map of the university facility and the division of the Politecnico into areas relating to the “Sede centrale” and “Cittadella”.

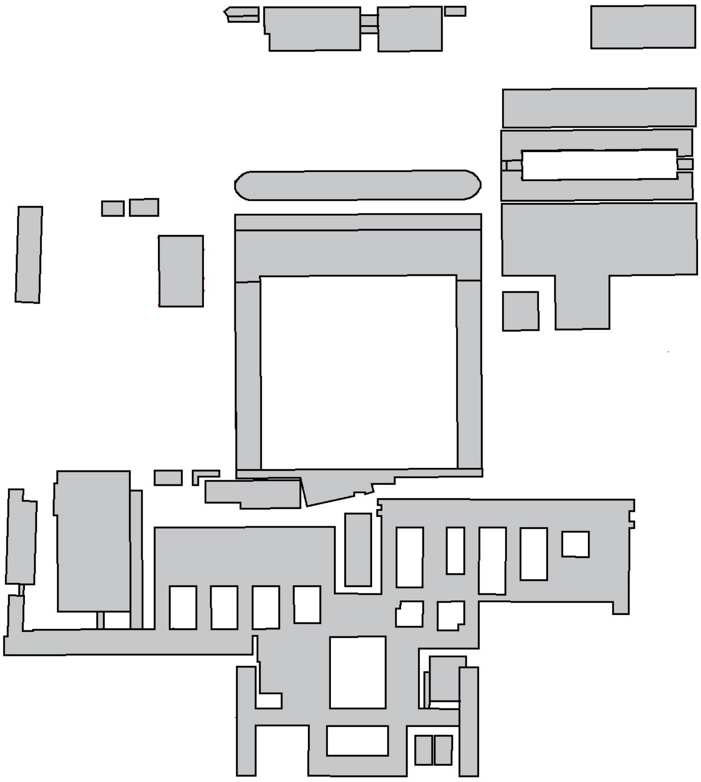


Figure 60: Map of the Politecnico di Torino

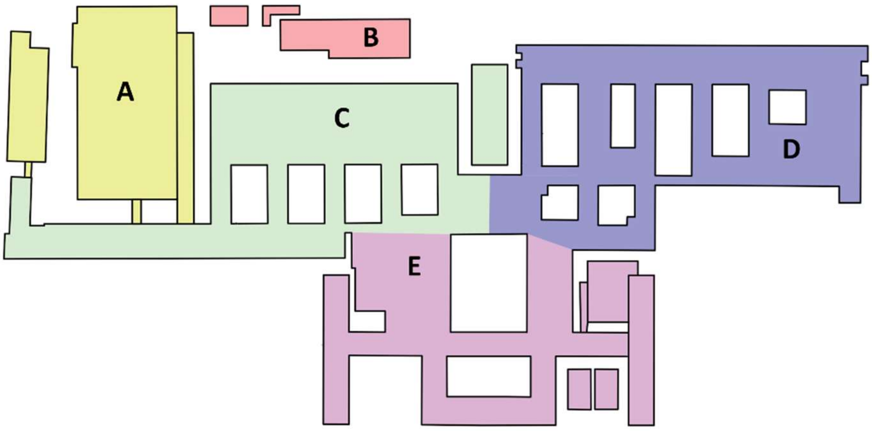


Figure 61: Subdivision of "sede centrale"

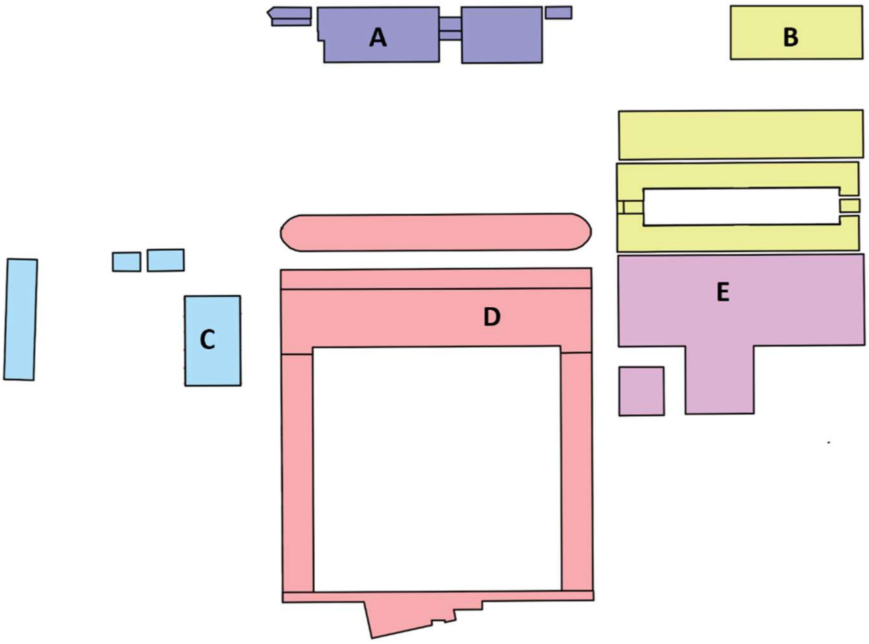


Figure 62:Subdivision of "Cittadella"

In a different way, the dashboard of the maintenance supervisor consists of five sections: "Warning", "Work order", "Trend", "Planning" and "Data monitoring".

