UNIVERSITÀ DEGLI STUDI DI FIRENZE
DIPARTIMENTO DI ARCHITETTURA
DOTTORATO DI RICERCA IN ARCHITETTURA
CURRICULUM TECNOLOGIE DELL'ARCHITETTURA

DOCTORAL THESIS

FAR

Flexibility in Airport ARchitectural design:

Including a life cycle approach in project design management of an airport terminal

PhD Candidate: Elisabetta Fossi
Advisor: prof. M.A. Esposito

TXP RESEARCH

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TXP RESEARCH

Elisabetta Fossi

elisabetta.fossi@unifi.it

www.txpresearch.wordpress.com

Università degli Studi di Firenze - Dipartimento di Architettura

Via della Mattonaia, 14 - 50121 Firenze

Doctorate coordinator: Prof. Arch. Maria Teresa Bartoli

Cover: Taking off airplane by Elisabetta Fossi from BASIC Master degree thesis

DOTTORATO DI RICERCA IN ARCHITETTURA

CICLO XXIX

COORDINATORE Prof. Maria Teresa Bartoli

FLEXIBILITY IN AIRPORT ARCHITECTURAL DESIGN:

Including a life cycle approach in project design management of an airport terminal

Settore Scientifico Disciplinare ICAR/12

Dottorando
Arch. Dott. Elisabetta Fossi

____

Tutor
Prof. PhD Arch. Maria Antonietta Esposito

____

Coordinatore
Prof. PhD Arch. Maria Teresa Bartoli

____

Anni 2013-2016

“Fossi, vediamo di levarti quel sorriso compiaciuto dalla faccia.”

Paolo Chiari

Il mio Professore

“You’ve got to find what you love. And that is as true for your work as it is for your lovers.

Your work is going to fill a large part of your life, and the only way to be truly satisfied is to do what you believe is great work. And the only way to do great work is to love what you do.

If you haven’t found it yet, keep looking. Don’t settle. As with all matters of the heart, you’ll know when you find it. And, like any great relationship, it just gets better and better as the years roll on. So keep looking until you find it. Don’t settle.”

Steve Jobs

ABSTRACT (ENGLISH)

For reading the Italian summary of the thesis, please see Appendix B.

The research deals with project design management and sustainability; it refers to the discipline of Technology of Architecture.

Airport terminals are characterized by technical requirements of a building; whereas they also are an infrastructure. The very first requirement in airport terminal design is to respond to demand for passenger air transport. Thus, they must accommodate passenger traffic, by ensuring an adequate capacity.

But the real progression trend of future traffic demand is not certain; it is only possible to issue a forecast while bearing in mind that the future will possibly differ from projections of it. Consequently an airport passenger terminal has to respond to change, in order to accommodate passengers in the number and with the level of service required. It has to accommodate such changing travel demand.

But how to face uncertainty? How does an airport terminal effectively respond to the main requirement - which is to accommodate and process passengers - through a proper, correct and effective design over its lifecycle?

Recent research developments suggest answers to uncertainty by adopting design procedures for flexibility in building lifecycles. **Embracing change means to face uncertainty and giving the right inputs to design processes**. In particular operative flexibility is required as an input to design, enable and make possible product and environmental flexibilities, as a result.

Interesting approach and solution enabling flexibility as a design input are suggested by the recent research developments in life cycle costing, going beyond its usual use as a purely economic tool. The experimental methodology of the Design Catalogue [1]has been set up by an American research team in this framework applied to a parking garage. The evaluation method supports the designer with forecasting possible future scenarios for

[1] Cardin, De Neufville 2013

the development of the building and with using this information as input to the design process.

The research aimes at adapting this method as a tool for the planning phase of an airport terminal, focusing on the core aspects concerning the tailoring. Indeed at first, the general Catalogue methodology has been embedded within the general layout of a design process of an airport terminal. Then, the model for the evaluation of economic performance in the lifecycle, core of the methodology, has been tailored to one specific airport terminal. In the end, through a data collection on field and one iteration of the model, the algorithms were embedded in an automatized spreadsheet, as a tool for the pre-briefing (planning) phase.

At the end of the research, strengths, weaknesses, opportunities and threats have been identified and highlighted. The discussion of possible future developments of the work involves e.g.: the portability to other terminal cases; more tests for the validation of the model tailored; guidelines for the application of the results to other cases; exploration of the full decision support level for the methodology; tool upgrading concerning above all sheet C1; guidelines for the use of the tool. Scientific dissemination of the partial results was managed while the research work was ongoing.

LIST OF PUBLICATIONS

This work has been the basis for the following publications:

I. Fossi, E., Esposito, M.A. (2014). Snapshot of the Italian airport design. An analysis of the Italian core network existent terminals situation. In: Energy, sustainability and building information modelling and management, 1st ed. Maggioli Editore, pp. 175-187, ISBN 978-8891-6043-61

II. Fossi, E., Esposito, M.A. (2015). Green airport terminals: the Italian state of the art - overview of the current situation in Core network airports. City Safety Energy, I, pp58-66, ISSN 2283-8767

III. Fossi, E., Esposito, M.A. (2015). L'analisi dei costi nel ciclo di vita in supporto alla gestione di un'infrastruttura. In: Sostenibilità ambientale, economia circolare e produzione edilizia. La ricerca scientifica sulla produzione edilizia nell'era delle nuove sfide ambientali nel settore delle costruzioni, 1st ed. Maggioli Editore, pp. 542-552, ISBN 978-88-916-1222-9

IV. Fossi, E., Esposito, M.A. (2015). Life cycle approach and airport terminal design. In: S.Arch 2015 Environment and architecture, 1st ed. Get it published, pp. 48-56, ISBN 978-3-9816-62450

V. Fossi, E. (2015). Disposable Terminal Design. In: OSDOTTA Looking to methods and tools for the research in design and architectural technology, 1st ed. Firenze: Firenze University Press, pp. 163-170, ISBN 978-88-6655-848-4

VI. Esposito, M.A., Fossi, E. (2016). Airport planning and design: the airport projects development within the Italian regulatory framework. In: Back to 4.0: Rethinking the digital construction industry, 1st ed. Maggioli Editore, ISBN 978-88-916-1807-8

Al mio babbo. Alla mia mamma. A mio fratello. A Federico.

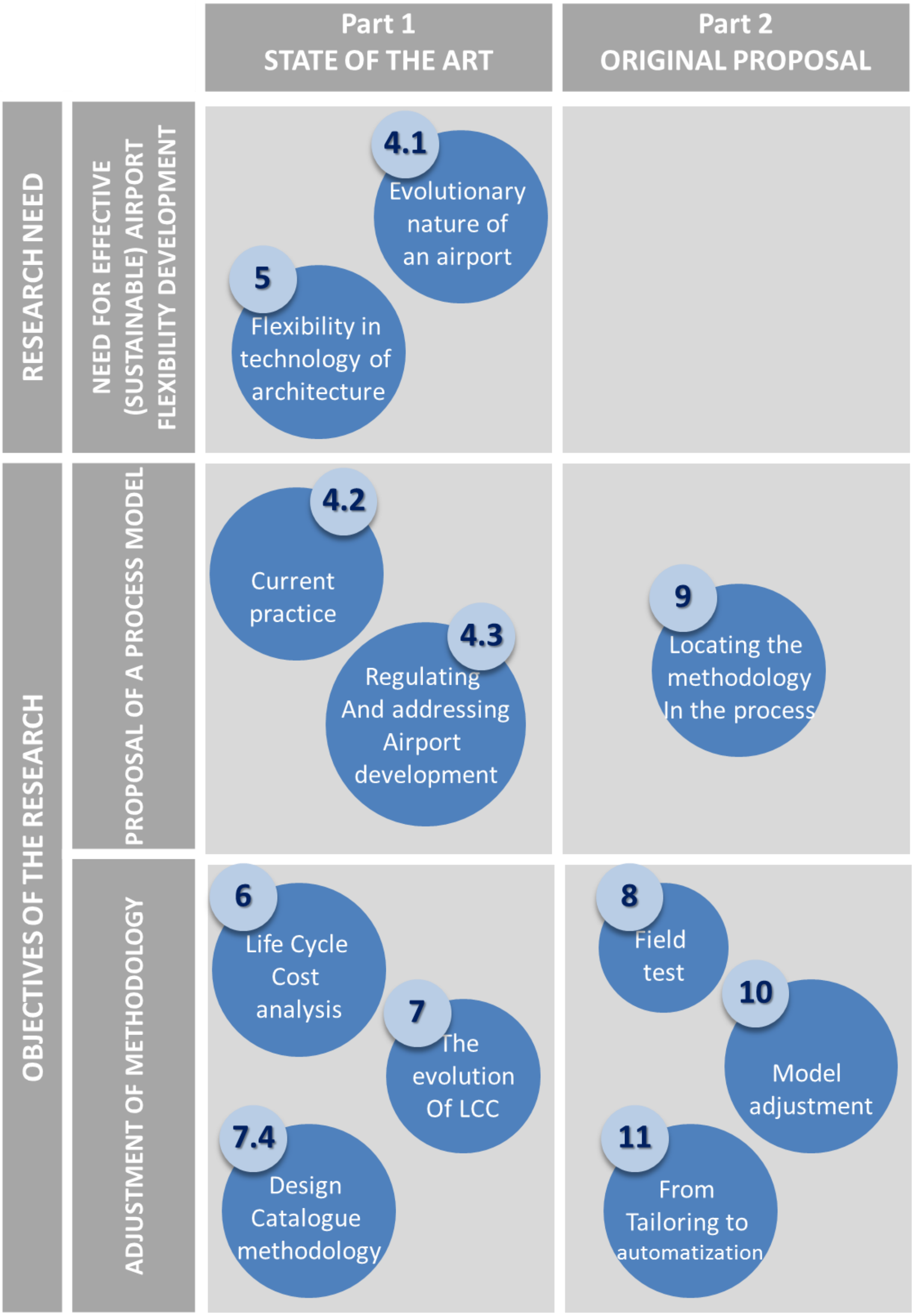
Alla Prof. Per avermi insegnato ad aprire ogni orizzonte; e per avermi cresciuto allenando la flessibilità dell'immaginazione, dell'intuito, del cuore. Perché crescere ed abbracciare il cambiamento sono la stessa cosa.

Al mio Professore, Paolo Chiari. Perché mi ha fatto cambiare prospettiva. Studia, fai quello che devi fare tutti i giorni. Ma solo perché ti piace. Altrimenti non ne vale la pena. E adesso mi direbbe ancora: "Fossi, vediamo di levarti quel sorriso compiaciuto dalla faccia".

A Paolo, Francesco, Francesco Giuseppe. Mi hanno lanciato all'improvviso verso sfide, cose, persone inaspettate. E mi costringono sempre a buttarmi oltre i miei limiti. D'altra parte è urgente.

A Valentina, perché abbiamo deciso di decollare insieme e, benché su rotte diverse, abbiamo continuato a supportarci via radio più spesso che sempre. Ad Angi, Ile, Leo: abbiamo percorso tre intensi anni di viaggio uniti e compatti: è stato un onore.

A tutte le persone che mi hanno insegnato o mi stanno insegnando a volare, consapevolmente o inconsapevolmente.



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PART 0

INTRODUCTION

In short…

In Part 0 the reader will understand and learn:

- The scientific position of the FAR research
- A general overview of the background of the work
- Objectives of the research
- Results achieved
- Original features of the work
- Recipients of the research
- Methodological considerations about the research

1. SCIENTIFIC POSITIONING

The research refers to the Macro-area 08/C1 – Design and Technological Design of Architecture and classified within the discipline ICAR/12 - Technology of Architecture. In this paragraph the issues expressed by the declaratory of the Ministry of Education, Universities, and Research (MIUR), which the present research responds to, are pointed out and analysed.

1.1. SCIENTIFIC AREA

The MIUR declaration about the scientific and discipline contents of the Macro-area 08/C1 – Design and Technological Design of Architecture, defines the following points, concerning the Technological Design of Architecture. The issues concerning Technology of Architecture, to which this research responds, have been highlighted in bold.

- Disciplinary contents:
    - The **tools**, **methods** and **techniques** **for architecture design** at **each scale**
    - and techniques of transformation, realization, maintenance, restoration/recycling and operation of the natural and built environment
    - With reference to topics related to technological design of architecture products, **considering a performance-based design**
    - **The ideation related to the constructive conception** of architecture products
    - **Technological innovation and experimentation**, considering social, economic and environmental **sustainability**
- Scientific contents:
    - Technological history and culture of design and construction

- Study of building technologies and constructive systems in their historical development
- Study of natural and artificial materials
- Design and experimentation of materials, elements, components, and constructive systems
- Environmental design and sustainable design of buildings, included their energy efficiency
- **Project design process management**
- Maintenance and operation of buildings
- **Innovation of** product and **process**
- Critical evaluation of design alternatives
- Demand dynamics, performance issues and control of architectural and environmental quality
- Representation of problems through engineering models
- Laboratory and in situ experimentations and data analysis

In order to provide the reader with a clear framework and to better introduce the research, each of the points of the declaratory have been related to the topics of this research and the chapters referring to them.

	Contents of MIUR declaratory	Correlation with the research?	Chapter/ paragraph
Discipline contents	The tools, methods and techniques for architecture design at each scale,	The research proposes a methodology -and related tool- for including an evolutive approach to project design management of a complex project (airport terminal)	4, 9, 10
	With reference to	The methodology proposed leads to	4, 5, 9

	topics related to technological design of architecture products, considering a performance-based design of building products	the acquisition of design requirements to be included in the project brief, necessary to achieve the operation flexibility performance of the final building product (complex project, airport terminal), as a final answer to the evolutive approach to design	
	The ideation related to the constructive conception of architecture products	Beside the methodology proposed, oriented to operation flexibility design requirements, the research conveys a new flexibility-oriented mind-set for design conception	4, 5, 7, 9
	Technological innovation and experimentation, considering social, economic and environmental sustainability	The methodology proposed by the research and the resulting design conception mind-set conveyed are aimed at the economic sustainability of the final product, as a consequence to the life cycle approach proposed	5, 6, 7, 10, 11
Scientific contents:	Project design process management	The research proposes a methodology that aims at optimizing project design management by the contracting authority (referring to complex project and airport terminal design, it is the airport company); and a new vision of project design management, in which the methodology is framed. In particular, the methodology seeks requirements and needs to be included in the design brief in order to achieve life cycle perspective in design itself.	4, 9, 10
	Innovation of process	The research introduces and transfers a methodology and a tool that are not currently used in project design management of an airport terminal	4, 9, 10

1.2. SCIENTIFIC SECTOR

The MIUR defines contents of the scientific sector ICAR/12 - Technology of Architecture, in which the research is classified. The contents are defined in the following points; the issues to which this research responds have been pointed out in bold:

- **Theories, tools, methods for an experimental architecture at different scales,** based on the **evolution of its use**, of the constructive and environmental concept, of the transformation and maintenance techniques of built environment
- Technological history and culture of design
- Environmental design of elements and systems
- **Technologies for design**, construction, transformation and maintenance
- **Innovation of process** and organization of building production
- **Demand dynamics, performance issues** and control of quality

In order to give a clear framework to the reader and a better introduction of the research issue, each of the points have been better focused in relation to the topic of this research.

Contents	Correlation with the research?	Chapter/ paragraph
Theories, tools, methods for an experimental architecture at different scales, based on the evolution of its use	The research proposes a methodology -and related tool- for including operation flexibility in design of a complex project (an airport terminal), in order to answer to the evolutionary nature of this specific system (the continuous changing in traffic demand)	4, 9, 10
Innovation of process	The research introduces and transfers a methodology and a tool that are not currently used in project design	4, 9, 10

	management of an airport terminal	
Demand dynamics, performance issues	As previously underlined, the proposed methodology seeks a new class of design requirements to be included in the project brief, necessary to achieve the operation flexibility performance of the final building product (complex project, airport terminal).	4, 5, 9

1.3. THE MAIN SCIENTIFIC PILLARS OF THE RESEARCH: PROJECT DESIGN MANAGEMENT AND SUSTAINABILITY

According to Habermas (1969) the evolution of society, production and administration made the construction sector a complex system. Given this transformation of the whole building industry, it has been necessary to expand research activities to each of the fields involved in this new complex system (Cetica, 1974). Indeed in order to manage and cope with complexity, it is advisable to embrace a “systemic approach”, including the whole system, without omitting any sub-elements. For instance, when considering a building programme, a systemic approach entails that all the issues (social, environmental, functional, economic, procedural, constructive and aesthetic) are examined and related one to each other (Spadolini, 1974).

Therefore, Technology has the task to deal with this complexity, managing more than just technical aspects (as they are only a part of a whole), calling for political, economic and social choices. The effects of every technical choice will undeniably have a consequence on all these universes (political, economic, social) and will in turn be influenced by them (Spadolini, 1974).

> Technology, the study of applied science related to the **transformation of materials into artifacts useful** to men cover institutionally a fairly wide scope of this field of **relations of cause and effect**, because only through this knowledge it is possible to operate the **transformations processes control.**
>
> (Spadolini, 1974)

In this general framework that depicts Technology of Architecture as the subject having to face cause-effect relations for the creation of “artefacts useful to men”, in a wide, comprehensive and complex environment (the construction industry), the two main scientific pillars of this research are:

- Project Design Management
- and Sustainability.

1.3.1 FOCUS ON: PROJECT DESIGN MANAGEMENT

Design Technology is a set of scientific knowledge from different disciplines, that use techniques, processes and tools to cope with construction, with the aim of optimizing procedures, rationalizing decisions and the choice of strategies (Esposito, 2010).

A process is a chain of interdependent facts. In architecture, it is a sequence of actions necessary for the construction of a building (Sinopoli, 1997). It is an organized sequence of operational steps, leading from the definition of demand and needs to their satisfaction (UNI 7867-4).

Process and project design management have been within the leading research paths in Technology of Architecture since the second half of the 20th century. Zaffagnini et alii (1971) were within the earlier authors to address the importance of an active research concerning the Building Process and possible related tools, in their contribution to *Il Boomerang Tecnologico*.

Furthermore, Spadolini and the School of Florence defined and explored the issue of Design Process and Construction one, and proposed the key role of “design tools” as “Invisible Technologies” for the success of the final architectural product. Active research has been operated by Spadolini and its fellows is this way. The effort to transpose industrial mechanics into design (and construction) processes is a clear example.

Concerning design (for construction) process, the Florence School fixed two main areas of research (Spadolini, 1974):

1. **the early attempt toward exploration fields concerns all the pre-design activity that ends with the definition of design requirements;**
2. **the second attempt concerns the design activity dealing with the possible shapes and forms to answers to these requirements**.

For instance the studies of the Florence School concerning the interpretation of the needs, conceived as the basis for the whole design process and that are the history of the performance-based design are referred to the first point. The analysis of needs was indeed the starting line to identify design requirements; then environmental and spatial parameters could be chosen and defined, in order to declare what the research called Environmental Units. The main aim of these studies was to **systemize the design production,** by proposing a “descriptive model” as a tool for the designer, which the designer could then transpose into an “operational model” (Del Nord, 1974).

Therefore, Spadolini dealt with processes and tools, which are the “soft” resources for the control of all the transformation processes from the needs and requirements identification to the completion the final architectural product. As a matter of fact, architecture is generated by the synergy between visible technologies and invisible ones that usually underlay the hard ones (Sinopoli, 1997).

The whole building process and the relations among its actors are the rationalization and systematization of knowledge, know-how and resources devoted to the construction of an architecture system, of any typology. Every activity in the design (as in the construction) process can be considered as a transfer of information from one actor of the process to another, always different in contents since operational levels vary as well (Spadolini, 1974).

Therefore, the correct reception, the proper transformation and the right transfer of information are necessary steps defining the quality of the final product. This makes clear that an effective organization of the whole Building Process, from planning to operation, is necessary.

Project Management, from which stem different methodologies for Design Management, overlooks an approach based on processes. Project Management is a set of techniques guiding planning; organization; control; verification of the processes for the optimization of resources, increase in effectiveness of design and a better flexibility (Cucurnia, 2010). Project design management in public works is controlled and operated by the contracting authority, which in the case of an airport terminal design process is the airport company itself.