The first section, "Warning", is itself divided into two parts. The top section displays warnings of various anomalies detected by the sensors according to the flow chart illustrated above (figure 48). Depending on the severity of the anomaly, the maintenance supervisor authorises work orders with a high, medium or low priority, to which he or she can attach outline activities (such as a visual inspection). At the bottom, on the other hand, appear the alerts related to the interferences that the facility manager is managing and suspends a given activity until the interference is resolved,in case of differences between data if a visual inspection in the room is necessary , the "Trend" section allows a display of the trend of the data according to the stock level, the budget and the maintenance trend. This view is useful for making possible improvements in the planning and designing of interventions.

In addition, in the "Work order" section, the maintenance supervisor checks the work orders (in order of priority level) that may be running, planned, pending or authorised. The table shows:

- the code of the individual work order consisting of the floor indication, the room code, the fan coil code and a progressive number;
- the priority level;
- a brief description of the problem;
- the code of the technician who is carrying out or will carry out the intervention.

All other information that is not displayed instantly is entered in the work orders, in fact, by clicking on the work order ID the work order completed by the supervisor will appear.

The "Data monitoring" section in the bottom right-hand corner allows the supervisor to view real-time data from the sensors by entering a room ID and a fan coil ID. The dashboard only allows this section to be used if the "Planning" section is not being used. This last section can also only be used if the monitoring section is not active

The following figures show a different view of the dashboard according to the priority level of the work order issued by the sensor warning and the graphs in the "Trend" section.

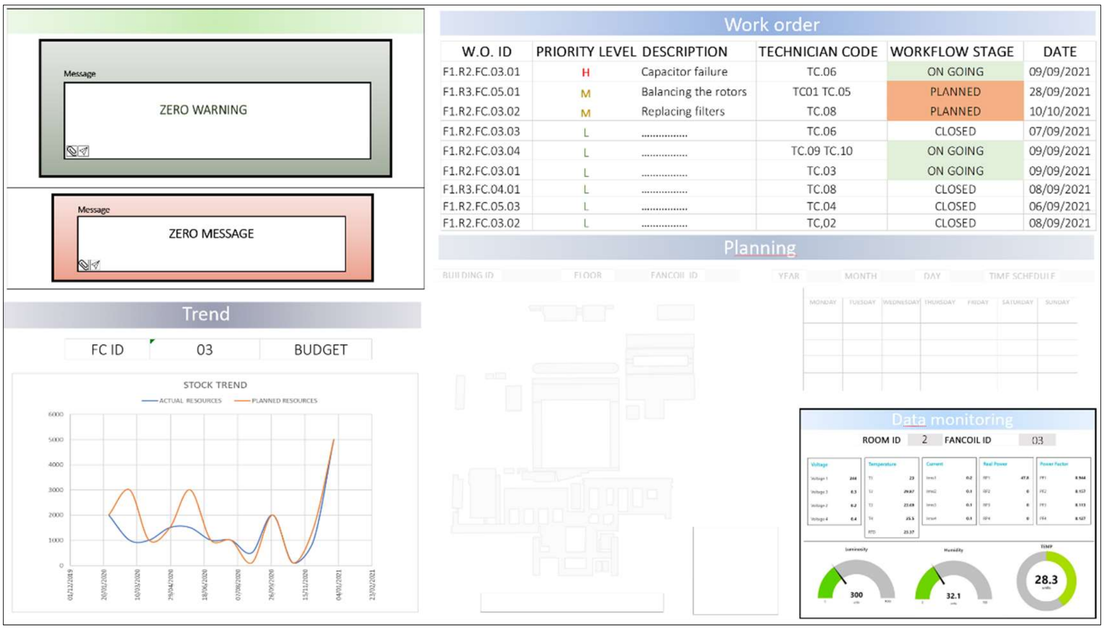


Figure 63:MS dashboard display without warnings

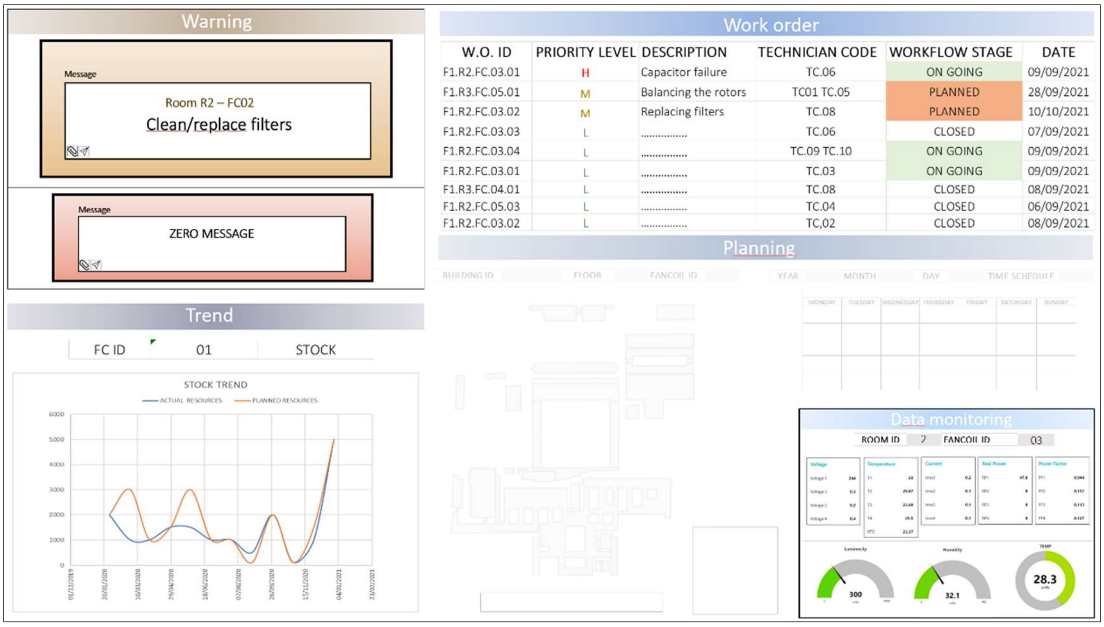


Figure 64:MS dashboard display with a warning - medium priority

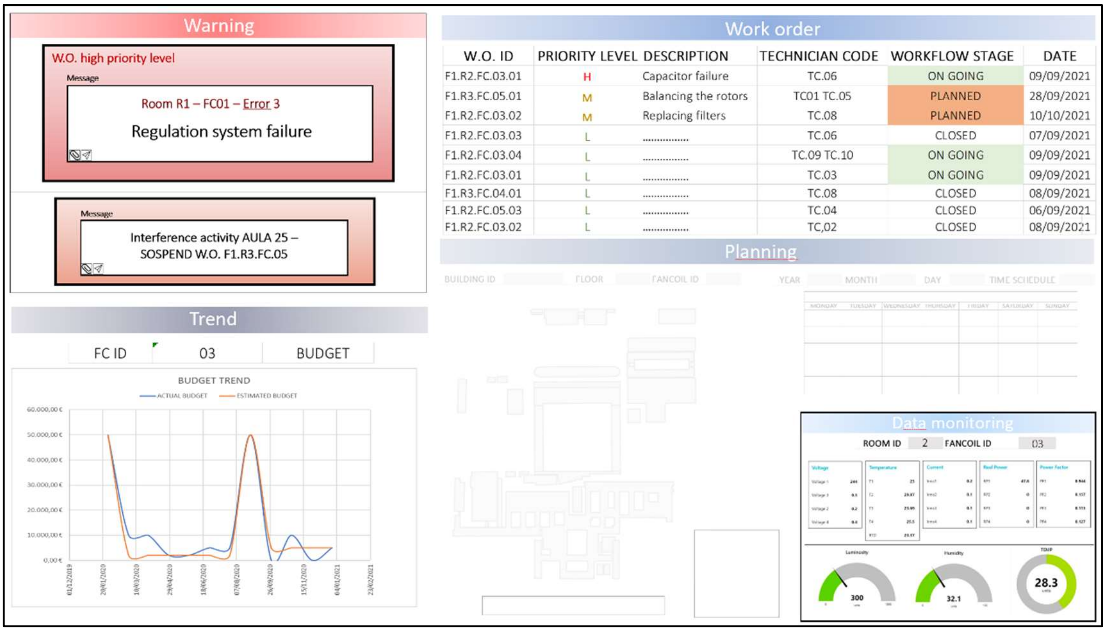


Figure 65:MS dashboard display with a warning - high priority

In the last section, "Planning", the maintenance supervisor, after obtaining instructions from the facility manager, plans and designs the maintenance activities. To identify the fan coil on which maintenance is to be performed, he clicks on the portion of the building in which the fan coil is located. Then, he selects the floor so he can choose the portion of the building that is identified by clicking on the screen the 3D model appears (from which information can be extracted clicking on the icon), To identify the fan coil, it is necessary to click on the model and then it turns green . At this point, the maintenance supervisor has all the previous information on the maintenance progress and can plan the maintenance by finding the date on the calendar and starting the procedure for drawing up the work order. All these steps are represented in the following figures.