Failure in the effectiveness of project design management leads to a design gap, that is difference between design goals and final built results, as indicated in 2005 by European Construction Technology Platform (Esposito, 2009). In the building process, the main critical phases are the ones characterized by a high number of operators and, as underlined by statistics, the poor coordination within the team is one of the major causes of design mistakes (Del Nord, 2008). These threats can be avoided through a proper training of professionals and a research aimed at improving efficiency in time, economic, performance (Del Nord, 2008). Consequently it is necessary to strengthen the effectiveness of the design phase, as it is the information creation **engine of the entire process** (Esposito, 2008). Moreover, the design phase should be informed in the planning phase, using **every tool and methodology** available to create a complete set of **information and inputs** (Esposito, 2010).

Management of processes is one of the issues listed in the documents of the ECTP (European Construction Technology Platform). It defines a picture of medium-long term (until 2030) possible future challenges for the construction industry in 21st century (Del Nord, 2008). As a result and demonstration, processes and their management have been widely explored even by the OsDOTta (OSservatorio dei DOTtorati in Tecnologia dell'Architettura) network in the last years.

Project design management is one of the scientific foundations of this research. Indeed the research proposes a methodology, and the related tools, for including a life cycle perspective in project design management of a complex project, starting from giving right input during the planning phase. The field test is an airport terminal. The choice of the airport design area arises from many interesting features of this field for project design management (Esposito, 2009):

- International regulatory framework combined with a national transposition
- Importance of a life cycle perspective in planning
- Standardization of the design phase in typical steps (Masterplanning, Planning and Brief, Concept, Detailed design, Design for construction)
- Integration of know-how and different professionals within the entire process
- Complexity of design, given the number of requirements to respond to (safety, security, environment, costs, management, operation etc.)

1.3.2 FOCUS ON: ENVIRONMENTAL DESIGN

The European Union treaty of Amsterdam stated as key objective the sustainable development, as in the EU Communication on the Sustainable Consumption and Production and Sustainable Industrial Policy Action Plan (2008).

Sustainable development aims at the continuous improvement of the quality of life and wellbeing for present and future generations. Global changes are increasing and becoming rapid, from the melting of the icecaps to growing energy and resource demand (EU Communication, 2008) that makes this EU objective particularly challenging. Numerous actions have been addressed and planned in the interest of this common goal. In addition to an Ecodesign Directive, the labelling of products and proper incentives, the following main activities are promoted and supported by European Union, in order to better achieve sustainability:

- Need for consistent and reliable data and **methods**, in order to assess the overall environmental performance of products
- Need for strengthening **Green Public Procurement** (GPP), by voluntary measures
- Need for a better coordination with Retailers and Consumers

In this action framework, Europe has required an approach that includes a life-cycle perspective, to be considered when dealing with sustainability. Making reference to products, the challenge is to create a virtuous circle: improving the overall environmental performance of products throughout their life-cycle, promoting and stimulating the demand for better products and production technologies (EU Communication, 2008).

A number of publications, research and studies have been carried out on the subject. For instance, the Buying Green guidelines have defined the steps to be made by contracting authorities in order to achieve a green public procurement. Among these steps, a special place is reserved to the description of detailed and accurate technical specifications that are necessary to address effectively the entire life cycle of the final product. When possible such approach should adopt a cycle costing methodology evaluating costs in the life cycle (EU Buying Green, 2016). In order to facilitate the approach to life cycle costing by contracting authorities the EU has financed many studies. In particular the aim is to create a tool to facilitate the use of the LCC (Life Cycle Costing) approach, and to gain a common methodology to be used in LCC (EU Commission GPP meeting, 2015). The EU Directive 24 of 2014 states that the most economically advantageous tender from the point of view of the contracting authority shall be identified on the basis of the price or cost, using a cost effectiveness approach, such as life cycle costing in accordance with Article 68 (Directive 2014/24/EU Article 67 - Contract Award Criteria).

In the European framework, the common objective of sustainability of products is achieved through a life cycle perspective and approach, that is made possible by developing (and then using) tools such as Life Cycle Costing, whose research has been widely supported by EU in the recent years.

Sustainability has become a key issue in every decision field and the research community should provide elements to determine what is sustainable and how to measure sustainability through a scientific approach. The life cycle approach is a method to integrate sustainability in design, innovation and evaluation of products, services, technologies, systems, sub systems. (Zamagni, 2013)

The importance of the issue of costs for defining sustainability of products is confirmed and underlined by the Brundtland report (WCED, 1987), that gives a picture of sustainability as a combination of economic, environmental and social sustainability. In this framework the economy is the evaluation of the produced capital, generated by the application to the natural heritage of productive activities and able to produce other capital.

The contribution of the scientific sector on these topics is clearly listed in the MIUR definition of ICAR/12. It is based on a system overview and a life-cycle approach applied to sustainability issues, an approach that has been typified for some years now within the project's sciences, those very disciplines dealing with technology (Torricelli, 2015).

Then this research deals with sustainability of products (building products). It aims at introducing a methodology for including a life cycle approach –given the evolutionary nature of a complex project as an airport terminal- in the building process, making reference to the tool of life cycle costing.

Chapter Keypoints

The research is referred to the Macro-area 08/C1 – Design and Technological Design of Architecture within the discipline ICAR/12 - Technology of Architecture. In particular, the research is managed between the two pillars of project design management and sustainability.

2. General

In this chapter the research general framework is defined, in order to introduce the reader to the main issues of this work: boundaries, objectives, recipients, results and limitations, related to the scientific location as explained in the first chapter.

2.1 Background and boundaries

The research makes reference to the European framework, now defined by the so called Common Air Space. Air transportation is recognized as a focal point for Europe to enhance economic growth of the nations, their connectivity and sustainable mobility. Then, the European Commission (EU Communication, 2011) fixed targets for the European common air space to be achieved within 2030 and concerning the issues of **capacity, quality and environment**. According to forecasts, Europe, in relation to a global trend, will have to face a growth in the request for air transportation that will remain in part not satisfied; the unsatisfied demand for air transportation will be of 1.9 million flights within 2035. **To <u>increase the capacity of airports</u>** in a so busy and congested transportation network is **<u>one of the main challenges</u>** defined by the European system (Eurocontrol "Challenges of Growth", 2013).

Within this framework defined by the European Commission concerning the entire air transportation problem, the single terminal infrastructure is also involved. The air traffic converges towards the airport terminal building. And the final users –passengers- flow through it and are processed within it. The airport terminal building indeed responds to an essential requirement: **<u>the need to process and accommodate the passenger traffic</u>**. It is a boarding factory, born to address this need (Bosi, 2016). Therefore, the airport terminal performance is measured towards the traffic demand before any other requirement characterizing every building or complex project. The terminal responds to this **requirement** through the **<u>capacity performance</u>**.

This requirement is very critical: passenger traffic always changes. It changes within the day, within the week, within the year, and it is **continuously evolving** from one year to another. In particular global forecasts show air transportation demand increasing worldwide, given the growth in world population, globalization, decrease in prices, etc. So, the terminal **has to be able to accommodate the traffic whenever and however it occurs**. Then, the terminal **has to evolve accordingly, in response to the demand.** Moreover, the real progression trend of future traffic demand is not certain; it is only possible to issue a forecast while bearing in mind that the future will possibly differ from projections of it.

This is what makes terminal design so challenging: a terminal presents the technical features and characteristics of a building, together with the evolutionary nature of an infrastructure. It follows that the design should collect not only every requirement typical of a complex building, but also the ones proper of an infrastructure.

Given this continuous evolution in capacity requirement, a terminal undergoes more than one service life and a sequence of renewal phases, before coming to the end of its life cycle.

So, how can a terminal building optimize its performance responding to this capacity requirement and given this continuous change in demand (and uncertainty)?

The terminal must be designed to change during time.

Moreover airport terminal is managed by private company. One of the main goals for an airport company is the **economic sustainability** of the building and construction processes. Every new construction, renewal, replacement is first of all an infrastructure investment.

Given the evolutionary nature of an airport terminal as described before, a real economic sustainability of a new construction, renovation or other action on the terminal building has to include the perspective **of the entire life cycle of a terminal**, rather than the initial cost of construction alone. In this way, the life cycle approach proposes the methodology of LCC (Life Cycle Costing; UNI EN ISO 15686) for enhancing economic sustainability. LCC is usually used as a mere economic tool. Recent research developments suggest a smarter approach, as a tool to aid to embed uncertainty (in this case in passenger traffic demand) in design. It could achieve interesting results for development and control of terminal projects, and to project design management in general. **A life cycle approach devoted to economic sustainability could help project design management of an airport terminal and decision making as well**.

In the end, given:

- The dynamics of project design management in airport terminal design,
- The evolutionary nature of an airport terminal
- The need for economic sustainability of construction process

The main research purpose is to answer this question: **how to include life cycle approach as a methodology to optimize both economic sustainability and capacity in airport terminal design?**

The main limitation of this work could be the difficulty in identifying the path and process of airport facilities development, given the scarcity of scientific literature. The research has overcome this gap by using the field experience as source of necessary information and data.

2.2 General and specific objectives

The main objective of the research is to include **a life cycle approach** aiming at flexibility **in project design and process management** of **an airport terminal**. Besides, the research aims at proposing flexibility in airport terminals to face effectively uncertainty in changing of demand (traffic demand).

An airport terminal is a building characterized by the evolutionary nature of an infrastructure. This means that the main requirement this building has to satisfy is traffic demand. And traffic demand is in a continuous change over the years. Consequently, an airport terminal needs to be adaptive and its design needs to consider the continuous change of traffic that the building has to accommodate.

The specific objectives are:

A. To propose **a new process concept**, integrating the Catalogue (Cardin, 2013) approach as a tool located in a specific phase of the process.

B. To gain portability of the Catalogue (Cardin, 2013) to a test airport terminal,

C. Through the **adaptation of the model** for lifecycle performance and economic effectiveness evaluation

D. and the **adaptation of a set** of decision rules and planning variables, to a test terminal.

E. To transpose it into a spreadsheet **tool**,

F. Through a **data collection on field**

G. And through one iteration of the model concerning one scenario.

H. **Scientific dissemination and popular science** of preliminary and finals results of the research.

2.3 RESULTS

In order to answer to the general and specific objectives explained before, the desired results of the research are:

- The proposal of a new process concept for the case of an airport terminal, that includes the Catalogue as a tool for the definition of design requirements
- Application and transposition of Design Catalogue methodology (Cardin, 2013) to a test airport terminal

- Through the adaptation of the model for the evaluation of lifecycle performance and economic effectiveness evaluation
- And the adaptation of the set of rules and variables, core of the methodology itself.
- Collection of data on field and set up of tool through a test on a specific terminal, based on the model developed
- Dissemination of research results through scientific publications and specialized academic seminars

2.4 Original features and scientific value

The research proposes an innovation in project design management of airport terminals, identifying a suitable methodology for including life cycle perspective and flexibility in design, and proposing its transposition to a specific airport terminal through: the proposal of a process concept including the methodology as a tool for the definition of requirements; the adaptation concerning the core of the methodology (the model for the lifecycle performance measurement); and the transposition of the model into a tool. One of its strengths is the possibility of obtaining technical and scientific support from stakeholders from the industry, namely multidisciplinary design teams.

The research originates from an experimental methodology discussed in a 2013 publication. The Catalogue methodology (Cardin, 2013) was applied to a simple infrastructure, namely a parking garage, which makes the transposition to an airport terminal another original feature.

The researchers who set up the methodology pointed out the necessity for more tests on different cases, in order to optimize and improve it overall. The research follows this suggestion for covering a still undiscovered field.

Then, the scientific context is an open research issue, as well. Indeed the “new generation whole-life costing” (Fawcett, 2012), to which the methodology also refers, derives directly from the standard life cycle approach relating it to flexibility requirement as well. Such new approach is still open and object of active scientific debate. By dealing with this issue object of active debate, the research acquires another element of novelty.

Another original feature is the application to a specific terminal through a field test. As previously stated, an airport terminal is a building characterized by the main need of adaptation to continuous change in traffic demand. The said evolutionary nature of airport terminals makes them an interesting application test. The choice of a particular field test, then, has been explained in Chapter 8. As of today, professionals and architects fail to include flexibility in design brief and to make use of a dedicated methodology to identify the right requirements and address decision making to gain flexibility.

2.5 RECIPIENTS

Direct recipients of the research and of its results are:

- Researchers and research organizations operating in the field of:
    - Design and project design management of complex projects;
    - Design and project design management of terminals;

  Since they could develop the results of this work and go beyond them;

- Specialists and architects working in airport companies, influencing decision making and implementing airport terminal development, since they could directly use the results of this work (both the tailored methodology and the tool) for professional purposes .

- Consultants working for airport companies and aiding them addressing decision making and defining the requirements framework and the design brief of their terminal development projects.

The potential funders of the future research developments are:

- Stakeholders from the civil aviation industry

The professionals involved in development of airport terminals and design are the main direct beneficiaries. Researchers are direct beneficiaries too, inheriting the work in order to deepen and further develop it.

The indirect recipients are:

- Civil Aviation Authority
- Customers (e.g.: airlines, other companies operating in the terminal)
- Users (passengers)
- Designers

One of the indirect recipients is the Civil Aviation Authority, which is the "owner" of the infrastructure and controls the management of the airport company, which is its concessionaire. Furthermore, two other indirect recipients are customers and users that make direct use of the asset and benefit from its effective design and performance. Lastly, indirect recipients are also the parties involved in the process, first of all designers.

Chapter Keypoints

The general and specific objectives of the work are:

- To include a life cycle approach in project design and process management of an airport terminal.
- To propose flexibility in airport terminals to face effectively uncertainty in changing of demand (traffic demand).
- To propose a new process concept, integrating the Catalogue (Cardin, 2013) approach as a tool located in a specific phase of the process.
- To gain portability of the Catalogue (Cardin, 2013) to a test airport terminal, through the adaptation of the model for lifecycle performance and economic effectiveness evaluation and the adaptation of a set of decision rules and planning variables, to a test terminal.
- To transpose it into a spreadsheet tool, through a data collection on field and through one iteration of the model concerning one scenario.

The results achieved in the research are:

- The proposal of a new process concept for the case of an airport terminal, that includes the Catalogue as a tool for the definition of design requirements
- Application and transposition of Design Catalogue methodology (Cardin, 2013) to a test airport terminal through the adaptation of the model for the evaluation of lifecycle performance and economic effectiveness evaluation and the adaptation of the set of rules and variables, core of the methodology itself.
- Collection of data on field and set up of tool through a test on a specific terminal, based on the model developed

The direct recipients are:

- Researchers and research organizations
- Specialists and architects working in airport companies
- Consultants working for airport companies

3. METHOD

This chapter provides a description of the research design used which includes: research method; data collection and methods for analysis.

3.1 THE RESEARCH DESIGN

A research method can be defined as a set of processes, principles and procedures that a researcher uses to approach the problem and to find possible solutions. It can be seen as a link between two parts: the problem examined, the aim and the theoretical understanding; the data collection and the analysis (Sterner, 2002).

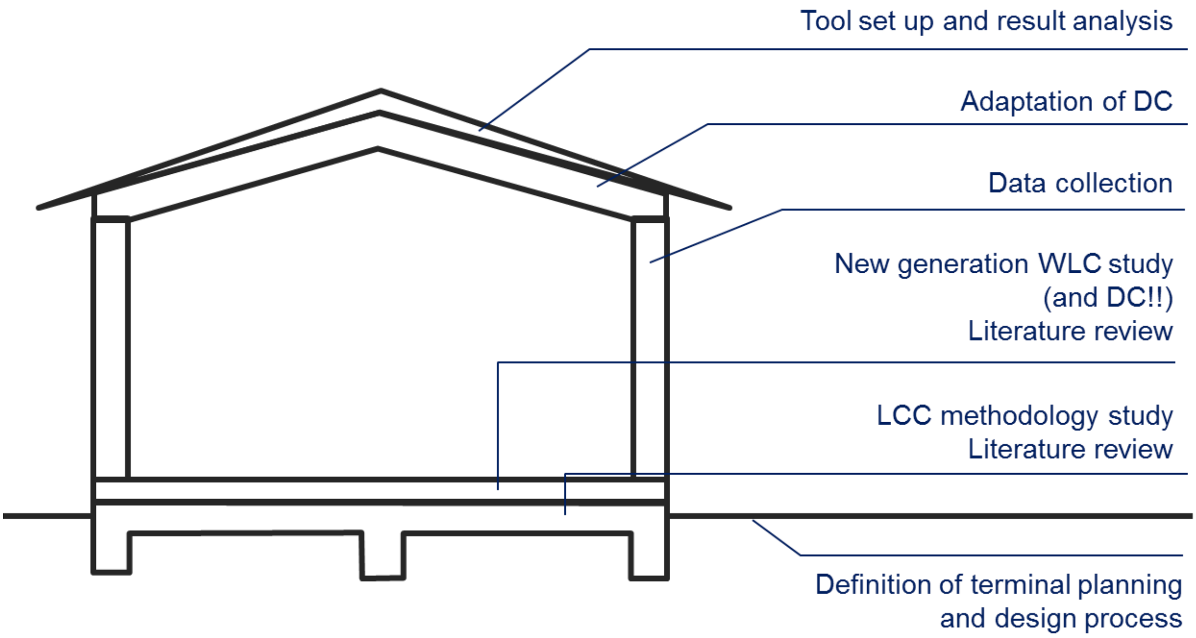
The picture below exemplifies possible steps of research designs in relation to different research problems (Andersson and Borgbrant, 1998; Sterner, 2002). The steps adopted in this specific research have been marked.

	THE RESEARCH PROCESS				
TYPE OF RESEARCH	THE RESEARCH QUESTION	METHOD	METHOD FOR DATA COLLECTION	ANALYSIS AND INTERPRETATION	RESULTS AND PRESENTATION
CHANGE OF PRACTICE	What should be changed and how	**Case studies within organizations and working environments**	**Dialog Open and closed questions**	**Feedback Deeper data collection**	**Knowledge about changes in processes Working material Seminars**
EVALUATION	Mapping what characterises the object studied	Investigations Examining of different objects	Questionnaire Interview	Description of parts and entirety Causes and effects	Knowledge about the studied phenomenon Internal and public report
DEVELOP THEORY OR MODEL	**Knowledge theory Development of new theories and models**	**Studies of published materials**	**Empirical studies and original sources**	**Combination of known and new knowledge**	**Documentation of developed theories, concepts and models in articles, papers**
VERIFICATION	What characterise a specific function	Laboratory studies Experiments	Measurements Simulations	Hypothesis trying Model building	Facts about the object studied Scientific publications

PICTURE 1 DESIGN OF A RESEARCH PROCESS – TXP GRAPHIC PROCESSING FROM STERNER, 2002

3.1.1 Research design for this project

According to the chart in Picture 1, the research performed in this thesis is a combination between development of theory or model and change of practice. To support the description of the methods and analysis models used herein, the research design is illustrated in the following picture.



PICTURE 2 DESIGN OF THIS SPECIFIC RESEARCH PROCESS – PHD CANDIDATE ORIGINAL ELABORATION

The research proposes an innovation in project design management of airport terminals, identifying a suitable methodology for including life cycle perspective and flexibility in design, and proposing its transposition to a specific airport terminal through: the proposal of a process concept including the methodology as a tool for the definition of requirements; the adaptation concerning the core of the methodology (the model for the lifecycle performance measurement); and the transposition of the model into a tool. Contextual boundaries are the sector legislation and regulations, the airport terminal planning process and the design one.

The main steps of this research have been faced as follows:

Definition of terminal planning and design process

- The basis for the research work is the understanding of the processes of planning and of design. This has been achieved through a desk research, by understanding the main steps reviewing regulations, circulars and guidelines of the aviation authority; and at last through field experience, by documenting how the two processes operate when implemented by an Italian airport company.
- Then, the life cycle of an airport terminal and the causes determining its evolution have been defined through a literature review.

LCC and new generation WLC study

- Concurrently, the work focuses on the application of the life cycle approach for an economic sustainability of the airport terminal development; the life cycle costing methodology is explored through monographies, regulations and attendance of thematic seminars. Literature concerning the new generation WLC (Whole Life Costing) and its recent developments was reviewed, including the experimental proposal of Design Catalogue methodology.