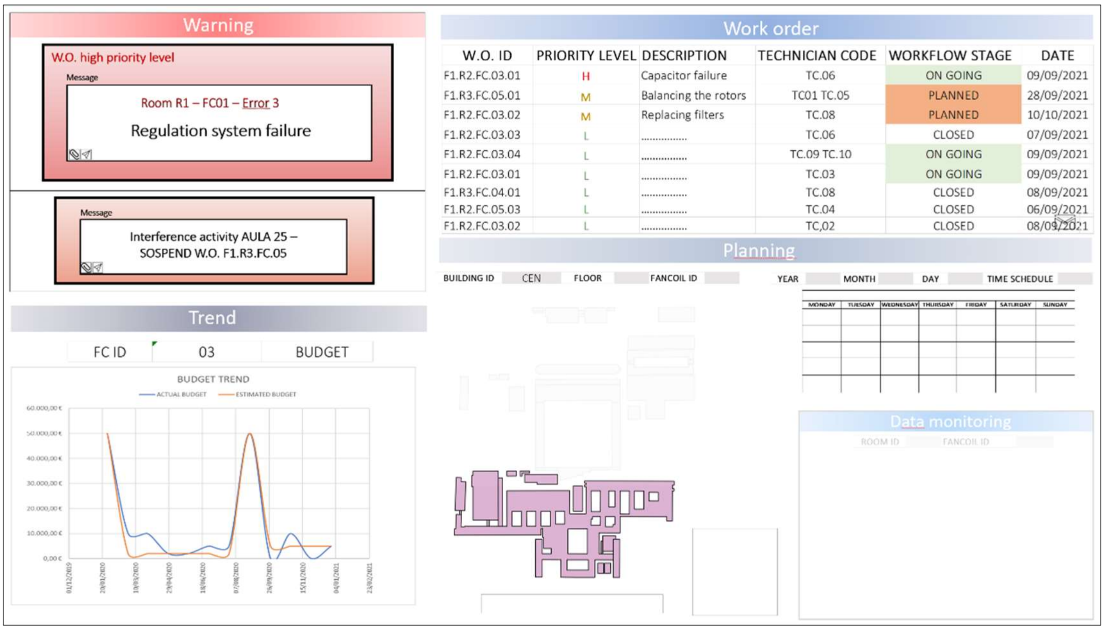


Figure 66:MS dashboard display with building ID identification

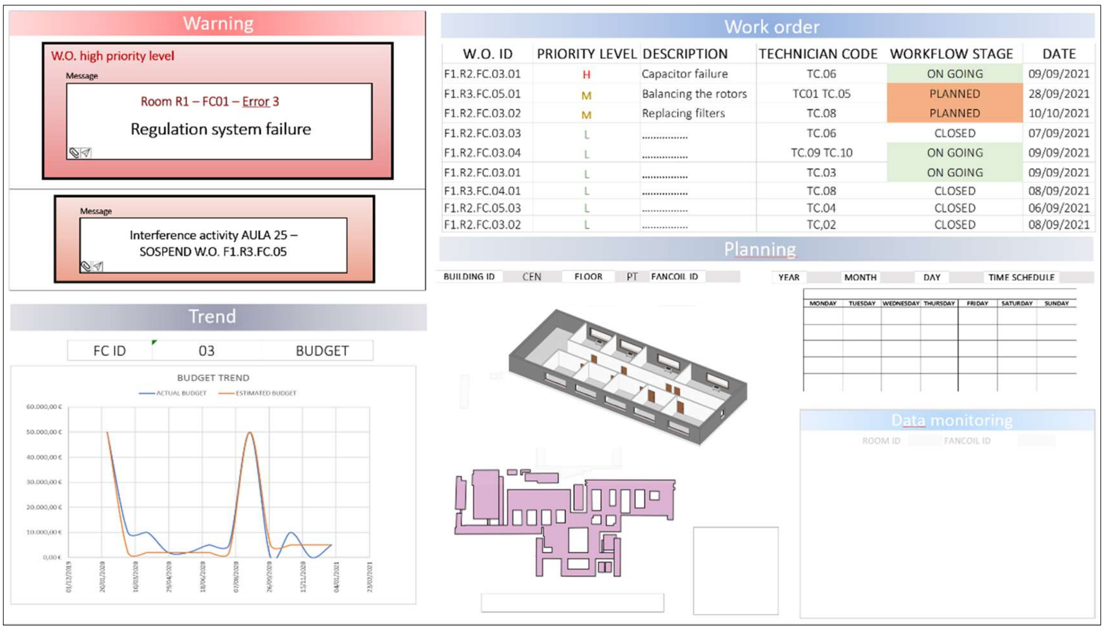


Figure 67:MS dashboard display with floor and building's portion identification

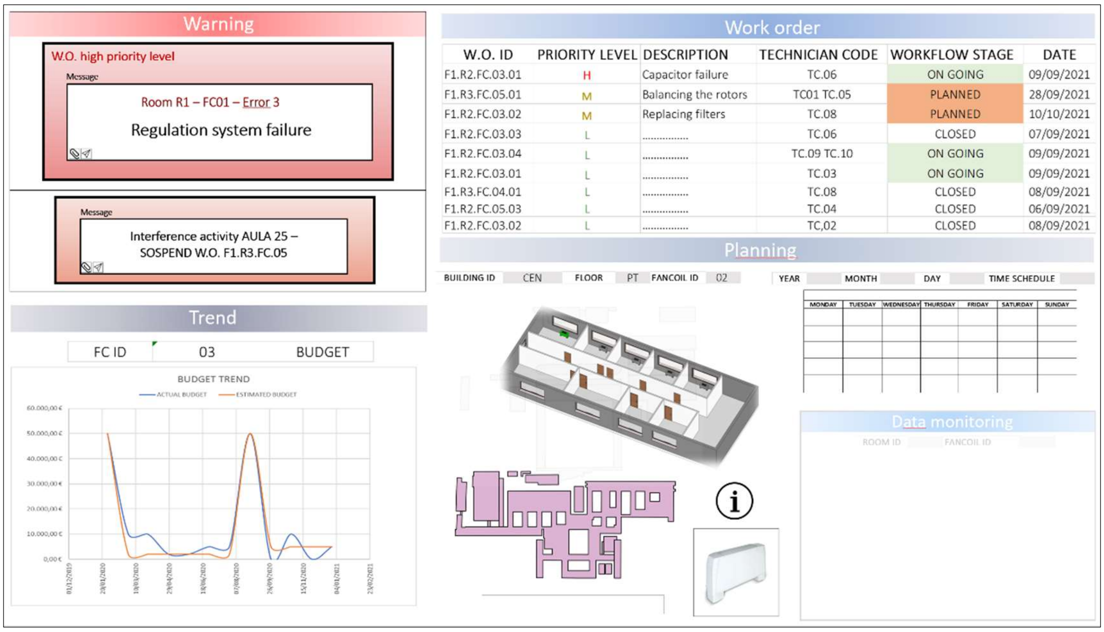


Figure 68:MS dashboard display with fancoil identification

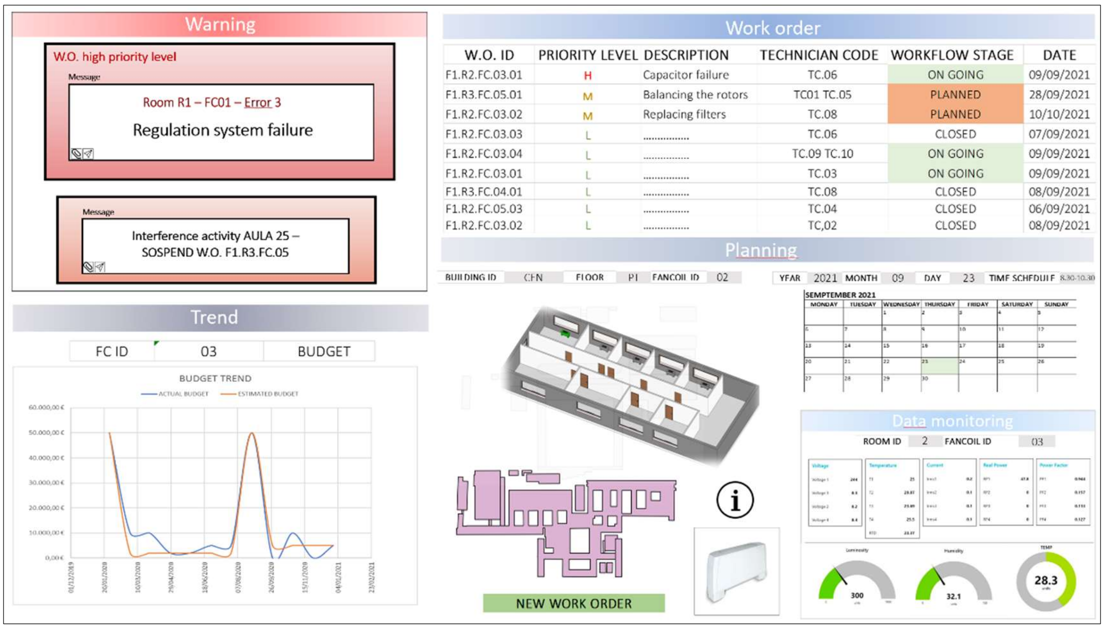


Figure 69:MS dashboard display with date identification

After clicking on "NEW WORK ORDER", a worksheet will appear for the supervisor to fill in first, and for the technician to fill in later, after the work has been carried out.

Priority:

WORK ORDER n°

Supervisor

Date of registration
Date of opening
Date of closing

Fancoil ID:

DESCRIPTION:

PROBLEM:

EXCECUTION

TECHINICIAN

Intervention:

Procedure

Planned materials		Additional material	
	€		€
	€		€
	€		€
TOT.	€		€

Replacement

	€	Timetable	
	€	Days of delay	

Description of work carried out

Cause of failure