Adaptation of Design Catalogue methodology

- The model for the evaluation of the performance, core of the Design Catalogue methodology, has been adapted to the case of an airport terminal. This has been further explained in the second part of this thesis, in particular in Chapter 10. The adaptation has been done on a new airport terminal to be realized in Italy within 2050.
- The test case has been selected because it is the only case of a new airport terminal in Italy, making reference to our regulatory framework; whereas the other Italian upcoming works are mainly expansion or renovation of current terminal facilities, therefore not suitable for a general application of the methodology. For this reason this research acquires characteristics of a field research too, facing and testing a specific terminal case. Chapter 8 introduces the test case. The issue of portability to other cases is explained in Part 3.
- Given this, the tailoring was done making reference to the annual reports of the airport company that the field test makes reference to.

- Besides, the set of rules and variables making the Catalogue working was tailored too.

Data collection

- Together with adaptation and tailoring, data collection has been driven. The collection was managed using 3 strategies: extraction of data from databases concerning the field test; abstraction of data from existing documents of the airport company; interviews of professionals directly involved in the test case and working for its economic sustainability. Chapter 11 introduces data collection.

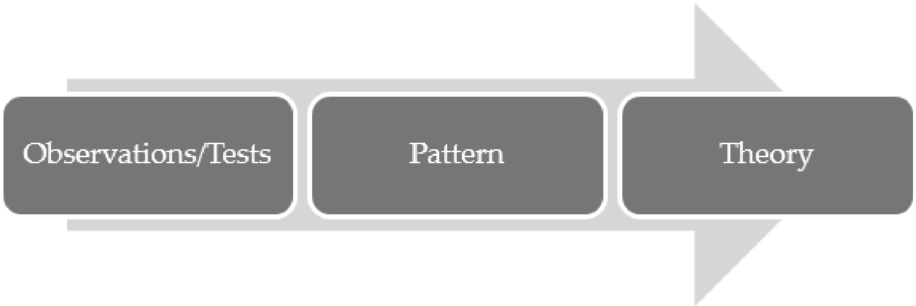
Tool set up through one iteration of the methodology

- Once the model and the set of rules and variables were adapted, a tool aiding the application was tuned in spreadsheet.
- While being produced the tool was tested through the inputs given by a data collection on field and one traffic scenario, for functionality purpose.

3.2 METHODOLOGICAL CONSIDERATIONS

The research is developed with an inductive approach. Indeed the application of the Design Catalogue methodology, framed in a life cycle perspective, is identified as an interesting possibility of tailoring and application to the airport terminal facility. Then, the development of a model tailored on the airport terminal is possible through the observation of reality, made with desk research, interviews, access to documents and data. In the end, the research leads to the formulation of a proposal.

Inductive research is concerned with observations of the world, to develop generalisations and ideas. When applied to quantitative research it concerns exploratory data analysis.



PICTURE 3 INDUCTIVE APPROACH SCHEME – SOURCE: RESEARCH METHODOLOGIES 2011

This work acquires the characteristics of a field research, since the test of the methodology is carried out on a specific terminal facility case. Its adjustment and the data collection are oriented to the test case.

Field research or fieldwork is the collection of information outside a laboratory, library or workplace setting, through informal interviews, direct observation, participation in the life of the group, collective discussions, analyses of documents produced within the group, etc. The method is generally characterized as qualitative research and quantitative research.
A disadvantage could reside in the distance of this specific adaptation from a general application to airport terminals. This issue is developed in Chapter 8 and Part 3.

Research validity can be internal and external. Internal validity deals with how the research findings match reality, while external validity deals with the extent to which the research findings can be replicated to other cases (Pelissier, 2008). The validity of the result is dependent on what is measured. Collected data and adjustments of methodology make reference to a test case pertaining to the busiest infrastructure in Italy, and within the top 10 busiest in Europe. As explained in Chapter 8, the income and cost items identified in the tailoring of the methodology are the common items for Civil Aviation terminals, not depending on their size. For this reason, the structure of the model tailored to the test case can be transferred to other European hubs –similar to the test case in size- and to smaller Italian realities. In any case portability should be tested though access and use of statistics (e.g.: Airport Council International) as explained in Part 3.

Research reliability is the degree to which the research method produces stable and consistent results. The reliability of the result is determined by how the study is performed and how the information is collected. This information making the framework for the reliability of the data used is illustrated in Chapter 8 and Chapter 11.

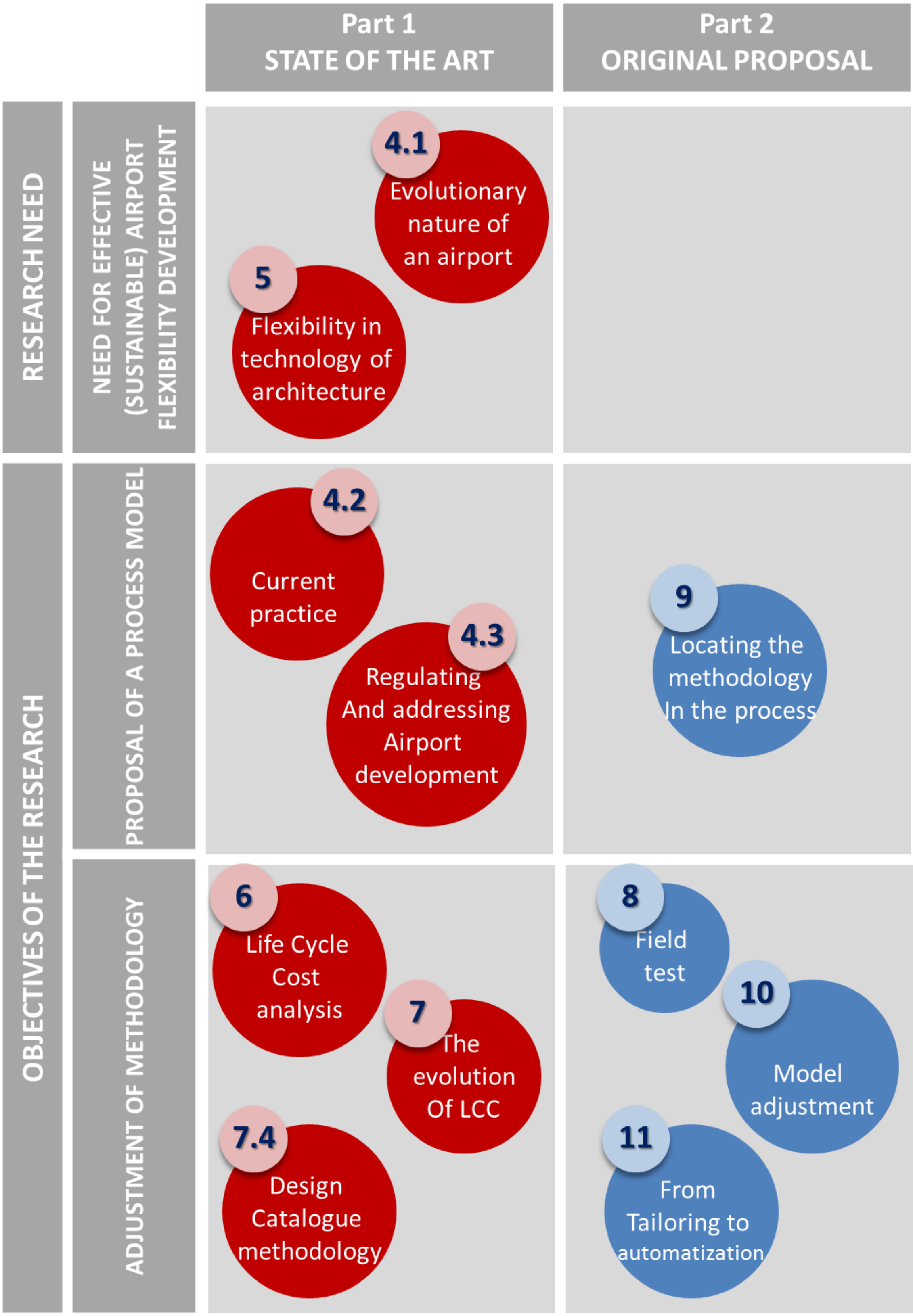
PART 1

STATE OF THE ART: CURRENT PRACTICE AND RELATED RESEARCH

In short…

In Part 1 the reader will understand and learn:

- The foundation of evolutive nature of an airport terminal
- How professionals and airport companies deal with this nature
- Flexibility definitions in technology of architecture
- Evolution of flexibility in technology of architecture
- Life cycle approach and life cycle cost methodology
- New generation of Whole life costing, until the Design Catalogue proposal


Part 1
STATE OF THE ART
Part 2
ORIGINAL PROPOSAL
RESEARCH NEED
NEED FOR EFFECTIVE (SUSTAINABLE) AIRPORT FLEXIBILITY DEVELOPMENT
4.1
Evolutionary nature of an airport
5
Flexibility in technology of architecture
OBJECTIVES OF THE RESEARCH
PROPOSAL OF A PROCESS MODEL
4.2
Current practice
4.3
Regulating And addressing Airport development
9
Locating the methodology In the process
ADJUSTMENT OF METHODOLOGY
6
Life Cycle Cost analysis
7
The evolution Of LCC
7.4
Design Catalogue methodology
8
Field test
10
Model adjustment
11
From Tailoring to automatization

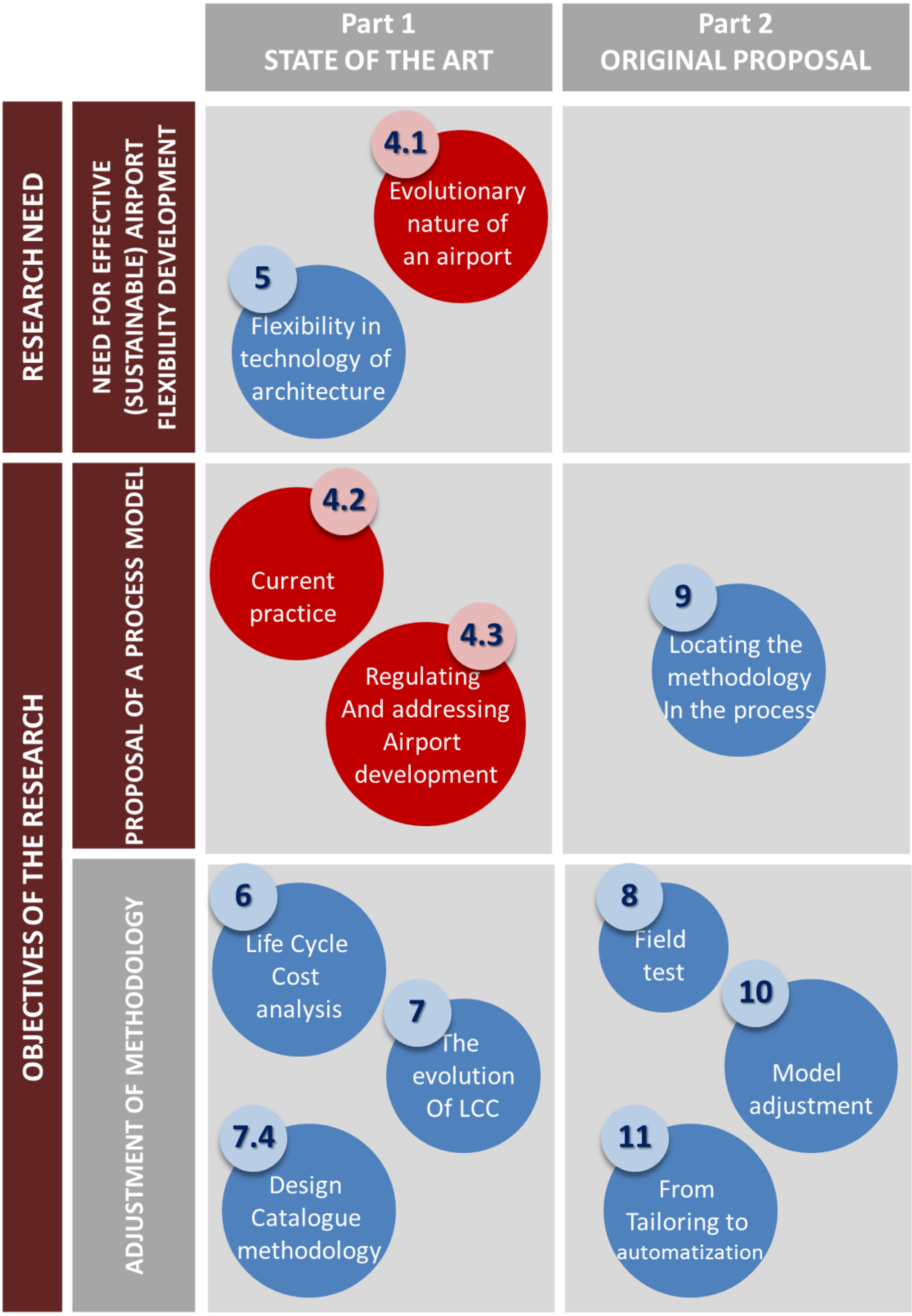
4. Development process of an airport infrastructure

Chapter objectives

In Chapter 4 the reader will understand and learn:
- The main issues of the evolutionary nature of an airport
- How professionals deal with the evolutionary nature of an airport
- The regulated path to plan the airport development in which terminal planning and then terminal design is located

Chapter Keypoints

Due to many causes an airport terminal is characterized by an evolutionary nature being a transport infrastructure. Therefore, the life cycle of a terminal presents many service cycles. These show progressive loss in performance until the end of its whole life cycle. The main reason affecting the evolution of an airport terminal is the necessity of capacity adjustment. Indeed the terminal responds mainly to a fundamental requirement: the need for air transportation that is to say passenger traffic. The need for processing passengers when and in the quantity that occurs as time goes by. Planning must answer to this very first requirement as design must.
In Italy the regulatory framework consists in a very articulated planning process of the whole airport infrastructure that each terminal design activity is referred to. Airports are indeed managed by airport companies and owned by the State, and this relationship is regulated by the ERA (Economic Regulatory Agreement).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4.1 EVOLUTIONARY NATURE OF AN AIRPORT

Airports are always evolving. The causes of this constant evolution are many and they make it necessary for airport companies to adjust the infrastructure subsystems to every new verified condition.

Therefore, design of airport systems is characterized by several uncertainty issues. First of all traffic demand, which presents a high degree of variability, and it is always addressed and recognised by Airport Companies financial departments as the major risk factor (Esposito, 2010). Indeed traffic demand is the issue that generates the requirement for the realization of an airport terminal facility in which to be processed.

PICTURE 4 TERMINAL EXTENSION WORKS IN FIUMICINO AIRPORT

4.1.1 REASONS AFFECTING THE EVOLUTION OF AN AIRPORT TERMINAL

An airport terminal has an interesting life cycle. It does not suffice to consider solely its structural stability or the condition of its finishes. It must meet many more requirements during its life cycle, the first of which is naturally traffic demand, as this is the prime reason for the existence of the terminal, along with accommodating and processing a certain number of passengers.

Nonetheless, many other secondary causes determine the evolution of its service cycles, as described in this paragraph.

The case of the air-transportation American market is now summarized. This market has a different history from the European one, since the two do not share the same regulatory framework. In the US, many terminal facilities are approaching the end of their design-life or are becoming obsolete (ACRP Report 068). Given the trend of the American air transportation market, today there are cases of expansion of terminal facilities and adjustment of their capacity that are not responding the real current traffic demand. Indeed, after the Deregulation Act a period of expansion and growth for all American airports took place. But after this first interval of growth and apparent increase in traffic, airlines came into financial difficulties: competition, growth of fuel prices, expansion and economic crisis have been the main causes. As a result, American companies have reduced the required overall traffic capacity. Consequently, in some cases, spaces dedicated to operation of these airlines have been reduced, so that many areas are now over-dimensioned despite the current traffic.

This example clearly illustrates how reasons affecting the life cycle evolution of an airport terminal are numerous. And they are not directly, or better not entirely, connected to the technical and architectural performance of the building. Indeed it often occurs that the components of a terminal facility reach the end of their life before the limit of their structural reliability is reached, or before the end of the design-life of the whole facility (ACRP 068).

In particular, according to Ricondo & Associates (2012), factors contributing to the development planning of an airport terminal are:

TABLE 1 CONTRIBUTING FACTORS TO AIRPORT TERMINAL DEVELOPMENT PLANNING

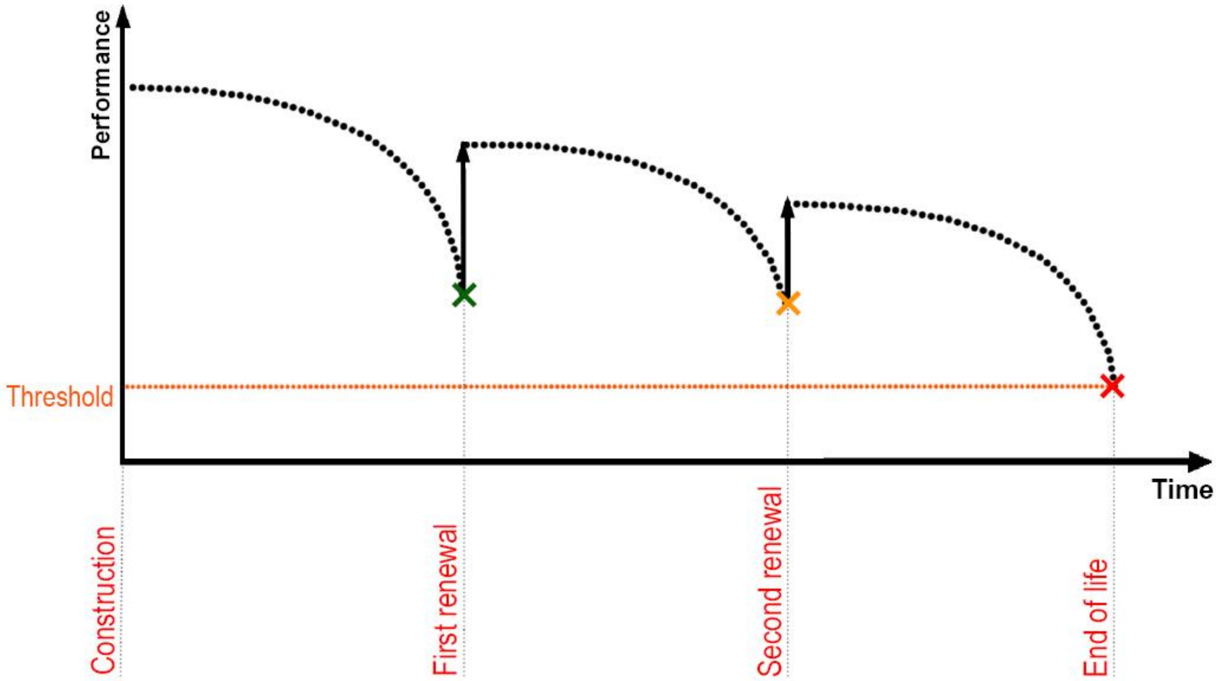
	Category	**Contributing Factors**
Business conditions	Governance	Ownership and management Airline agreements
	Current and historical market conditions	Aviation activity Airlines hub or focus city International service
	Aviation activities forecasts	Demand stability/assumptions (passenger characteristics O&D share; fleet mix)
	Strategic Plan	Mission statement

		Vision statement Airport's strengths, weaknesses, opportunities and threats Definition of strategic issues Long and short term goals, strategies, action plan Performance indicators
	Financial capacity	Quantifying current funding commitments and future funding availability
	Increase in revenues and diversification	Other airport competition Off-airport competition Aeronautical vs. non-aeronautical revenue Maximizing use of airport assets
Facility conditions	Mission	Capability Passenger level of service Capacity
	Inventory of building, system and equipment conditions	Asset age and condition Life safety and security compliance Building performance/utilization
	Capital Improvement Programme development	Activity timing Land availability Design alternatives Costs Benefits

4.1.2 AIRPORT TERMINAL LIFE CYCLE

Given this framework affecting the evolution of the airport terminal development, the service life of this system starts at the construction works completion. At this point, operative conditions, level of service towards passengers and reliability of the whole structure are at their maximum level (ACRP Report 068). Over time, this optimum performance decreases. Maintenance activities are then implemented in order to bring the terminal back to its original conditions. But original technical conditions cannot be wholly restored, leading to a gradual loss in value of the whole building.

As time goes by and with asset use, it becomes necessary to make a renovation of the terminal in order to extend its service cycle. A new service life begins at this point, as shown by the picture below.



PICTURE 5 TERMINAL BUILDING LIFE CYCLE TIME/PERFORMANCE CHART – TXP GRAPHIC PROCESSING FROM ACRP 2012

Hence, a sequence of refurbishment activities and renovation works on the asset lead to a layout reconfiguration, a functional redevelopment and changes in interior design. The satisfaction of users (passengers) decreases, together with the level of service and overall user experience. For this reason, after a sequence of renovations, the option to substitute the asset could be an economic seductive alternative. Indeed, new technologies could be more interesting and more environmentally and economically sustainable, and the overall resulting costs could be more convenient.
The following issues could also occur during this process, determining the need for airport terminal re-development (ACRP Report 068):

TABLE 2 MOTIVATION FOR TERMINAL REDEVELOPMENT – SOURCE ACRP REPORT 68, 2012

Trigger category	Typical triggers
Building age and physical conditions	Life cycle of building and systems past service life midpoint Regulatory changes Building code changes - Code requirements triggered by new construction - Building code changes (e.g., life safety, seismic)
Air Service Changes	New or increased international flights Recent declines or increases in airport activity Changes in activity type (e.g., greater percentage of business or tourist activity) Significant change in connecting vs. O&D passengers
Functional Obsolescence	Changes in passenger and aircraft service equipment and procedures - Passenger and baggage check-in - Passenger aircraft boarding and de-boarding processes - Increased demand for common use facilities - Regional aircraft passenger loading bridge requirements - Landside and airside concession locations - Restroom sizing and locations - Airline lounge requirements and locations - Aircraft size and seating capacity changes - Vertical circulation requirements Changes in passenger and baggage security processing and equipment New concepts in concession services Airport and airline employee security control requirements Facility energy efficiency, 'green' and other LEED initiatives
Optimizing Use of Multiple Terminal Buildings	Declining or increasing activity levels by airlines leading to poor facility utilization Changes in activity by larger airlines resulting in relocations of smaller airlines Imbalance in terminal roadway and curbside demand Imbalance and congestion on taxiways resulting from aircraft gate capacity constraints
Related Airport Development and Airport Master Plan	Non-terminal airport development that affects the operation or site conditions of the terminals Changes to airfield that constrain or expand terminal area site conditions Changes to landside entrance and exit roadways or new

	automated people mover systems Facility development adjacent to the terminal
Passenger Activity Forecasts and Civic Aspirations	Changes in passenger levels of service caused by changes in activity levels - Master Plan forecasts - Local and regional socioeconomic growth projections Civic aspirations caused by changes (usually decreases) in passenger levels of service Civic aspirations related to terminal image and passenger services offered
Availability of Funding	Availability of additional funds Changes in activity levels affecting ability to carry or sell debt
Airline Agreements	Terminal development initiated by airlines Terminal development constrained by conditions and controls in Airline-Airport Use and Lease Agreements

Any update in the regulatory framework must also be considered in addition (e.g.: seismic regulations, fire regulations, etc.). Moreover, growth in air transport service of the airlines operated by a specific airport determines either an excess or a lack of sufficient dedicated space in the terminal building. Increase in number of boarding passengers stresses the terminal asset, if it pushes the limits of its capacity. Another factor needs to be taken into account is functional obsolescence, due to the changes of the conditions and needs, whereas the terminal has an original functional, interior, envelope design which is not enough adaptive. Furthermore, several occurrences might take place: changes in operations of airlines; evolution in technologies for passenger processing; regulatory changes in safety and security; new services and devices to meet new needs of the users. Ricondo & Associates (2012) lists the areas that are more sensitive in terms of changes in operation, technologies and needs:

- Check-in hall: continuous improvement in IT (Information Technologies) produces new self-processing equipment and a progressive decrease of spatial standards;
- Concessions areas (retail, food&beverage) needed before and after security;
- Enhanced security control (body scanner; biometric data processing, etc.);
- BHS (Baggage Handling System) longer, faster and fully automated;
- Boarding areas equipped with floating gates.

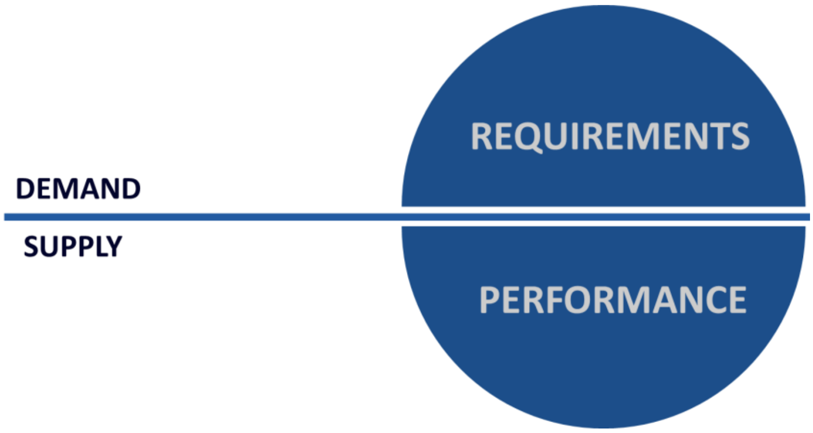
This entails that almost every Environmental Unit of the terminal is potentially changing, along with new needs and different modifications.
This complexity increases if a terminal system operates through a multi-terminal scheme. Airline allocation can certainly change requiring not only one building but the whole terminal system to be adjusted.

4.2 Current practice in facing the evolutionary nature of an airport

The continuous evolution, first of all due to changes in traffic demand and other causes examined in the above paragraphs, makes the airport (not only the airport terminal) design a very complex issue.

Moreover, "airport" is a single word identifying one system; but the system is actually composed by several infrastructures: runways, taxiways and aprons, airport terminals, curbside and access roads. Each one of them evolves in a different way and presents its own unique needs, requirements and the ensuing performance, as the hamburger model effectively summarizes.

This research focuses on the design of an airport terminal; thus every other infrastructure belonging to the airport system will not be further analysed.



PICTURE 6 HAMBURGER MODEL – TXP GRAPHIC PROCESSING FROM ESPOSITO, M.A. (2010).

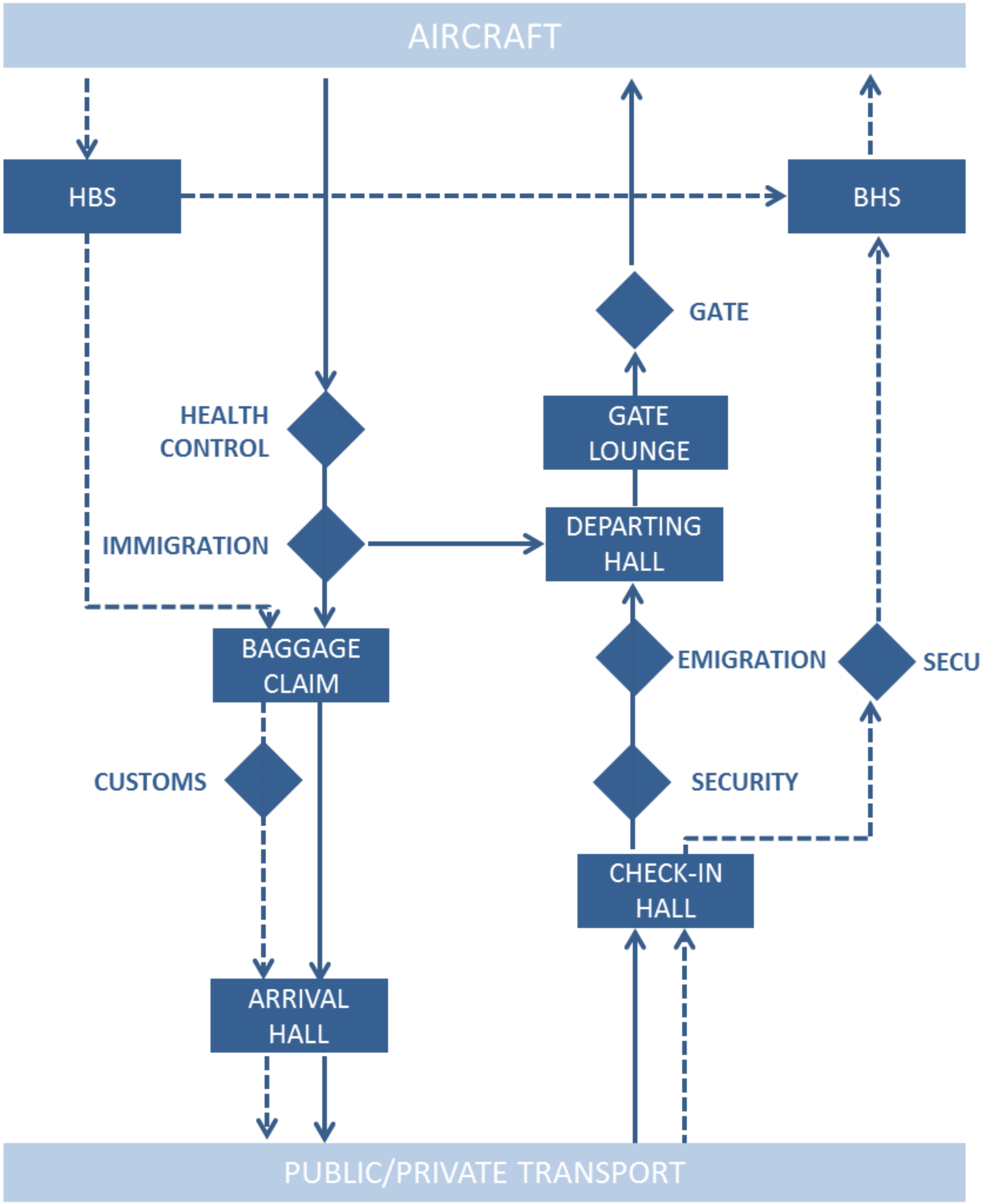
4.2.1 HOW TO DESIGN TERMINAL CAPACITY

As described before, an infrastructure is designed and conceived to supply up to a certain traffic demand: its first requirement is to accommodate and process a certain traffic demand. This rule is always true and applicable for the overall airport system. An airport terminal is indeed a factory dedicated to produce boarding and de-boarding of passengers within adequate standard Level of Services (LoS) (Bosi, 2016).

In compliance with the international standards set by IATA (International Air Transport Association) all airport terminal subsystems are properly dimensioned by technicians basically by UAT (Unit of Airport Terminal) (Esposito, 2010) -to be intended as the architectural Environmental Units- in order to achieve due capacity. The capacity must respond to traffic demand forecast within the masterplan for the upcoming years and it is the very first input to terminal design. Therefore, each UAT and the whole terminal itself are designed to guarantee the expected capacity level for the planned period, according to future demand trends. Generally UAT (Unit of Airport Terminal) is going to be over-dimensioned, while as time goes by and traffic increases this capacity is being saturated until a further development action by technicians and planners.

Depending on the terminal considered UAT, dimensioning models refer to aircrafts movements (movs) or departing passengers (pax) forecasts in order to find out the required space for each function. The main terminal UAT (e.g.: check-in hall, security controls areas and more in general any landside Unit) are dimensioned in relation to passengers' movements. Aircrafts movements are used mainly to dimension airside areas (e.g.: boarding gates).

The next picture illustrates the main functions of each UAT of a terminal.



PICTURE 7 THE SUBSYSTEMS OF AN AIRPORT TERMINAL – TXP ORIGINAL GRAPHIC ELABORATION

Passenger traffic is kept under control both by the airport company and airlines as well. It is an essential input for managing the terminal during its life cycle and an essential input for new design activities, as explained before.

Control of passenger flows is managed through high technology devices that track said flows from their entrance in the terminal to their departure. Passengers tracking is a constantly evolving subject, given the advanced industrial research in airport IT. Normally, data from the various flows tracking check-points become part of the historical data base of the airport and airlines companies. The databases of historical traffic flows are the basis for producing periodical traffic forecasts.

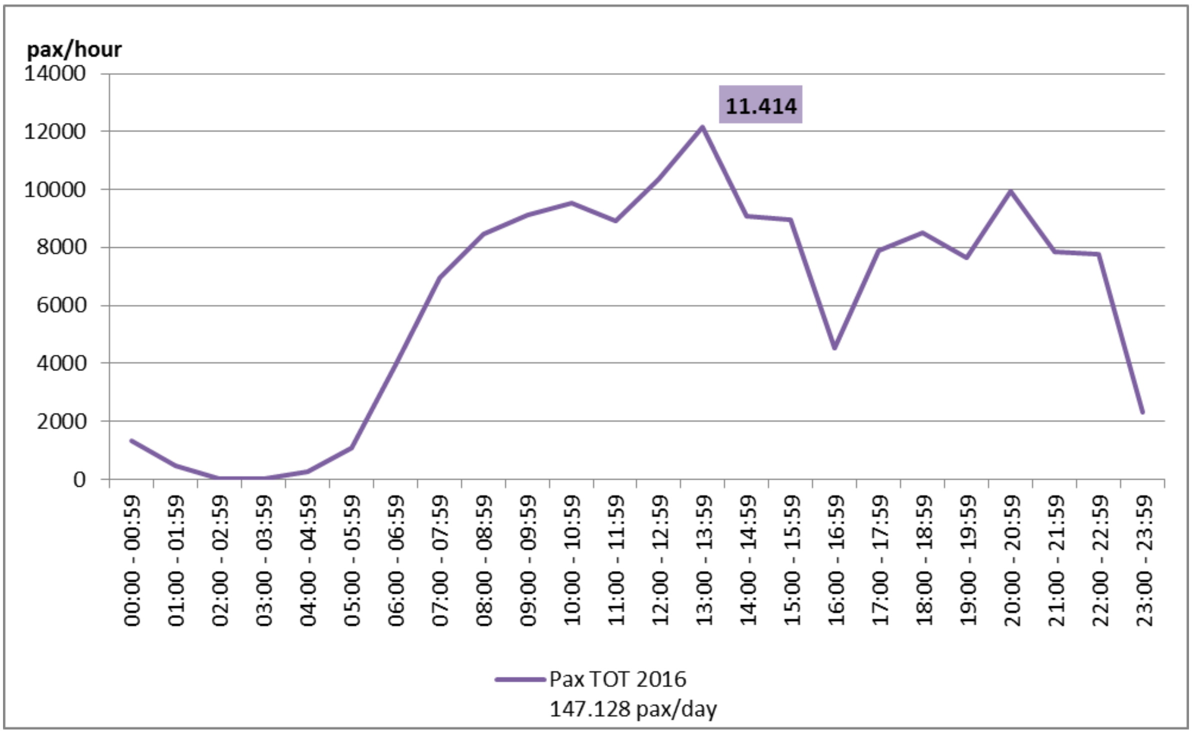
Historical data and traffic forecasts make it possible to plan future terminal development, with design brief including every requirement about terminal spaces dimensioning and design as final output. The capacity performance definition within the planning period is achieved through the dimensioning of the terminal system and its UAT. This is achieved through the use of proper international aviation standards and the quantities of passenger traffic to host during time-lapse.

The most relevant data for airport terminal system and its UAT dimensioning are:

- The busy day: the second busiest day of the average week in the peak month (IATA, 2010)
- The Typical Peak Hour: the busiest hour of the busy day (IATA, 2010)

Typically the busy day in Europe is located in the aeronautical Summer season, often in August. Note that the Typical Peak Hour is not the peak hour over a year, otherwise the terminal and its UAT would be designed to be excessively over-dimensioned towards an average flow.

Picture 7 shows the traffic during the busy day and the peak hour of the busy day, which is the TPHP.

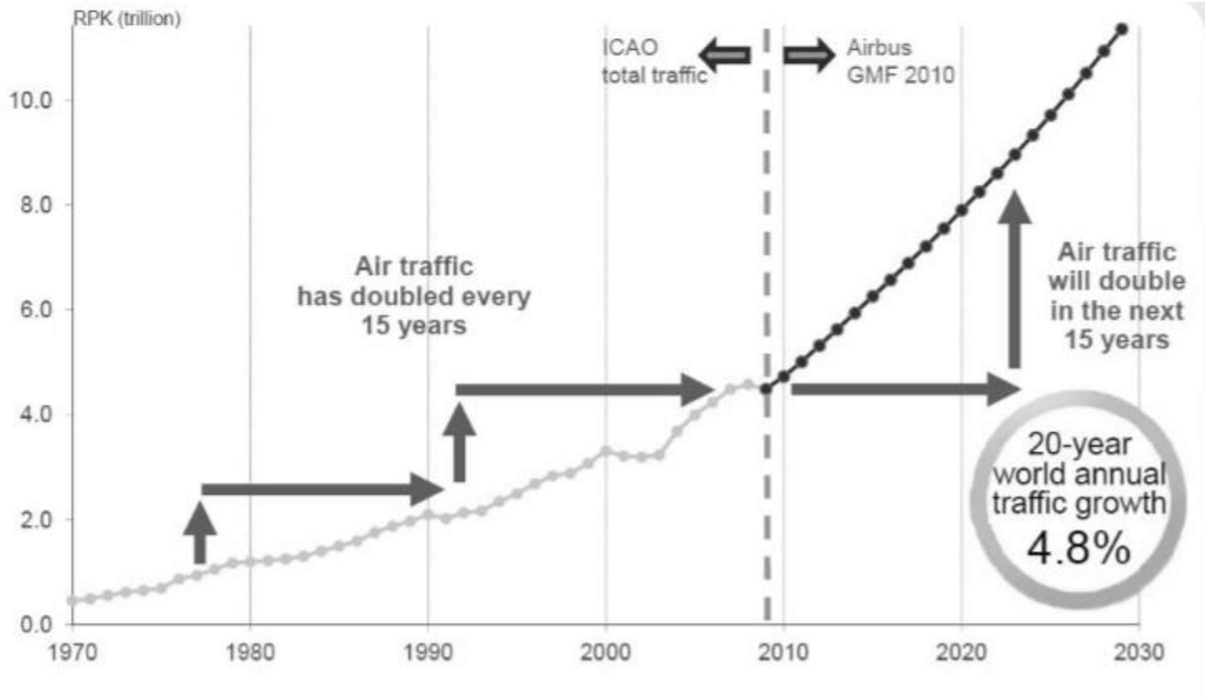


PICTURE 8 IDENTIFICATION OF THE PEAK HOUR OVER A BUSY DAY - PHD CANDIDATE PROCESSING FROM FIUMICINO AIRPORT 2015 BUSY DAY DATA

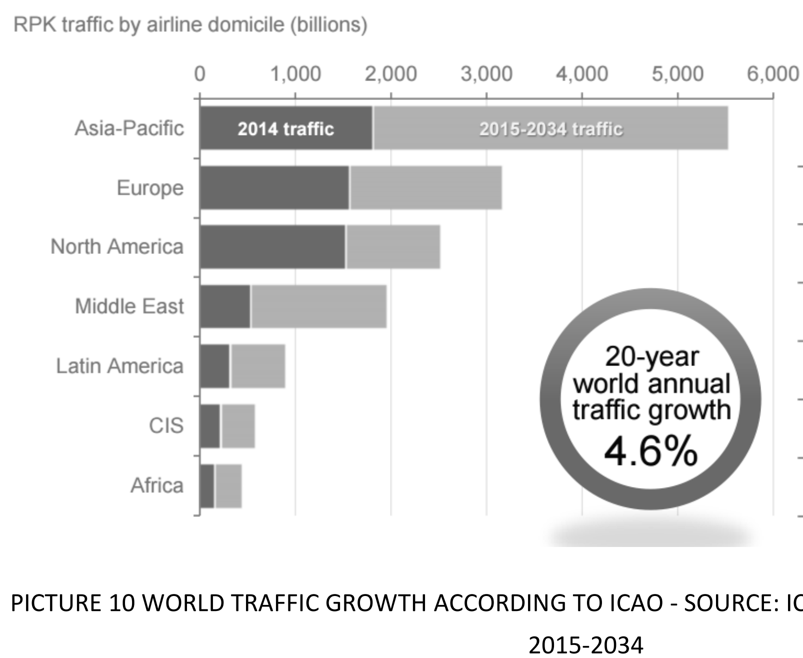
4.2.2 TRAFFIC FORECASTS

It is now clear that the **most important input to airport terminal design is the <u>capacity</u>**. As other requirements expressed in the design brief, the capacity need arises from previous traffic data analysis activity. Indeed planning (pre-design) and design of future terminal renovation/ construction activities rely on forecasts of future passenger traffic, produced by the airport company analysis.

Traffic always evolves; and the global trends show a **general increase in demand in the next future** due to the growth in population and in the number of people that can afford and want to globally travel by air, as in the following pictures from ICAO (International Civil Aviation Organization).