Figure 70:Displaying a work order before compilation

The supervisor must fill in the work order by providing the information, which has been identified in advance, that is necessary to carry out the task, such as the procedures to be carried out, description of the fan coil, any elements needed to carry out the activity and the timeframe. The maintenance supervisor may attach to this sheet an additional sheet with the following information about the safety and environmental regulations.

The recording date and the start date are filled in autonomously depending on the day on which the work order is drawn up (date of registration) and depending on the day in which the work order is actually authorised (date of opening).

The spaces highlighted in light blue below are the ones that the supervisor will fill in and that the technician will read and cannot make changes to.

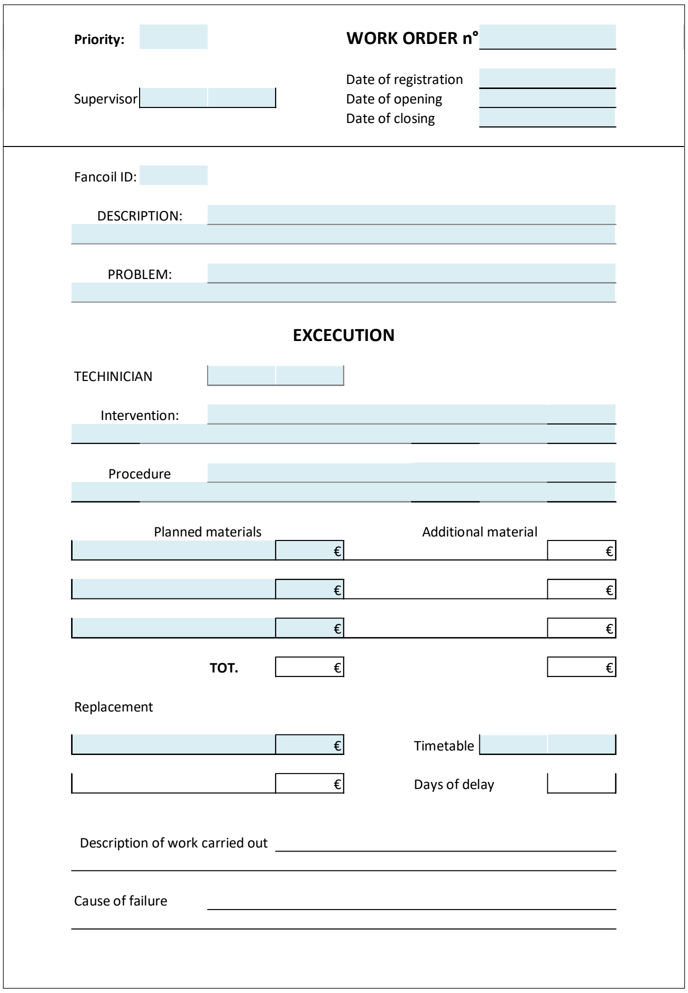
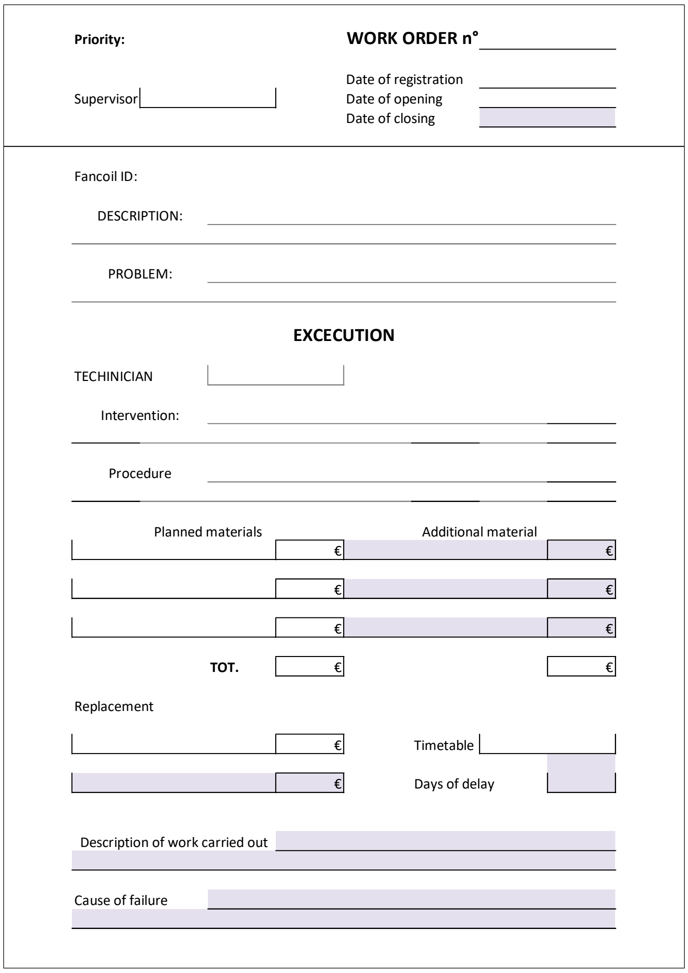