PICTURE 9 WORLD TRAFFIC GROWTH ACCORDING TO INTERNATIONAL CIVIL AVIATION ORGANIZATION - SOURCE: ICAO GLOBAL MARKET FORECASTS 2010-2030

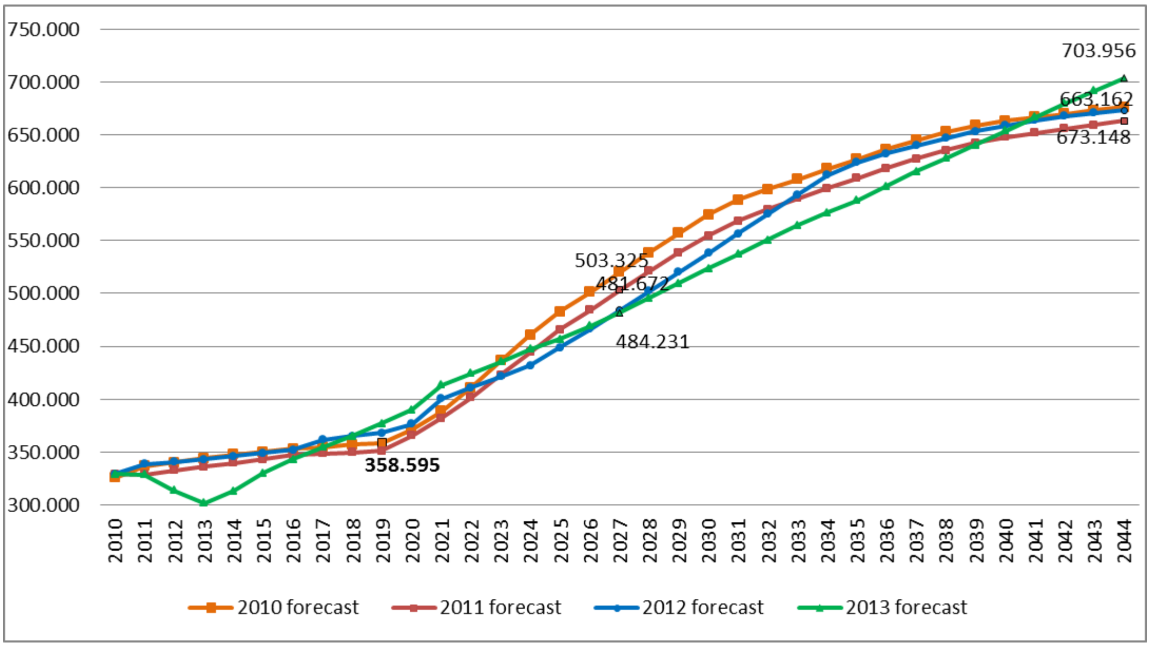


	% of 2014 world RPK	20-year growth	% of 2034 world RPK
Asia-Pacific	29%	5.7%	36%
Europe	25%	3.6%	21%
North America	25%	2.5%	17%
Middle East	9%	6.7%	13%
Latin America	5%	5.2%	6%
CIS	4%	4.9%	4%
Africa	3%	5.3%	3%

Source: Airbus GMF2015

PICTURE 10 WORLD TRAFFIC GROWTH ACCORDING TO ICAO - SOURCE: ICAO GLOBAL MARKET FORECASTS 2015-2034

Yet, **design inputs are currently based on forecasts**. The most significant and interesting factor is that, by observing **different forecasts referring to the same airport and produced in a sequence with intervals of a few months**, it is possible to **detect quite relevant differences, as shown in picture 11.** The forecasts differ from one another, even if produced within the framework of the same airport company and by the same company technical structure.



PICTURE 11 EXAMPLE OF DIFFERENT FORECASTS FOR FIUMICINO EXPECTED PASSENGER TRAFFIC IN SEQUENCE

Therefore, on one hand forecasts of passenger traffic demand are the cornerstone for the definition of the main design requirement to be introduced in a design brief: the terminal capacity. But on the other hand, it is clear that forecasts are not certain: these could be denied by the immediately following forecasts or by the final traffic numbers achieved in reality.

Then, the question is easy: **how could planning and design recognize and deal with this uncertainty in forecast data?**

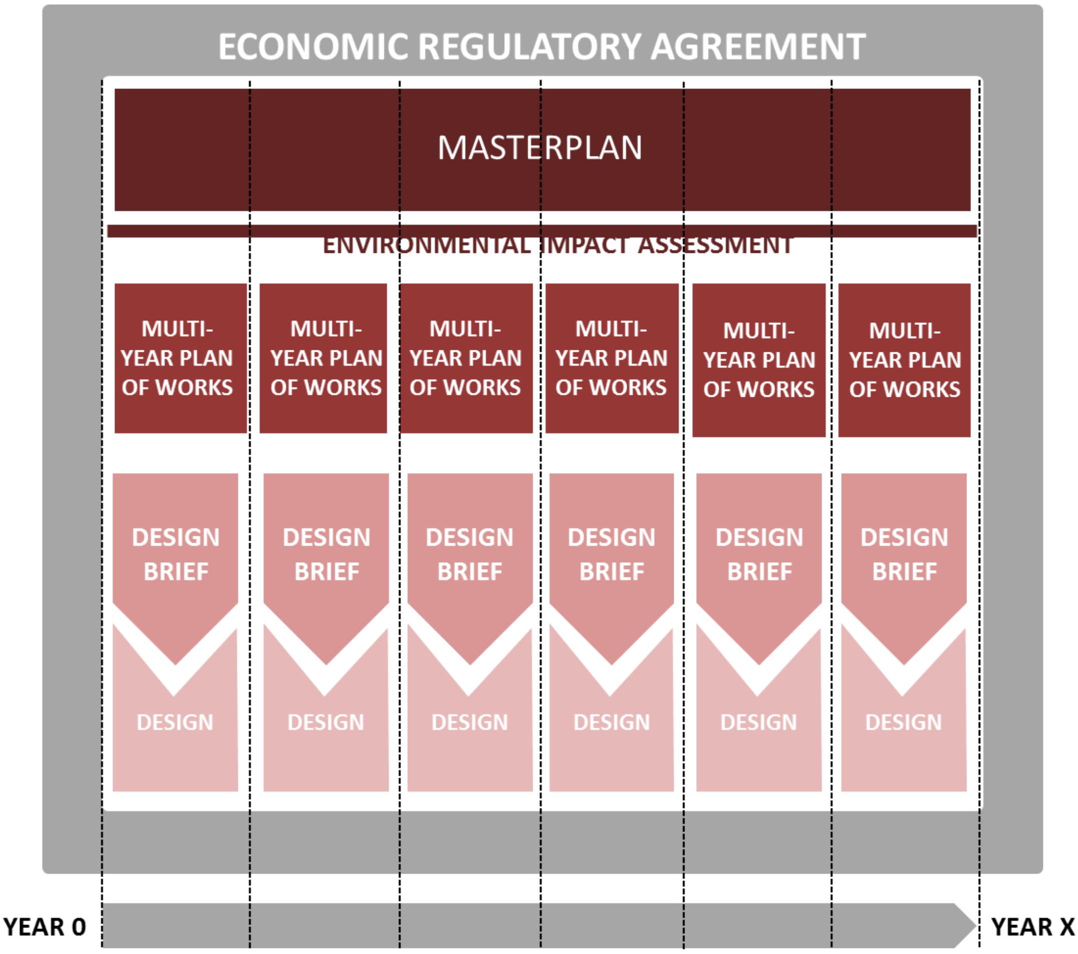
The text has been addressing the general modus operandi in Europe and worldwide concerning airport terminal planning. From now on, the paragraphs are going to focus on Italy and its regulatory framework.

4.3 REGULATING AND ADDRESSING TERMINAL DEVELOPMENT IN ITALY

According to the ERA (Economic Regulation Agreement) airport development is promoted by airport company. The Agreement regulates the relationship between the public Civil Aviation Authority (the owner) and the private company (the concessionaire). The process generating airport development (ENAC, 2015) comprehends these steps:

a) Planning and programming (strategic phase);
b) Design (ideation phase);
c) Construction (execution phase);
d) Operation (maintenance, use and control);
e) Decommissioning (reuse and recycling).

In bold the steps object of this research, further analysed later. The design phase (b) is strictly connected to the important phase of planning and programming (a). Indeed design outputs derive from planning and programming inputs, declared into the design brief documentation. Moreover, planning (a) and design (b) processes are both characterized by a continuous information exchange between the airport company and the public authority. Specific milestones within the planning process (a) are set up, in order to allow the airport company to share the main decisions concerning infrastructure development with the public authority. Check and control activities are carried out by the Civil Aviation Authority during the entire process, in addition to checks at the end of the planning phase and of each design phase.



PICTURE 12 AIRPORT DEVELOPMENT PROCESS WITHIN THE ERA – TXP ORIGINAL GRAPHIC ELABORATION

4.3.1 Planning and programming phase

The planning and programming phase is the framework of the whole airport development. It is the base of every activity of improvement and masterplanning of the airport infrastructure, the terminal building included. This phase regulates the commitments of the airport company, in terms of infrastructure works for airport adjustment and development during the entire Agreement period.

Two types of contract between the Civil Aviation Authority and the airport company are possible (ENAC, 2015):

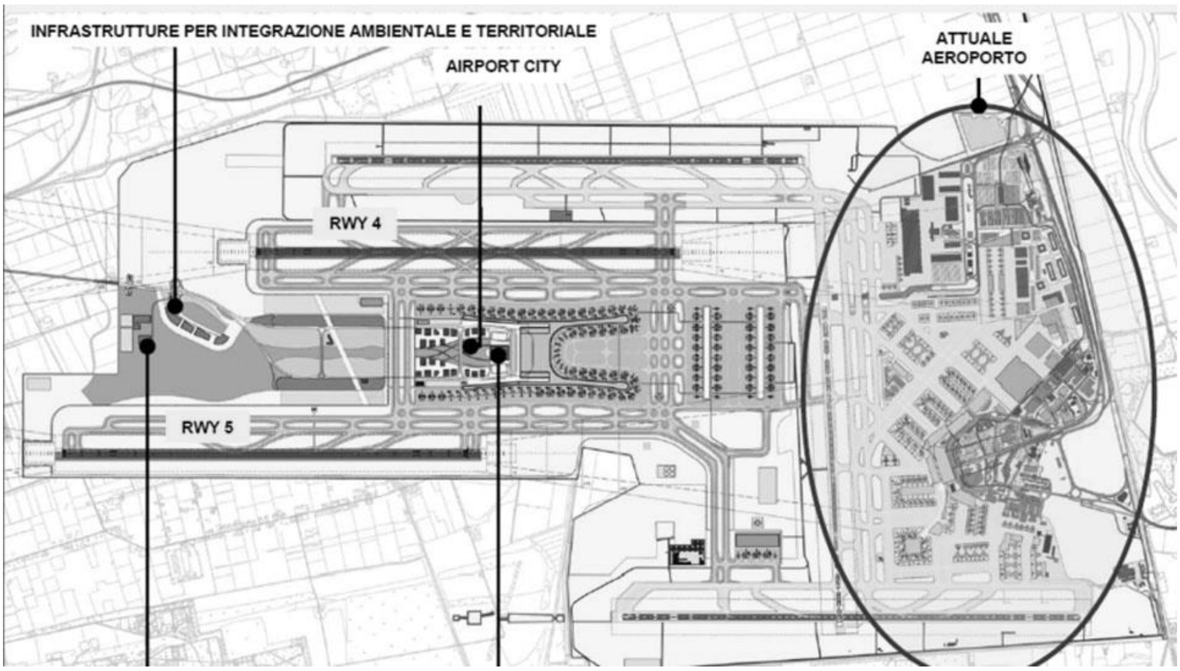
- Notwithstanding (dedicated only to companies managing Rome, Venice and Milan airports), with a period of effectiveness of 10 years and completely managed by the public authority in contract and tariff issues;
- Ordinary (all the other concessionaires), with a period of effectiveness of 4 years

The ERA (Economic Regulation Agreement) specifies aims and targets for the contract period, in relation to national and international overview. It disciplines the tariff framework, the investments plan fulfilment, concessionaire quality and environment goals compliance.
Focusing on the implications of the contract on infrastructure development, this document regulates the obligation of the concessionaire to realize all the works related to goals compliance, in terms of **quality, level of service to passengers** and **environment safeguard**.

DEVELOPMENT PLAN

The development plan is the following reference document describing the whole infrastructure development and regulating the following steps of planning and design processes.
The masterplan is the general reference document, since it describes and plans project development phases in the long term. The masterplan (ENAC, 2015) focuses on the development phases to be completed within 10/15 years following the completion of the plan. Referring to the Italian urban regulatory framework and terms, an airport masterplan takes the place of a *Piano Regolatore* (L. 351/1995) or any further urban planning regulation adopted. The actions that it describes and outlines indeed are motivated by public utility and by the **need for air transportation**, so that each expansion of the airport boundaries described in the masterplan is allowed even on private areas.

The masterplan is the document that describes the main issues concerning the development of airports; every activity promoted within the masterplan is motivated by traffic forecasts of passengers and movements, beside the company development target about the whole airport. The main concern of masterplan is to **respond to the need for an adequate Level of Service (LoS) to passengers** through the formulation of development steps therein listed and proposed as response to the public need for air transportation. Masterplan also aims for the critical target of satisfying safety and security issues. Lastly, it also correlates the airport to the transportation networks and access roads and to environmental restrictions as well.



PICTURE 13 THE MODEL OF FIUMICINO AIRPORT MASTERPLAN - SOURCE: ADR-ENAC ERA

FOUR-YEAR PLAN OF WORKS

The planning documentation is a framework that describes and guides the economic investments towards the development activities (and the related works) devoted to answering the need for an adequate level of service to passengers including the four-year plan of works.

The four-year works plan consists in the investment plan that the airport company elaborates during the Agreement period. The plan is drawn up in compliance with a programme shared between the public Authority and the airport company itself. The document describes the design, work and go-live milestones leading to the completion of each investment action proposed in the Masterplan.

ENVIRONMENTAL SAFEGUARD PLAN

This document regulates the environmental goals of the airport company with respect to the public Authority. The objective of the documentation is to verify and mitigate the environmental impact of the airport accordingly with regulation. If considered as target the aim could also be to improve the environment quality of the surroundings with specific actions during the concession contract period.

FINANCIAL ECONOMIC PLAN

Through the Financial Economic Plan the airport must demonstrate its capability of achieving the goals that have been fixed in accordance with the public Authority. This document explores and justifies the economic sustainability of the development actions list provided in the four-year plan.

ENVIRONMENTAL IMPACT ASSESSMENT

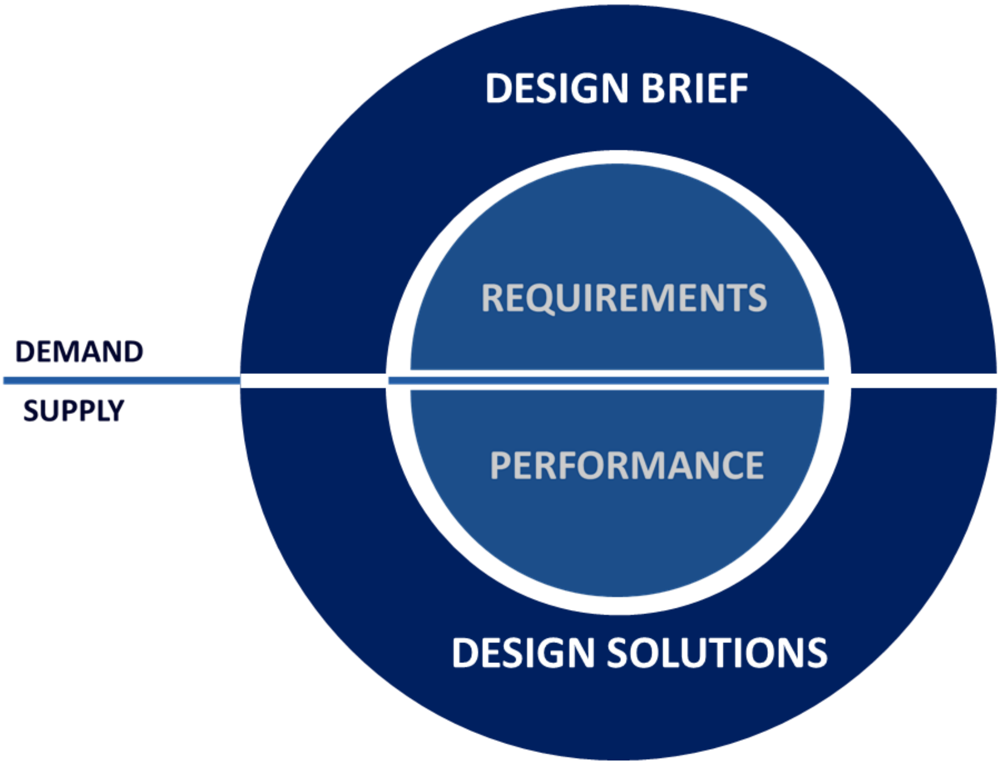
The EIA (Environmental Impact Assessment) procedure is the last main step -addressing the planning phase- required by the Italian regulatory framework.
The core of an EIA is the Environmental Impact Study, which provides all the necessary technical information about environmental impacts of the planned development activities and works. The Study is the foundation for the assessment of the whole environmental compatibility. Provided the full completion of such administrative procedure the analytic environmental impacts report are assessed and the related works are approved and allowed to start.

4.3.2 FROM PLANNING TO DESIGN: FIXING REQUIREMENTS DESIGN HAS TO MEET

The steps described in the previous paragraph define and regulate every necessary further step (from design to operation) for the adjustment of the airport and of its systems in order to respond to the requirement of traffic demand. Thus, each action that will be carried out - through design first and construction later - is properly described and financially validated. Every action is incorporated in a programme established upon a timing shared with the public Authority. Moreover, these were all related to planning and development goals of the whole infrastructure. Therefore, from a general framework, described by the masterplan and related documents originate single specific interventions. Each one must meet specifications according to requirements that caused their occurrence. Hence, more accurate planning activity must be finalized by the airport company in order to make the design phase effectively start.

The airport company has **the very hard task** to **translate the general goals** within the four-year plan, the masterplan and the overall issues related to the single activities **into clear technical specifications addressed to the designer**.
The requirement list must be clearly identified and conveyed to the designer through the kick-off document as design brief (*DPP - Documento Preliminare alla Progettazione*). This is the direct design start if the designer is internally entrusted with the process. Otherwise, in case the designer is going to be selected externally through a public competition the requirements must be detailed in the technical specifications.

These documents (design brief and technical specifications) are **the final outputs of the planning phase** and, at the same time, **the very first step of the design phase**. **The needs and requirements contained in these documents are the key information and design inputs for granting a design process addressed to the achievement of a good performance of the final architecture product**. Every qualitative and quantitative requirement and specification has to be clearly studied, examined and explained before the conclusion of the planning phase and the start of the design phase. Additionally, it should be stressed in the brief, in order to describe the desired final product as accurately as possible and in order to address the designer immediately.



PICTURE 14 HAMBURGER MODEL REPRESENTING PLANNING VS DESIGN PHASES – TXP GRAPHIC PROCESSING FROM ESPOSITO, 2010; SZIGETI ET AL., 2005

During the final step of the planning phase, according to the level of the specific development action (e.g.: building a new terminal is very different from refurbishing an existing one, even if they are both actions described in the masterplan) and making reference to the case of an airport terminal the airport company could identify qualitative issues such as: specific requirements concerning the functional layout; specific needs in terms of finishes in order to optimize the quality perceived by passengers; specific requirements about furniture and equipment for a good performance of the terminal UAT. Moreover, the airport company may underline all the quantitative requirements, such as: dimensioning needs for each of the UAT of the terminal involved in the specific development action, according to international standards and to international best practices; timing for works; expected amount for each work category.

The more thoroughly the intervention is described, the more correct, responsive, addressed and controlled by the airport company will the design, and the more will the final product meet the client’s (the airport company, as concessionaire, and the Civil Aviation Authority, as the owner) and the user’s (the passenger) needs.

4.3.3 DESIGN PROCESS

The designer, referring to the specifications by the design brief, carries on the three design steps required:

- Feasibility study,
- Detailed design,
- Design for construction.

Each design step must be approved by the airport company: it operates as concessionaire appointed by the Civil Aviation Authority. Its task is to promote and supervise the development of the infrastructure for the satisfaction of users also in order to respond to the necessity to meet the public air transportation need. After the approval by company the design output must be approved by the Civil Aviation Authority too. This means that from the starting point of each of the three design phases to the final approval a continuous information exchange and decisions sharing takes place between the owner of the final product (the Authority) and its concessionaire (the airport company). This synergy verifies during the design phase as much as during the planning and programming phase; through this informal interaction every further design requirement is defined for proper inclusion in the project design.

So, while the designer is in charge of drawing up all the design documentation for each of the three design steps (feasibility study; detailed design; design for construction), the concessionaire has the role of:

- Managing the whole design process as contracting authority
- Assessing the coherence with aeronautical norms
- Approving and validating each design step outputs.

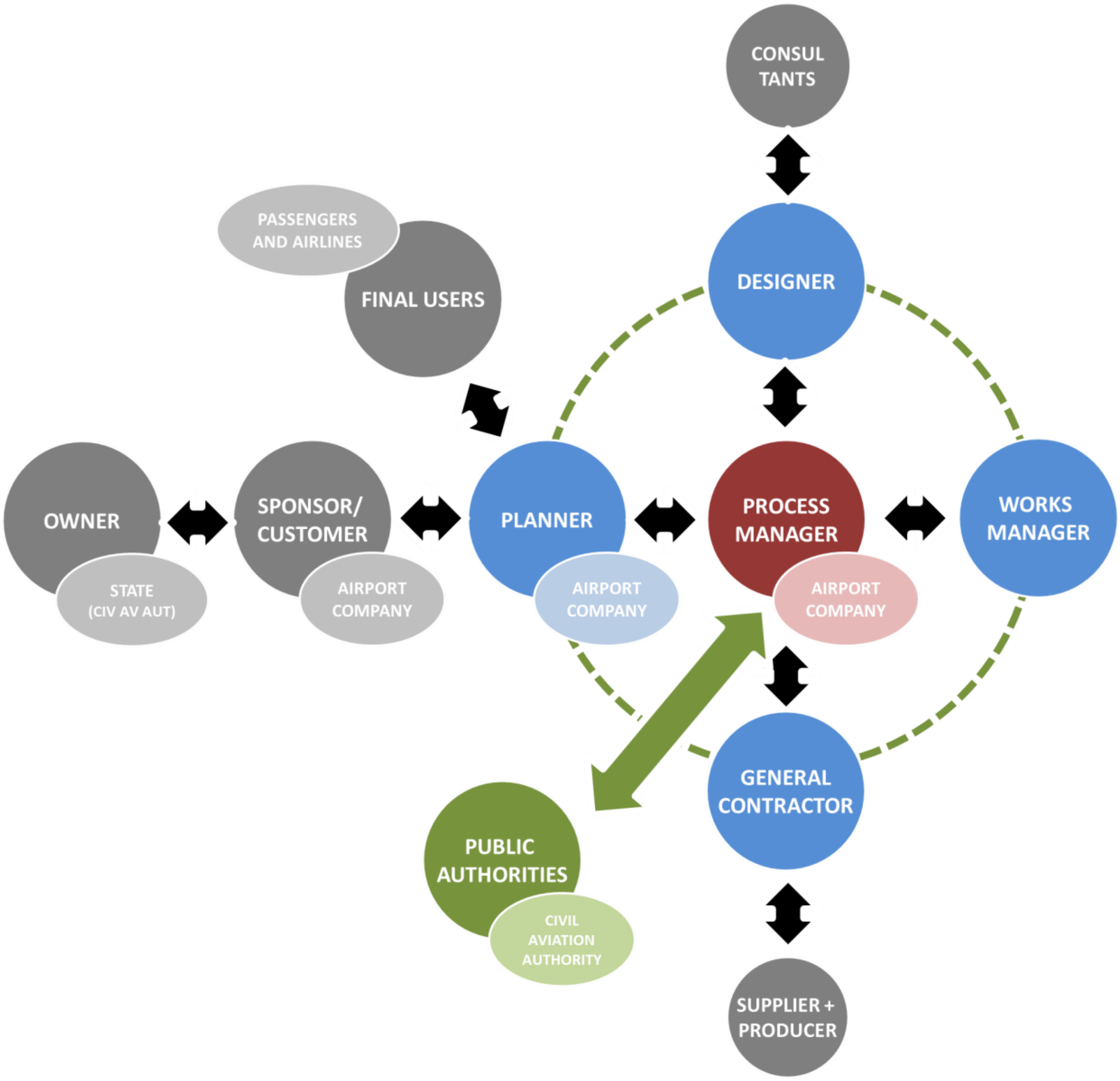
At the end of each design phase, the public Authority approves the documentation or asks for technical in-depth studies.

4.3.4 PLANNING AND DESIGN PROCESS ACTORS

The development process is complex and structured. The airport is constituted by several system sets, given the many infrastructure issues involved. Moreover, the regulatory framework is also quite complex and it defines the process for managing the infrastructure and its development. In view of all this, the actors that interact in the process that was described before are summarized below:

- The concessionaire company has the role of the **customer or promoter**, since it is the one who promotes the interventions for development, as regulated by the ERA (Economic Regulation Agreement). The airport company supports the needs of the owner (Public Authority). The public need for air transportation must be met and granted first the financial needs of the concessionaire notwithstanding.
- On the other hand, the Aviation Authority has the main role of **approving authority**. It has to approve all the activities, programmes and plans, and in the end the design documentation too. It gives any authorization to move forward in the development process. In case approval is not given, the Authority requires technical in-depth studies or modifications to the proposed plan or project design (depending on the phase).
- Moreover, every authorization concerning special issues requires the proper Ministry *nulla osta*. For instance, no development activity can be carried out without a positive conclusion of the Environmental Impact Assessment procedure.
- The airport company is the **process manager**, responsive of and coordinating the whole processes of planning, of design - but also construction and operation.
- Third parties such as engineering and architecture societies are contractor **designers**
- The final **users**, whose demands and needs the planning and the design activities are tailored to satisfy, are the passengers. Actually, it should be noted that from the standpoint of the airport company the final users are the airlines; they are the ones that, by choosing one airport or another, bring their own customers, which are passengers, with them. But for simplification,

passengers are the final user to be considered in the process, from a performance-based design standpoint



PICTURE 15 PLANNING AND DESIGN PROCESS ACTORS – TXP ORIGINAL GRAPHIC PROCESSING

5. Flexibility in technology of architecture

Chapter objectives

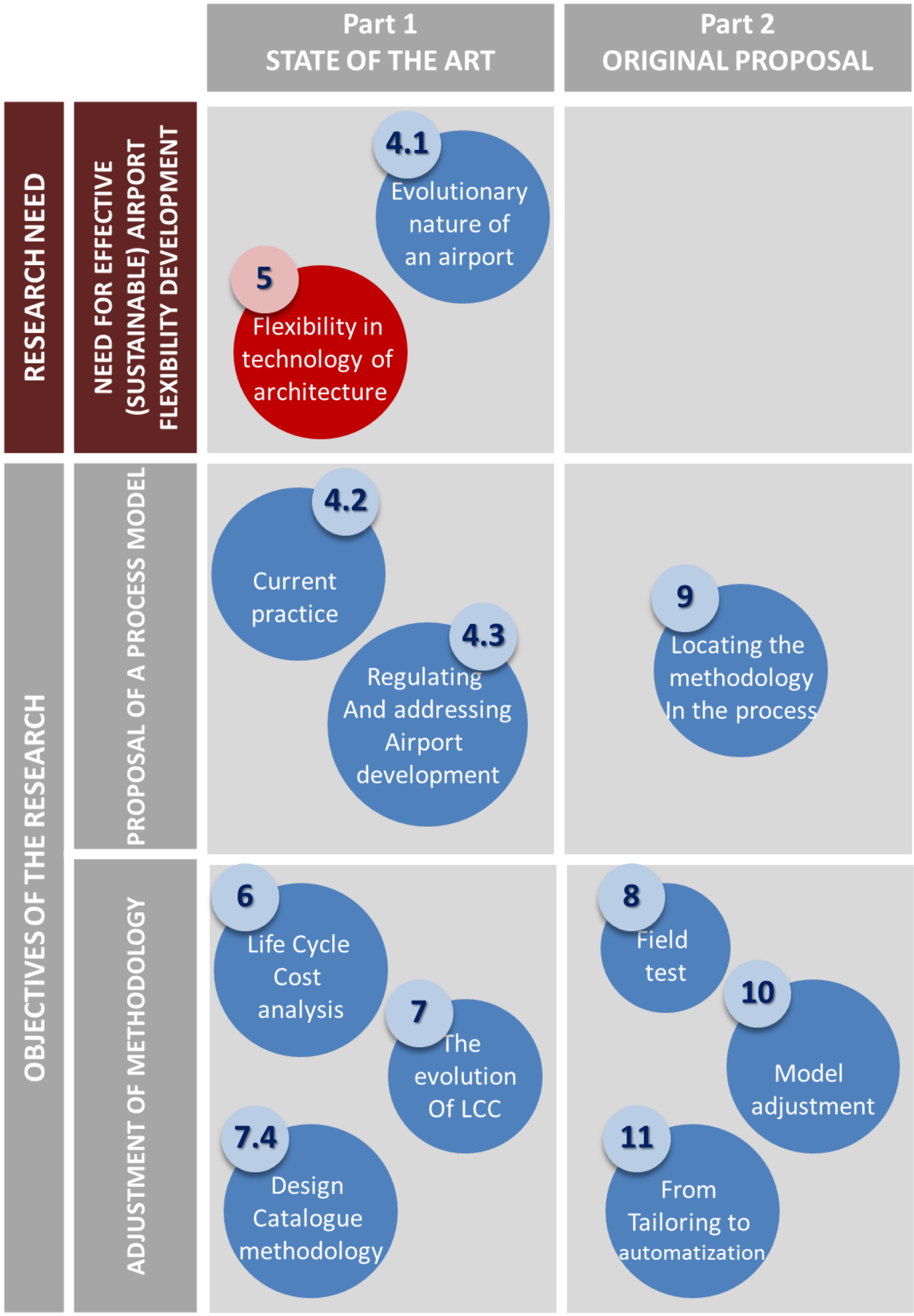
In Chapter 5 the reader will understand and learn:
- The main definitions for flexibility
- The possibilities of translation of flexibilities in industrial production to flexibilities in architecture
- The academic and design research experiences of the 2nd half of the 20th century, defining product and process flexibility in architecture
- The contribution of the Italian research to the evolution of the issue of flexibility in architecture
- The basis of the need for a more defined, focused and effective approach to flexibility
- The concept of operation flexibility

Chapter Keypoints

Flexibility is a concept associated to the industrial production. In architecture definitions of flexibility are mainly related to:

- Product
- Process
- Operation of a building

Research concerning flexibility was born in the 20th century and continued worldwide until today. Italian contribution to research has been dominant in the second half of 20th century, when Spadolini and its School developed academic and design research concerning industrialization in architecture. Efforts then were spent into process management and industrialization of design process. In this framework product flexibility was explored together with process flexibility. Recent research addresses flexibility as a more complex issue, that has to go further and first of all understand that there is no possibility to know which changes architecture should face being "flexible". As soon as certainty of uncertainty is recognised, architecture should make an effort in order to also achieve operation flexibility in order to better respond to the desirable and advantageous, but still not determined, requirement of product flexibility.


Part 1
STATE OF THE ART
Part 2
ORIGINAL PROPOSAL
RESEARCH NEED
NEED FOR EFFECTIVE (SUSTAINABLE) AIRPORT FLEXIBILITY DEVELOPMENT
4.1
Evolutionary nature of an airport
5
Flexibility in technology of architecture
OBJECTIVES OF THE RESEARCH
PROPOSAL OF A PROCESS MODEL
4.2
Current practice
4.3
Regulating And addressing Airport development
9
Locating the methodology In the process
ADJUSTMENT OF METHODOLOGY
6
Life Cycle Cost analysis
7
The evolution Of LCC
7.4
Design Catalogue methodology
8
Field test
10
Model adjustment
11
From Tailoring to automatization

5.1 INTRODUCTION TO FLEXIBILITY: DEFINITIONS FROM THE INDUSTRIAL FIELD

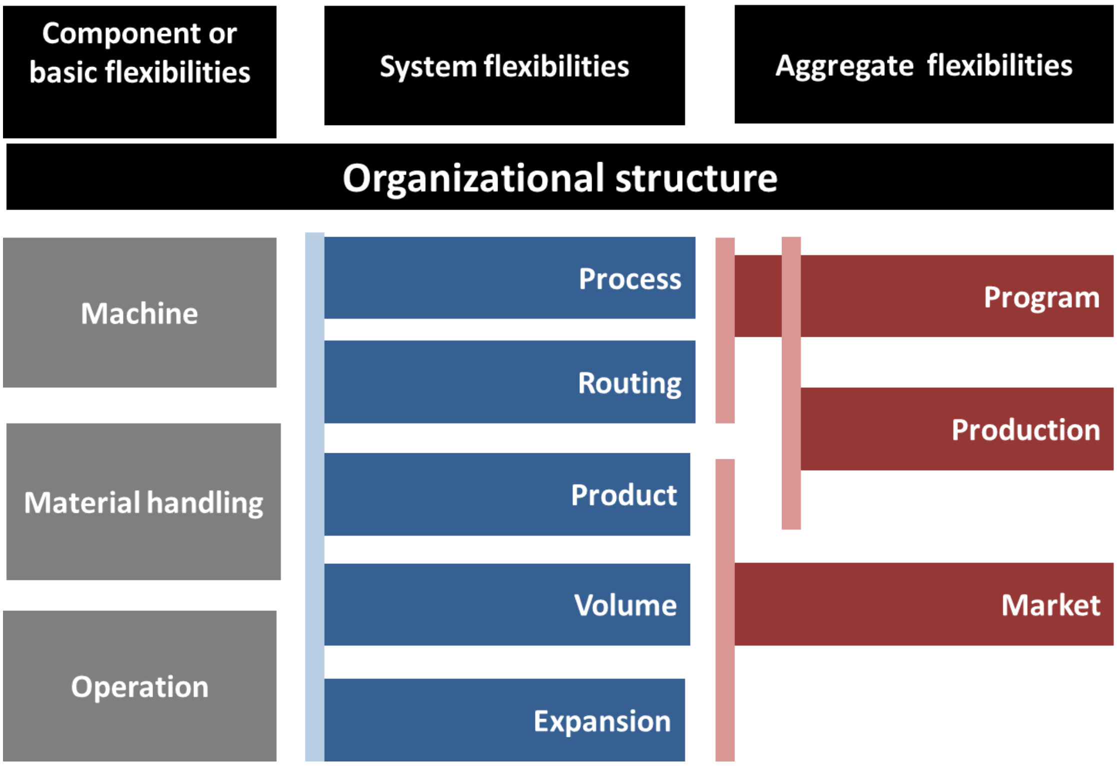
Flexibility has been deeply explored in product manufacturing, in connection to the issue of industrialization. Browne et al. (1984) and Sethi (1990) defined the flexible manufacturing system as an integrated, computer-controlled complex of automated material handling devices and numerically controlled machine tools that can simultaneously process medium-sized volumes of a variety of part types. They also classified manufacturing facilities in:

TABLE 3 CLASSIFICATION OF FLEXIBILITY IN MANUFACTURING – TXP GRAPHIC PROCESSING FROM SETHI 1990

Class	Description
Machine flexibility	The capability of a machine to perform different kind of operations
Material handling flexibility	The ability to move different part types efficiently for proper positioning and processing through the manufacturing facility it serves
Operation flexibility	The ability to interchange the ordering of several operations for each part type. (The ability to produce a product in different ways.)
Process flexibility	The ability to produce a set of part types with different materials, in several ways
Product flexibility	The ability to add a new set of products in the production system.
Routing flexibility	The possibility to handle breakdowns and to continue producing the given set of part types.
Volume flexibility	The ability to operate a system at different production volumes.
Expansion flexibility	The capability of building a system and expanding it as needed, easily and modularly.
Program flexibility	The ability of the system to run virtually untended for a long enough period.
Production flexibility	The number of products that a system can produce.

Market flexibility	The ease with which the manufacturing system can adapt to a changing market environment.

Flexibility, being a pillar of industrial production was transposed in many other engineering fields, among which building and architecture.



PICTURE 16 CONNECTION AMONG DIFFERENT TYPOLOGIES OF FLEXILIBITY – TXP GRAPHIC PROCESSING FROM SETHI 1990

5.2 WHICH FLEXIBILITY IS ACHIEVABLE IN ARCHITECTURE?

While this classification by Sethi is clear and effective for industrial products, some of these definitions can be applied to building products too.

Flexibility is connected to the concept of Open Building, that was conceived in the second half of the 20th century, and progressively consolidated up to this day. It indicates a number of different but related ideas about the making of environment, such as:

- The idea of distinct levels of intervention in the built environment (e.g.: difference between 'support' and 'infill')
- The idea that users/ inhabitants may make design decisions about the building as well, according to their needs
- The idea that, more generally, designing is a process with multiple participants also including different kinds of professionals
- The idea that the interface between technical systems allows the replacement of one system with another performing the same function
- The idea that built environment needs to transform
- The idea that built environment is the product of an ongoing and never ending design process in which environment is transformed part by part.

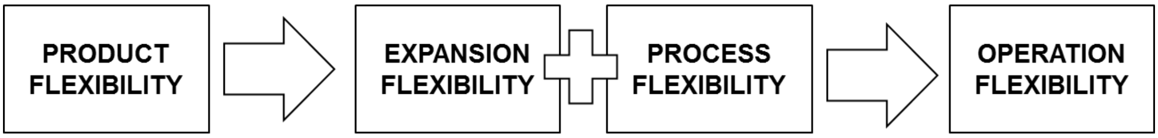
Architecture has explored more degrees of flexibility in the last decades, which will be further addressed in the next paragraphs. In particular, making reference to the Sethi classification, attention has to be focused on:

- Product flexibility
- Expansion flexibility
- Operation flexibility

Typical in the housing projects and above all in the industrialization research effort of the second half of 20th century the need for space customization and for producing many different buildings by using the same prefabricated modules is shown related to **product flexibility**. Building users (inhabitants in case of housing) want to customize the spaces in which they live in consonance with their needs. Moreover in highly standardised public hub programs (e.g.: social housing programs) there could arise the need for producing different types of house, in keeping with different kinds of final users, but using the same constructive components. For both these reasons architects should consider the need for product flexibility in their design activity.

An evolutive system needs **expansion flexibility**. The faculty of the user to expand a building should be included in the design requirements by architects. Expansion flexibility is related to the issue of **process flexibility**: expansion should occur whenever it is needed and in the way that is needed. It may implicate the necessity of **product flexibility in the short term** in order to gain expansion flexibility in the long term: when expanding a building a former functional layout could become obsolete with respect to the new asset and could thus need a reorganization.

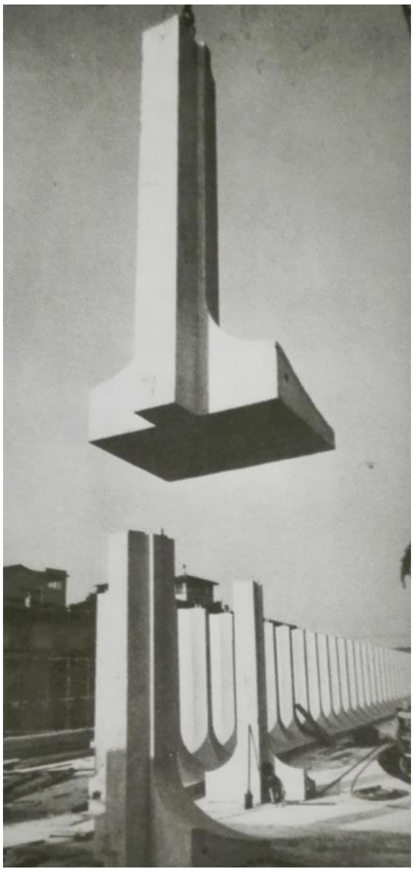
When considering evolutive systems, it should be noted that they usually exist to fulfil a main, single and fundamental requirement. Relevant cases might be those of schools, hospitals and airport terminals, etc. Each one of these evolutive systems has to accommodate a specific target of users that are subject to change as time goes by. These changes of the main requirements are the primary uncertainty factors concerning their design. Looking at uncertainty architects have to consider one more element in their design: **operation flexibility**. Operation flexibility could be enabled through expansion, process and product flexibility.