Priority:
WORK ORDER n°
Supervisor
Date of registration
Date of opening
Date of closing
Fancoil ID:
DESCRIPTION:
PROBLEM:
EXCECUTION
TECHICIAN
Intervention:
Procedure
Planned materials
Additional material
€
€
€
€
€
€
TOT. €
€
Replacement
€
Timetable
€
Days of delay
Description of work carried out
Cause of failure

Figure 71:Fields to be completed by the maintenance supervisor

The last dashboard is the one for the technicians that carry out maintenance operations. This dashboard consists of five sections: "Warning", "Location", "W.O. of the day", "Data monitoring" and "Storage".
The "Warning" section warns the technician that an urgent, high-priority task, which is detected by the sensors and not planned, needs to be carried out. This activity has previously been authorised by the maintenance supervisor. Instead , the "W.O. of the day" section shows the work that needs to be carried out. The table shows the work order code, the priority level, a brief description of the problem, the identifier of the supervisor who authorised the intervention and the status. Thanks to the "Location" section, the technician can see where the fan coil to be serviced is located. By clicking on the number on the map, it is possible to display the route to reach this fan coil. In this way, the location of the fan coil can be read immediately. Then, when opening the work order and by clicking on the ID, the technician will be able to see all the information necessary for carrying out the work. After the execution, the technician will fill in the remaining missing parts of the work order, indicating any delays or unforeseen additions.
.


Priority:

WORK ORDER n°

Supervisor

Date of registration
Date of opening
Date of closing

Fancoil ID:

DESCRIPTION:

PROBLEM:

EXCECUTION

TECHINICIAN

Intervention:

Procedure

Planned materials €
Additional material €

TOT. € €

Replacement €

Timetable

Days of delay

Description of work carried out

Cause of failure

Figure 72:Fields to be completed by the maintenance technician

Furthermore, in the "Storage" section, you can check the availability of the system items through QR CODE codes. These codes not only allow a quick reading of the warehouse but are also an effective way to check the status of the warehouse.

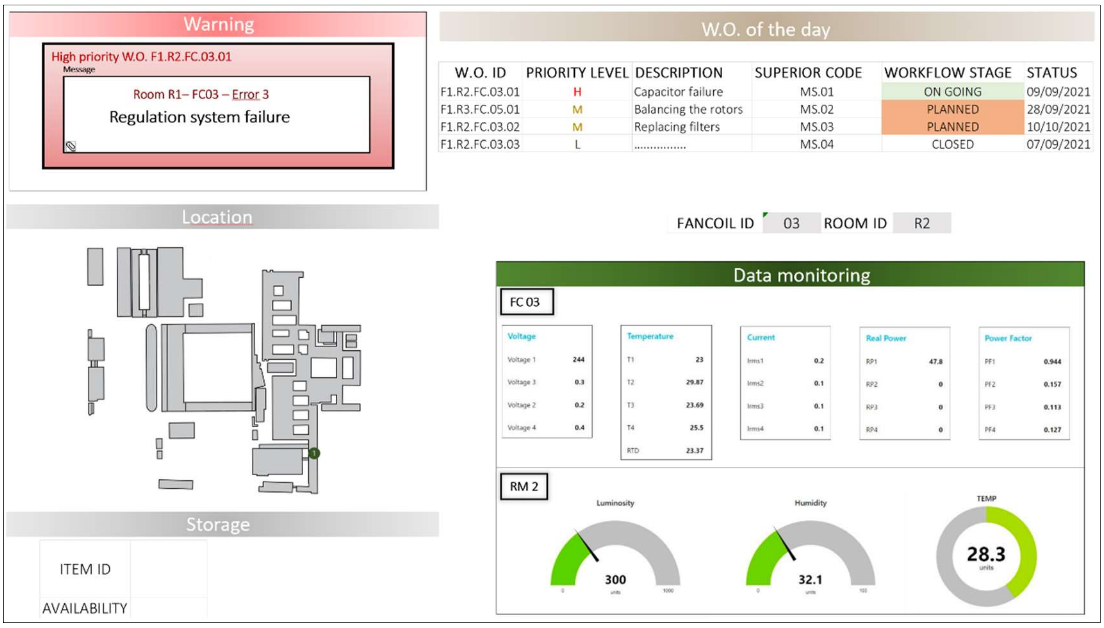


Figure 73:MT dashboard display with indication of work orders

Finally, in the last section it is possible to view the monitored data in real time by selecting the fan coil and room identification. The data that the technician displays are those that are processed by the IoT sensors. This section allows a quick check, after an intervention, of the actual functioning of the system.