PICTURE 17 ENABLING DIFFERENT FLEXIBILITIES IN ARCHITECTURE – TXP ORIGINAL GRAPHIC ELABORATION

5.3 PRODUCT, ENVIRONMENTAL AND EXPANSION FLEXIBILITY

Industrial production inspired the long discussion and theorization of industrialization in architecture in the second half of the 20th century since it has been risen up after Second War destructions in Europe asked for faster reconstruction. The interest for industrialization in architecture was explored in many research applications concerning both the building product and the building process, in Italy –with Spadolini- and in Europe. For instance, one of the main ideas related to the "product" was the Components Catalog. The Catalog was at the base of Spadolini's research: it is a design selection of components that can be aggregated and assembled by following fixed rules. Moreover, the research group SAR (Stitchting Architecten Research) led by Habraken in the sixties established that the key for industrialization was in the modularity and design of the building as a product . Modularity is achievable through the binomial and the interaction between fixed structure and removable components.



PICTURE 18 ASSEMBLING OF COMPONENTS IN THE CONSTRUCTION SITE OF PALAZZO DEGLI AFFARI, FIRENZE – SOURCE: TURCHINI, 2010

The main field of research and application in building industrialization and architectural products were low-income residential buildings. The vocation to serial production and systemic in such market segment is clear as its need for **product flexibility** in relation to the necessity of adaptation and customization of the final users – belonging to different social categories and also varying in family composition - of each residential unit.

After this attempt of integrating seriality in the building product, academic and design research was steered towards the integration of industrialization within the building process itself, through the efforts of the innovative Italian studies.

Methodologies for gaining **environmental flexibility** were perfected during recent research period. Environmental flexibility is not listed by Sethi (1990) and Browne (1984), since it is not appeared at that time related to the manufacturing process.

Environmental flexibility is deeply connected to **expansion flexibility** in constructed assets. This is true above all in systems as issue of an architectural complex design. A system is a group of connected components, forming a coherent whole that during its lifecycle needs to be designed and managed.

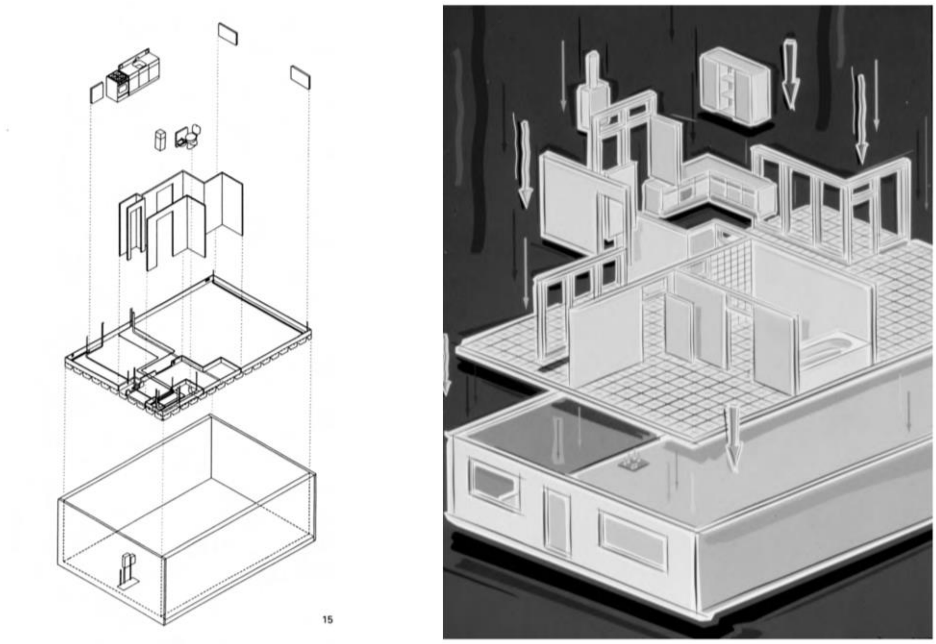
In the following definition by Fawcett (2014) the close relationship between environmental flexibility and expansion flexibility is assessed in a fair way:

"There is common agreement about the desirability of physical environments that can accommodate growth and change. If future growth and change could be predicted it would present a challenging technical problem but one that would be, in principle, capable of finely tuned solutions. However, growth and change cannot be predicted, which is why flexibility is sought."

5.3.1 THE EXPERIENCE OF HABRAKEN AND FLEXIBILITY IN THE SECOND HALF OF XX CENTURY

The Stichting Architecten Research was founded in 1965, a Dutch institution dealing with industrialization in construction industry, directed by Nikolaas J. Habraken. In those years, the housing issue was the main focus of architectural research, with specific reference to the possibility of application of industrialization to housing. While it was interesting to think of housing as an industrial output it was not acceptable to give inhabitants standardized and non customized houses. As a solution, SAR proposed to seek uniformity of constructive elements, in order to realise a "flexible" building, relating to the different inhabitants housing needs. In this concept, the housing system is identified as the sum of structural system and removable units. SAR proposed modular coordination as the basis for a flexible design together with a standardized construction industry. In this way, inhabitants could have their houses customized and composed depending on their living needs. SAR 65 summarizes the main principles of SAR manifesto. Modular coordination should be used as a mean to fix design choices; and its direct tool could be a "modular grid". Inhabitants could then manage this flexible system according to their preference (Bernstein, 1976).

This is called product flexibility: the architect designs the product pieces in a modular way, while the assembling phase is carried out by the user itself, which will produce a different final product according to his or her specific living needs. The final product could present different configurations, given the user needs and components modularity.



PICTURE 19 MODULARITY OF DESIGN FOR CUSTOMIZATION OF THE PROCUTS (OLANDA 76)

5.3.2 THE ITALIAN RESEARCH AND THE CONTRIBUTION OF FLORENCE SCHOOL PIERLUIGI SPADOLINI

In the general framework of an effort for bringing industrialization in architecture, active research was led in Italy too, where the objective was to transpose the industrial process in the complex system of architecture construction process. This meant considering not only technical and technological issues, but also any other aspect making the complexity of the construction process (Cetica, 1974), as illustrated in Paragraph 1.3.

The origins are in the mindset conveyed by Gropious in the first half of 20th century, which esteemed that in the future, architects would have at their disposal a number of architecture components, produced in industries, enabling the construction of buildings with different shapes and dimensions. Buildings could be built using a catalogue of components (Ruffilli, 1974). Similarly, Le Corbusier proposed the concept of a design system called Domino: the design in this case was a prefabricated concrete frame, whose elements could be assembled in different ways, resulting in a different final shape.

PICTURE 20 A MAISON DOMINO MODEL SCALE 1:1 AT VENICE BIENNALE 2014 "FUNDAMENTALS"

Industry could then very well lead to **product flexibility**. However, technical constructive aspects were not the only ones that could be related to an industrial approach.

The Spadolini School research activity were indeed stressing the importance of design process, divided into demand input and shape output, and its central role for the success of the final architecture product. In this perspective both methodology and tools and techniques as well are critical in enabling an effective design that was the uncontested issue of Italian research in the second half of 20^{th} century. For instance, in this framework research concerning meta-design developed the idea of Environmental Unit (Unità Ambientale), as the primary element for designing a space, as introduced in Paragraph 1.3.1. An Environmental Unit is defined by the requirements of activities that the Unit is designed to accommodate, but also by other more general requirements such as flexibility, combinability, etc. Flexibility is the capacity of a space to accommodate different activities, at the same time or in sequence, and the ability to enable changes due to the probable variations of some specific requirements (e.g.: equipment that could soon become obsolete). Combinability, on the other hand, is the aptitude of a space to be associated to other spaces for a due period. (Trippa, 1974)

Hence, another concept related to flexibility was introduced: **environmental flexibility**.

We can find many examples of these interpretations of flexibility in Spadolinian research followers works concerning industrial design, meta-project and tools for design process.

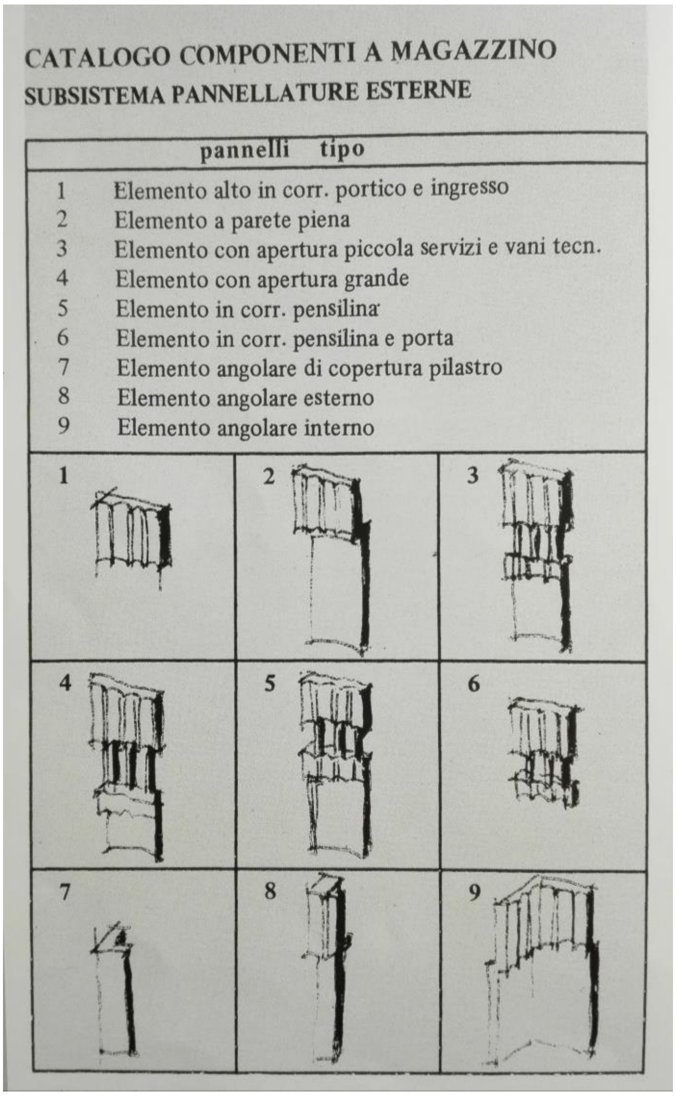
Early research activity led by Spadolini and his group was strictly devoted to the exploration of possibilities for prefabrication and industrialization in architecture. It is surprising how many different architectures Spadolini realized by using a restrained number of prefabricated components (Turchini, 2010). Composability was pivotal in this first research activity, as demonstrated by the following two pictures.

PICTURE 21 VIEW OF PALAZZO DEGLI AFFARI, FIRENZE

Another experience concerning flexibility in architecture was the research leading to the construction of MAPI (Modulo Abirativo di Pronto Intervento) module. In order to respond to a request for design research submitted by the Italian Civil Protection Department after the catastrophe of the Irpinia earthquake, and according to the research of those years concerning industrialized architecture, Spadolini coordinated a study for first aid temporary living modules. The result of this research was the MAPI module, a prefabricated module that was expandable and adaptable to many different uses.

PICTURE 22 MAPI - MODULE FOR EMERGENCY CASES

In 1974-1979 Spadolini was appointed of designing an industrialized production system for the construction of post offices in Italy. In this experience the Catalogue of Components methodology was set up and tested on an important program for public owned construction. The Catalogue of Components is a complete set of the possible combinations of different prefabricated building components. The Catalogue allows to realise different architectures by easily combining a limited number of standard components in different ways. The main result of such type of process is product flexibility.



PICTURE 23 COMPONENTS CATALOGUE FOR THE POST OFFICES PROGRAMME (FROM CETICA, 1985)

Nonetheless, after this experience the interests of Spadolini and his group moved progressively from product to process (Cetica, 1985). Gradually, the importance of a coordination of the whole design and building processes appears more clear, together with the importance of research for producing tools to aid these processes. The urgency of a unitarian and comprehensive project design management emerges.

This framework encompasses a research effort concerning housing space its requirements and design conducted (Buccolieri et alii, 1983) in those years. Flexibility is once again required in order to allow house transformation when needs change. This is possible through a flexible functional distribution and flexible constructive technologies (e.g. use of movable partitions), both enabling change. This need for adaptation to different requirements is also documented by the Emilia Romagna Regional Regulatory Framework of those years; the following picture is an example of possible combinations assembled by users, determining different house designs with different capacity.

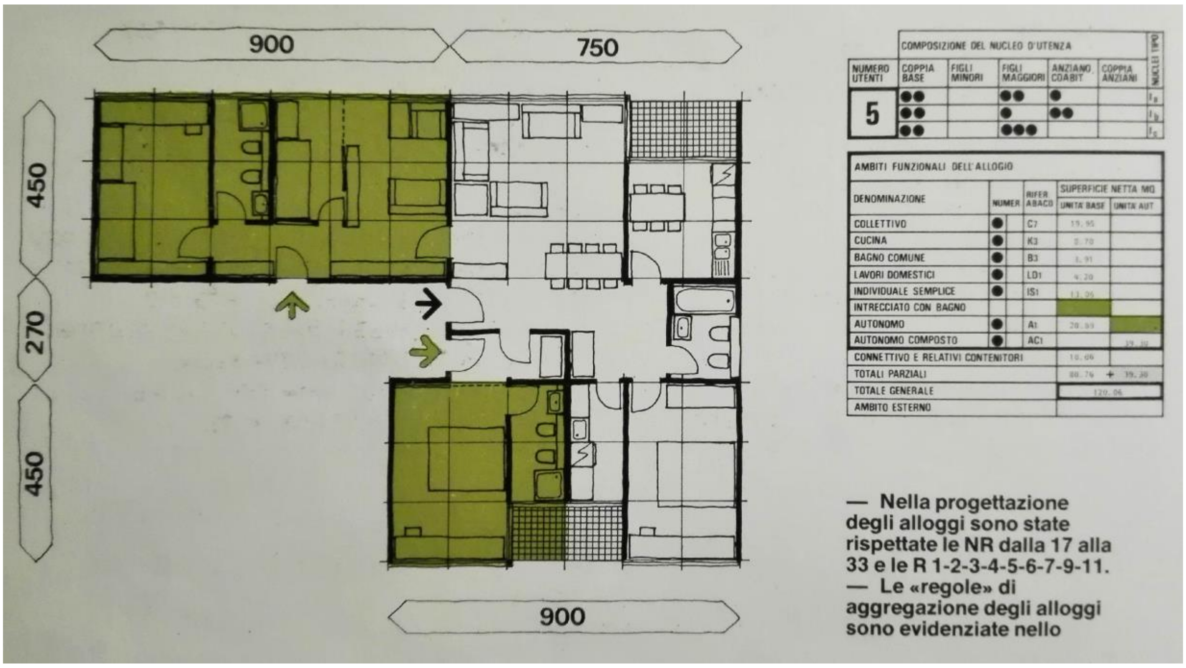
Numero componenti [1]	Numero d'ordine	Coppia capofamiglia	Figli minori	Figli maggiorenni	Anziani coabitanti
2	1	2/1			
3	2	2/1	1		
	3	2/1		1	
	4	2/1			1
4	5	2/1	2		
	6	2/1	1	1	
	7	2/1	1		1
	8	2/1		2	
	9	2/1		1	1
	10	2/1			2
	11	2/1			1+1
5	12	2/1	3		
	13	2/1	2	1	
	14	2/1	2		1
	15	2/1	1	2	
	16	2/1	1		2
	17	2/1	1		1+1
	18	2/1	1	1	1
	19	2/1		3	
	20	2/1		2	1
	21	2/1		1	2
	22	2/1		1	1+1
6	23	2/1	4		
	24	2/1	3	1	
	25	2/1	3		1
	26	2/1	2	2	
	27	2/1	2		2
	28	2/1	2		1+1
	29	2/1	2	1	1
	30	2/1	1	3	
	31	2/1	1	2	1
	32	2/1	1	1	2
	33	2/1	1	1	1+1
	34	2/1		4	
	35	2/1		3	1
	36	2/1		2	2
	37	2/1		2	1+1

PICTURE 24 POSSIBLE COMPOSITIONS/NUMBER OF INHABITANTS OF A FLEXBILE HOUSE ACCORDING TO EMILIA ROMAGNA NTR 1982 (BUCCOLIERI, TORRICELLI, ZAFFAGNINI ET ALII, 1983)

According to the housing need of those years, the issue of flexibility was related to the need of adjusting the housing space to the changing habits and numbers of its users without relocate them. This is exemplified by the picture below, which shows how the scheme for a flexibility of use and evolution of the house space was proposed and studied during experimentations of the NTR (Norme Tecniche Regionali - Regional Regulatory Framework) of Emilia Romagna.

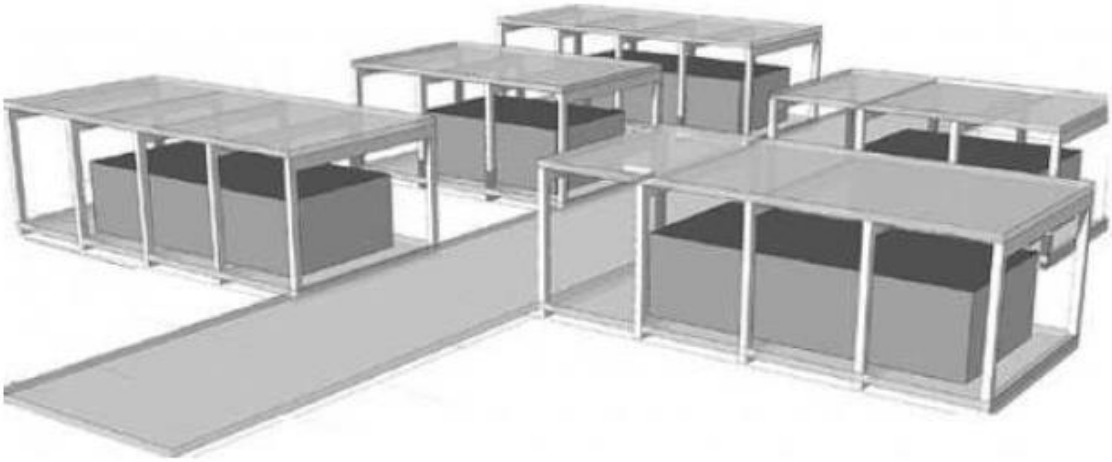
PICTURE 25 DIFFERENT SPATIAL SOLUTIONS FOR THE SAME HOUSE IN DIFFERENT YEARS, WITH DIFFERENT DIMENSIONING NEEDS OF ITS INHABITANTS, ACCORDING TO EMILIA ROMAGNA NTR 1982 (BUCCOLIERI, TORRICELLI, ZAFFAGNINI ET ALII, 1983)

Every house, according to this research project, is composed by an aggregation of modules. The modules aggregation is determined by proper aggregation rules, by the number of users, by the activities associated to each space.



PICTURE 26 EXAMPLE OF AGGRAGATION OF TYPOLOGICAL ELEMENTAR MODULE, ACCORDING TO A SET OF AGGREGATION RULES - EMILIA ROMAGNA NTR RESEARCH (BUCCOLIERI, TORRICELLI, ZAFFAGNINI ET ALII, 1983)

In Italy, the recent sad occurrence of emergency situations lead professionals and researchers to deal again with emergency housing, which once again invokes the need for product flexibility. Product flexibility in state of emergency gives users the possibility to customize spaces, in a background where both simplification and speediness of processes are extremely valuable. One example of this is the MIA housing unit (Bologna 2015). This design research proposes two modules divided in separate functional units, according to a binomial structure already introduced in the 20th century research: external module; internal module. Modularity of this recent exercise, also resides in the dimensions of components and spaces, in order to guarantee customization according to the users' needs. Product flexibility furthermore enables usage for other purposes.



PICTURE 27 EMERGENCY/TEMPORARY HOUSING MODULARITY IN MIA PROJECT (BOLOGNA, 2015)

5.4 INTRODUCING OPERATION FLEXIBILITY

The previous paragraph recognised the concepts of product and environmental flexibility, together with their evolution in the Italian research through the Spadolini School contribution.

The main problem that faces an architect is that he has to try to picture the future of human being and life in his architecture. He has to look forward, as the "project" word suggests: the Latin "projectum" means **to take a glance forward** (Guazzo, 2010).