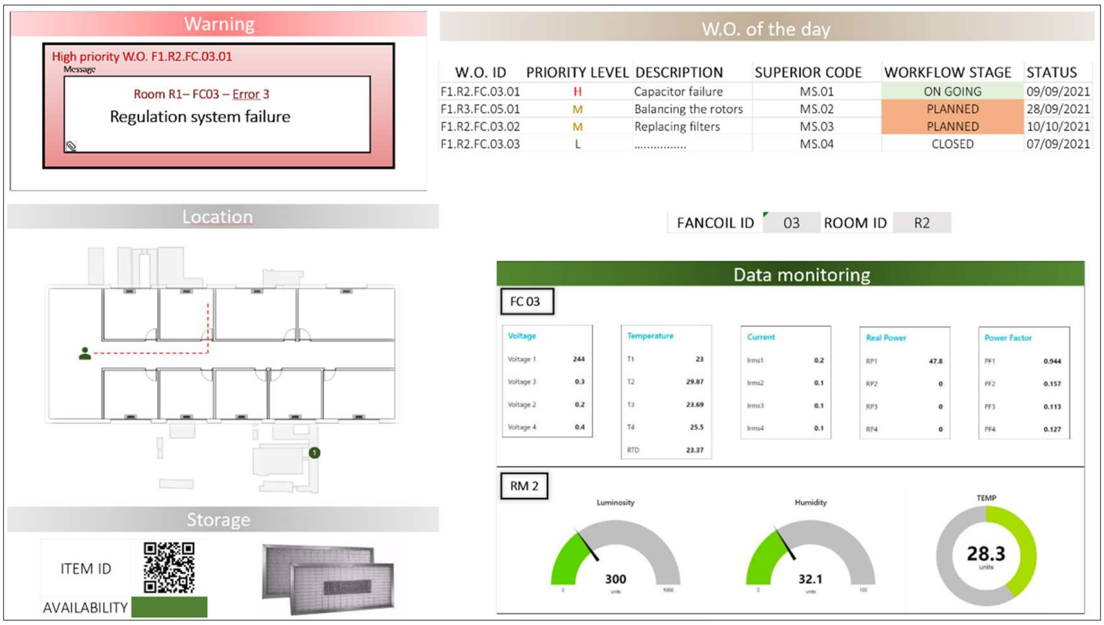


Figure 74:MT dashboard display with indication of the location

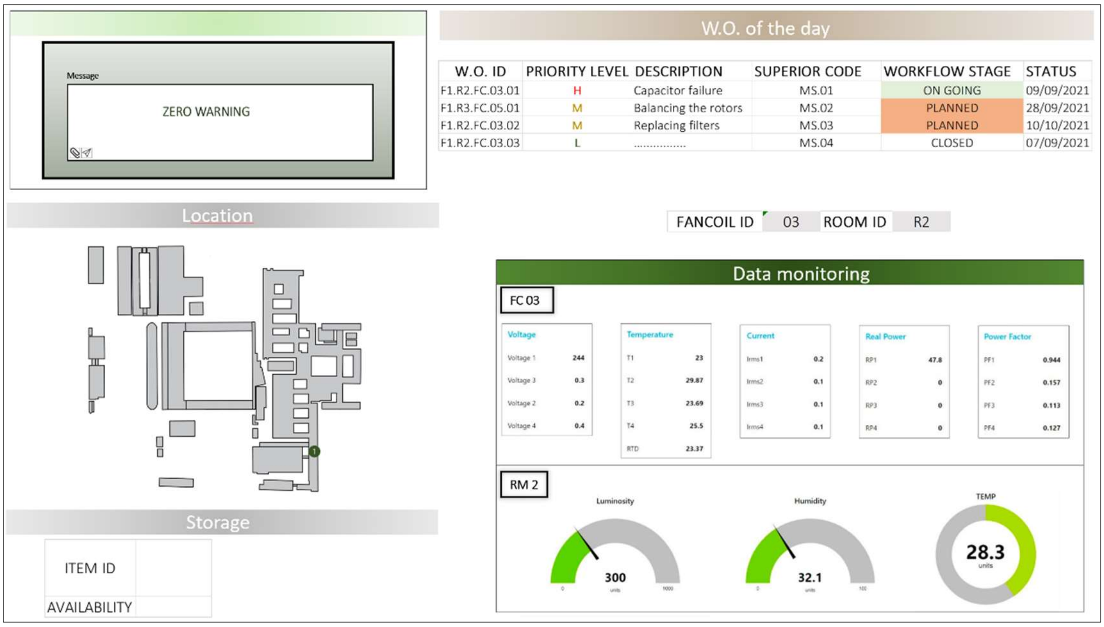


Figure 75:MT dashboard display without warnings

6. Conclusions and future works

This study has shown particular interest in the treatment and study of an approach to maintenance known as 4.0, which aims to contribute to an improvement in the entire management of this phase, with the objective of identifying the flow of information that underpins this process, which must be collaborative and traceable. This process is managed through the new technologies of the Industry 4.0 era (IoT, BIM and DT), which allow the detection and prediction of faults, thus enabling the design of targeted and immediate interventions.

The thesis work was divided into several phases. In the first phase of analysis of the state of the art, it emerged that many studies are still necessary regarding the improvement of the integration of the BIM with the IoT sensors, since the technologies in use today do not allow an automatic update of the BIM model and an immediate analysis of the data.

The next phase of study and analysis of the building process had the objective of identifying what should be the design and implementation path that makes the collaboration between the different figures as effective as possible. This study aims to underline the close connection that must exist between the design and construction phase and the management phase. In fact, today, the use phase of a building is the phase that is least structured and at the same time is the most critical phase of the whole life cycle of a building. A predictive approach is needed.

From the identification of the building process, the research moved on to the identification of the stakeholders and the information flow. These identifications were the basis for the creation of the dashboards.

With the creation of the dashboards, a reasoned maintenance activity was created in order to make all maintenance interventions effective and traceable. One aspect that has proved fundamental is that of data archiving and the creation of a history. These two aspects are fundamental for predictive management.

The case study encapsulates all the advances that have been achieved to date. In fact, with environmental sensors it is possible to manage environmental data and with fan coil data it is possible to manage the operation of the system.

All the analysis carried out and the design of the system with the integration of the BIM modelling with the IoT sensors and with the possible creation of a digital twin had the aim of overcoming the limits of these technologies highlighted during the study of the state of the art.

As far as BIM is concerned, the obstacle to overcome was the improvement of model interoperability, which was overcome by the use of open systems and formats (e.g. IFC), thus avoiding specific software houses.

Furthermore, one of the most significant objectives that has been achieved is to use modelling software not as a simple modelling tool but as a device, a useful means of managing the system. This is still one of the major problems, as a change in the way of approaching 3D modelling is needed. A digital twin is not a mere representation, a copy of reality, but it is a means, at our disposal, that helps to better understand reality, to anticipate, when possible, certain problems.

With reference to the 3 case studies presented in the first chapters:

1. Sensor-Revit integration with built-in functions of Revit software.
2. Sensor-Revit-Navisworks integration with built-in functions of Navisworks.
3. Sensor-Revit-Navisworks-API integration with add-in developed.

They had some limitations, i.e. in the first case only 2D data visualization, in the second case no historical data visualization but 3D model visualization, and in the third case, even if historical data and 3D model visualization were available, it did not allow real-time data visualization. The system designed has tried to incorporate 3D visualisation, real-time data and historical data in a single platform.

However, it must be stressed that not all limitations have been overcome. First of all, it will be necessary to improve the connection of IoT senses, improving the lower power networks. In addition, future research will have to focus on the implementation of scripts and on the actual IT performance. This kind of system has wide application margins and the whole system related to maintenance and internal well-being could be associated with the whole world of home automation. In this case, one could control both the quality of the indoor environment (by switching lights on and off automatically and remotely, or closing or opening windows). An application of this could tie in, for example, when there is a difference between the environmental data and the fancoil data due to windows being opened, the system could automatically close these windows.

The next step will certainly be to extend the system to more fan coils, but above all the most important step will be to try to initiate analysis using machine learning algorithms.

Machine Learning algorithms are algorithms that use mathematical-computational methods to learn information directly from data, without mathematical models and predetermined equations, and improve their performance in an "adaptive" way as the "examples" from which they learn increase. This term was coined in 1959 by Arthur Lee Samuel, an American scientist, although the most widely used definition is that coined by Tom Michael Mitchell, director of the Machine Learning department at Carnegie Mellon University:

"a program is said to learn from experience E with reference to some class of task T and with performance measure P, if its performance in task T, as measured by P, improves with experience E".

Machine Learning is to be understood as the ability of computers to learn without being explicitly programmed.

In addition, it should be emphasised that the objective of the whole study was to build an organisational programme of maintenance activities in order to improve and achieve all the benefits identified by the previous state-of-the-art analysis, such as:

- Reducing costs: this discipline not only deals with the selection of suppliers with the best value for money, but also seeks to reduce energy consumption, optimise resources and maintenance activities.
- Improving safety: this is a central aspect of facility management through the control of company security devices.
- Providing engaging and productive working environments: in addition to the physical management of spaces, the facility is also responsible for the cleaning of environments, maintenance of green areas and all those activities that can ensure a comfortable environment
- Extend the lifecycle of assets: efficient management of facilities and all their components reduces maintenance costs and extends their lifecycle.
- Improving customer satisfaction: FM manages lighting, escalators, cleaning, internal temperature.

From the considerations made, future research identified in the first chapters has certainly been analysed, although not completely overcome. Below is a table highlighting the challenges addressed and studied.

From the considerations made, future research identified in the first chapters has certainly been analysed, although not completely overcome. Below is a table highlighting the challenges tackled and explored in depth, underlining the results achieved.

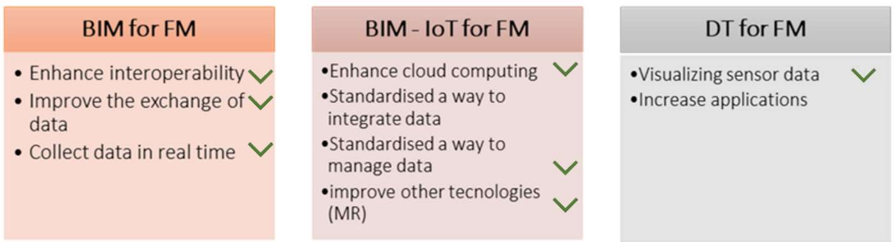


Figure 76:Challenges faced and overcome for BIM for FM, BIM-IoT for FM and DT for FM

As can be seen from the figure above, it will be necessary to structure a standardised system and to increase applications by raising awareness of maintenance 4.0 in the construction sector.

In conclusion, the entire study is intended to represent a step towards a completely innovative approach, based on new technologies and the advent of what has been called the fourth industrial revolution, for this reason it is not a point of arrival but a starting point for future research and further improvements and insights.

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