Spadolini acknowledged that, in view of the continuous progress in science, technology and research, existence is characterised by a **continuous change and evolution in habits, traditions, institutions**. Everything becomes relative and objectives and thoughts of men slowly change: **only time will ascertain the accuracy of predictions regarding a possible change in habits** (Guazzo, 2010).

The requirement of flexibility has been addressed and pointed out for decades. The problem is that **flexibility** and adaptation must **answer to changes that are not defined** and characterized as "unknown" (Sher, 2013).

We know that change is necessary, but we cannot specify where the building will need change, when the change will be needed, or what change will be needed. We are **asked**

to make designs flexible to meet future unspecified changes, gaining "sustainable" designs (Sher, 2013). And from this confused need of flexibility derives some un-proper use of the terms such as: flexibility, adaptation, growth, change, sustainability. For instance, the future will bring unpredictable changes, as global population growth and climate change. Change, which is not predictable, brings the necessity for sustainability, for growth, for adaptation and for flexibility in buildings and architecture. Expansion and growth are possible consequences of change. Adaptation is a requirement to face changes in use. Environmental flexibility is connected with both expansion and adaptation concepts. Sustainability is the future-proofing investment as well as robust and flexible planning for change (Sher, 2013).

Therefore given the future unpredictability, **flexibility in design enables a system to change in the face of uncertainty** (Fricke, 2005). A flexible design of an asset allows decision makers to face effectively changing environments and conditions (de Neufville, 2011). The lifecycle performance of an asset (a building, a system, a complex project) is significantly improved by **recognising uncertainty and including flexibility** in design.

Design for uncertainty and flexibility is a process not yet widespread in industry, therefore it needs a proper guidance in this direction (Cardin, 2013). Scientific efforts are being made in order to create supports to guide designers in including flexibility in their project.

Nevertheless, to desire flexibility in a system is not sufficient. One needs to enable it in the design concretely and manage it in operations (Cardin, 2013).

Thus, a new concept of flexibility arises as soon as uncertainty is recognized. Flexibility is not easily achievable, since it is not possible to anticipate entirely the changes the building will have to adapt to in the future. To yearn for environmental flexibility and for product flexibility is not sufficient to respond to the need for a "flexible" architecture. Operation flexibility has to be considered and identified, in order to set up a flexible building.

5.4.1 From operation flexibility to environmental flexibility

Buildings are open systems engaging with their context and surroundings from a perceptive, functional and thermal point of view (Marzi, 2008). They are made of a variety of single subsystems (Habraken, 2000), linked to each other through general rules, interacting with the external environment and evolving according to their users' needs. The need for adaptation to different situations and conditions requires buildings characterized by operative flexibility, so that architecture has to be adjustable and expandable in order to answer properly to specific needs and demand. Flexibility is the driver of a project and determines the choices therein made in functions, shape, typology (Cucurnia, 2010).

So, it is clear that physical environments which are able to accommodate growth and change are highly desirable. Growth and change cannot be predicted, which is why flexibility is sought (Fawcett, 2014). Then how to cope with the requirement for flexibility?

The success of design depends on the ability of a building to react to adjustments and changes during its life cycle, always meeting targets of quality, times and costs. The right use of all of the techniques, procedures, tools, scientific and technical knowledge allows the accomplishment of this main target (Cucurnia, 2010).

To translate inputs for operation flexibility to an output architectural product characterized by environmental flexibility is a task for the creativeness of the designer. It is clear that competence in the renovation of design shapes and signs is a subject reserved only to the designer, as a proof of his or her ability (Spadolini, 1974). But in order to make the designer able to create the right shape, it is necessary to inform him about every "pressure" weighting on the future architecture product. To design architecture project means to consider and process all the necessary information, in their complexity, eschewing simplification of the future context (Trippa, 1974).

In order to gain flexibility of the final product through a proper design, it is necessary to inform the designer about the changes that could occur and that flexibility is the answer to. To outline the expected operation flexibility is the first step to inform the designer about these changes, and to gain a subsequent flexibility in the final environment and product.

5.5 FLEXIBILITY: STILL AN OPEN ISSUE

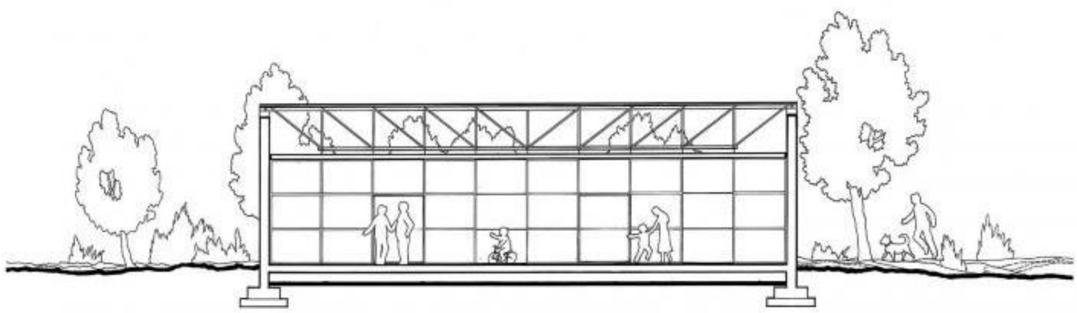
It is important to note that architects have been conducting an ongoing design research concerning flexibility since the 1980s. But flexibility in architecture is actually an open issue and it is subject of a continuous analysis.

As yet, the more up-to-date viewpoint has been offered by "Reporting from the Front", Venice Biennale 2016. Flexibility has been addressed by more than one pavilion, since it is a "front" to be gained and a need to be satisfied in our times: not permanence and un-changeability, but evolution and flexibility are the most desirable features.

PICTURE 28 DOES PERMANENCE MATTER? - VENICE BIENNALE 2016 REPORTING FROM THE FRONT

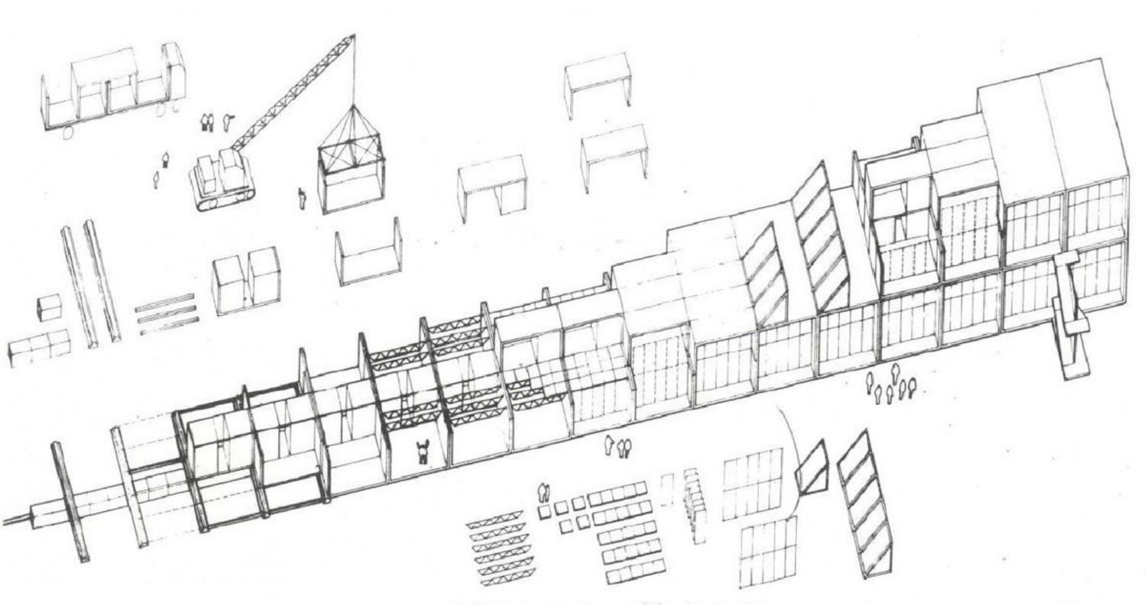
Buildings are not finished shells, but open platforms that enable living processes. Architects are the creators of the space, the unavoidable component of social dynamics. When architecture is involved in social movement from the very beginning, buildings and their content, their histories and futures, work and live together ("Reporting from the front" Venice Biennale 2016).

Even Renzo Piano is currently exploring the meaning of “front”, stressing the flexibility issue, since he has always been interested in the concept of evolutionary space (Piano, 2016). In “Reporting from the front”, he proposes a consideration about the ability of a building to adapt to changing conditions recalling his early works. In “Free-plan houses” (1970-1974) he decided to gain flexibility in the four houses devised in said project through four identical, single and wide spaces assigned for their completion to the users.



PICTURE 29 FREE-PLAN HOUSES, RENZO PIANO, 1970-1974

The notion of flexibility obtained through a free-plan was used in his first office building in Genoa (1968-1969), while flexibility in terms of evolutionary space was explored in his “Evolutive housing” project. The latter illustrated how a low-cost house could be built by assembling industrially produced modular systems.



PICTURE 30 ASSEMBLY SCHEME OF EVOLUTIVE HOUSING, PIANO 1978-1982

PICTURE 31 TIPOLOGY PLANS, EVOLUTIVE HOUSING, PIANO 1978-1982

Which flexibility is Piano referring to? Piano revises today questions through answers debated in the 1890s. This is once again a proposal for **product flexibility**, in which the architect must design a modular system in order to allow the users to produce a living environment reflecting their needs.

The Spanish Pavilion was awarded with the golden lion for its work. It highlighted the significance of working on the "process" rather than on the final "product". The Spain underwent a consistent building activity unsupported by proper dimensioning and economic evaluations, followed by an economic crisis. The denounce of the Spanish curators comprises "examples of architecture produced during the past few years, born out of renunciation and economy of means, designed to evolve and adapt to future necessities […]. These projects have understood the lessons of the recent past and consider architecture to be something unfinished, in a constant state of evolution" (Carnicero, Quintans 2016).

PICTURE 32 "UNIFISHED" AWARDED SPANISH PAVILION, VENICE BIENNALE 2016

Which flexibility do Carnicero and Quintans propose? In the light of the Spanish experience of these years, they propose an **expansion flexibility**. However, no expansion flexibility is possible without a product flexibility.

From the 1980s to 2016, the question still remains the focus of design research. Does permanence matter? And how to meet the evolutionary nature of buildings?

We instinctively believe that good architecture is a stone in the midst of running water. On the contrary the common environment is the running water and change by way of adaptation over time is essential for its continued existence (Habraken, 2006).

6. LIFE CYCLE COSTING ANALYSIS

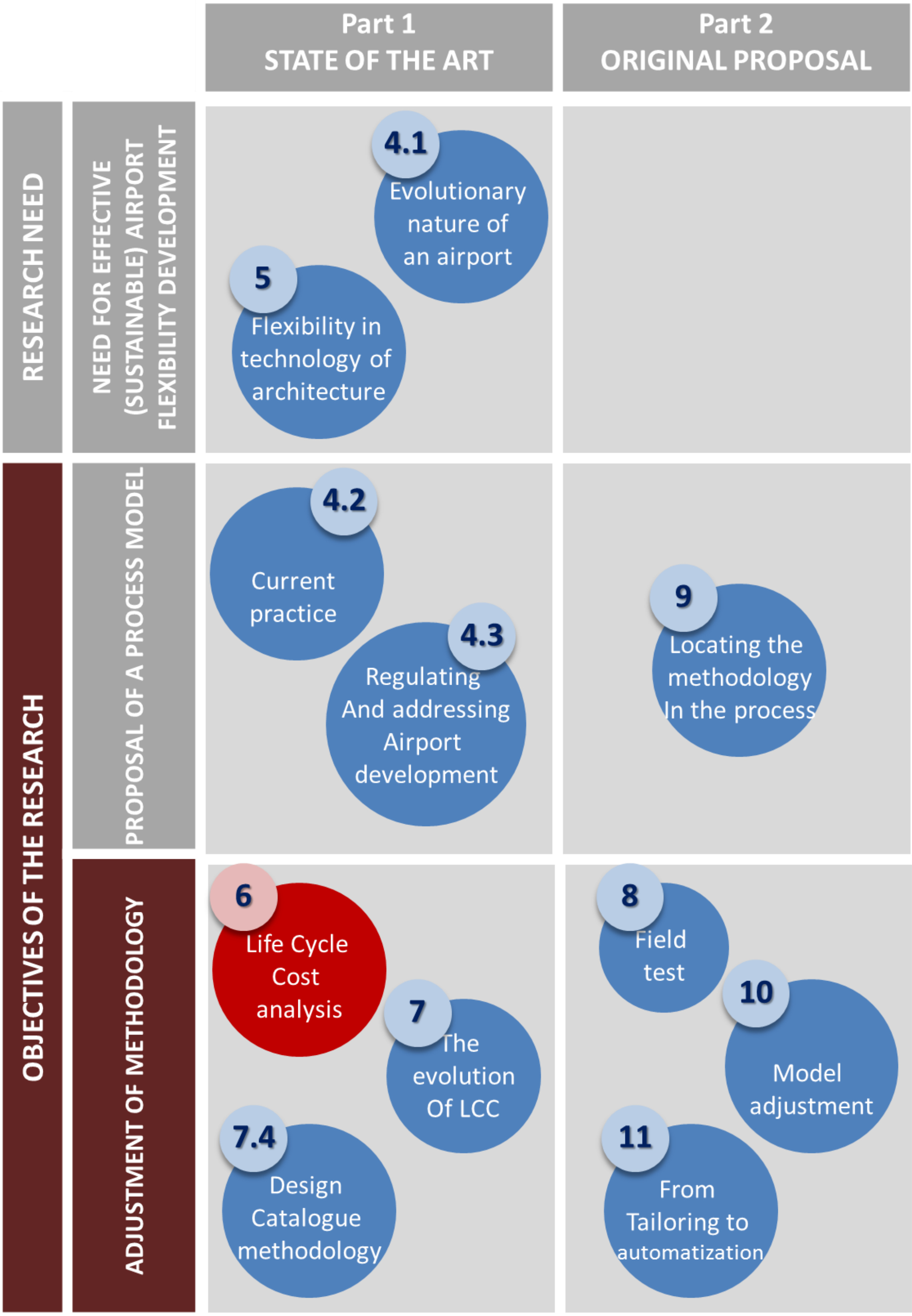
Chapter objectives

In Chapter 6 the reader will understand and learn:

- The framework of life cycle sustainability
- Life Cycle Cost analysis definitions
- Life Cycle Costing foundations
- Other issues concerning LCC analysis (e.g.: data collection, European applications, etc.)

Chapter Keypoints

In this chapter Life Cycle Costing is going to be introduced. At first, the general framework of life cycle sustainability is going to be defined. Definitions and purposes of application of the methodology are being proposed to the reader. In the end data collection issues, Italian regulation and cases of application of LCC to airport facilities are being explored.


Part 1
STATE OF THE ART
Part 2
ORIGINAL PROPOSAL
RESEARCH NEED
NEED FOR EFFECTIVE
(SUSTAINABLE) AIRPORT
FLEXIBILITY DEVELOPMENT
4.1
Evolutionary nature of an airport
5
Flexibility in technology of architecture
OBJECTIVES OF THE RESEARCH
PROPOSAL OF A PROCESS MODEL
4.2
Current practice
4.3
Regulating And addressing Airport development
9
Locating the methodology In the process
ADJUSTMENT OF METHODOLOGY
6
Life Cycle Cost analysis
7
The evolution Of LCC
7.4
Design Catalogue methodology
8
Field test
10
Model adjustment
11
From Tailoring to automatization

6.1 LIFE CYCLE SUSTAINABILITY FRAMEWORK

According to recent research, LCC (Life Cycle Costing) is deeply related to other life cycle sustainability methodologies, in connection with environmental and social aspects. An interesting research path concerning LCC focuses on an active research about its relation to the other pillars of sustainability. The Brundtland report (1987) defined sustainable development as the development that meets the needs of today and does not compromise the possibility for future generations to meet their needs too. Recently, the concept of sustainability has been embraced by United Nations through the Transforming our World agenda (Agenda UN 2030).

In particular, life cycle costing is defined as the assessment of all the costs associated to the life cycle of a product, directly managed by the actors of the life cycle, including the externalities that will be internalized in the immediate future (Swarr et al., 2011).
The Brundtland report defines economic sustainability as an enhancement of the produced capital, generated by the application of productive activities to the natural heritage and capable of producing more capital.

The LCC methodology has been criticized for the way it is oriented to business rather than to the whole dimension of sustainability (Torricelli, 2015). Indeed a complete evaluation of sustainability requires the contribution of an environmental, economic and social life cycle assessment. Together, the three methodologies give us a complete framework of the sustainability of an asset; the framework is called LCSA (Life Cycle Sustainability Assessment) and was proposed for the first time by Kloepffer (2008):

$$LCSA = ELCA + SLCA + CLCA$$

Where:

ELCA: Environmental Life Cycle Assessment
SLCA: Social Life Cycle Assessment
CLCA: Cost Life Cycle Assessment

The life cycle approach intends to integrate sustainability in design, innovation and evaluation of products, services, technologies, systems, sub-systems (Zamagni, 2013).
At the current state of the art, the three methodologies have to be applied in different moments, and they require to be described by the same scope, limits and functional unit.
Recently a more integrated approach has been proposed, relating the three topics of sustainability to a number of indicators including social and economic issues; this holistic approach is subject of active research. In order to advance in the development of the single methodologies, it is necessary to understand how to connect them and use them to meet the sustainability requirement (Torricelli 2015).

6.2 Definitions

The life cycle approach introduces the temporal dimension in the evaluation and assessment of sustainability of products, services and technologies. The issue of life cycle approach is discussed by the working group CEN TC 350, which has produced documents concerning the three topics of sustainability. ISO/TC 59 is the related technical committee. International standard introduces clear definitions for each of these key concepts.

TABLE 4 ISO DEFINITIONS

	Definition	**Source**
	General	
Life Cycle:	Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal	UNI 14040
Design life:	The design life of the constructed asset is a key performance requirement and should be defined in the client's brief	ISO 15686
LCC (Life-cycle cost):	LCC cost of an asset or its parts throughout its life cycle, while fulfilling the performance requirements	ISO 15686
Life-cycle costing:	Methodology for systematic economic evaluation of life-cycle costs over a period of analysis, as defined in the agreed scope	ISO 15686

WLC (Whole-life cost):	WLC all significant and relevant initial and future costs and benefits of an asset, throughout its life cycle, while fulfilling the performance requirements	ISO 15686
Whole-life costing:	Methodology for systematic economic consideration of all whole-life costs and benefits over a period of analysis, as defined in the agreed scope	ISO 15686
Asset	Whole building or structure, system or a component or part	ISO 15686
Discounted cost	Resulting cost when the real cost is discounted by the real discount rate or when the nominal cost is discounted by the nominal discount rate	ISO 15686
Real cost	Cost expressed as a value at the base date, including estimated changes in price due to forecast changes in efficiency and technology, but excluding general price inflation or deflation	ISO 15686
Net present value NPV	Sum of the discounted future cash flows NOTE 1 Where only costs are included, this can be termed net present cost (3.2.3). NOTE 2 This is the standard criterion for deciding whether an option can be justified on economic principles, but other techniques are also used as described in Annex B.	ISO 15686
Discount rate factor or rate	Reflecting the time value of money that is used to convert cash flows occurring at different times to a common time NOTE This can be used to convert future values to present-day values and vice versa	ISO 15686
Externality	Quantifiable cost or benefit that occurs when the actions of organizations and individuals have an effect on people other than themselves EXAMPLES Non-construction costs, income and wider social and business costs.	ISO 15686

	NOTE Externalities are positive if their effects are benefits to other people and negative, or external costs, if the external effects are costs on other people. There may be external costs and benefits from both production and consumption. Adding the externality to the private cost/benefit gives the total social cost or benefit..	
Equivalent annual value or annual cost	Is the regular annual cost that, when discounted, equals the NPV of the investment	ISO 15686
Costs		
Acquisition cost	All costs included in acquiring an asset by purchase/lease or construction procurement route, excluding costs during the occupation and use or end-of-life phases of the life cycle of the constructed asset	ISO 15686
Capital cost	Initial construction costs and costs of initial adaptation where these are treated as capital expenditure NOTE The capital cost may be identical to the acquisition cost if initial adaptation costs are not included	ISO 15686
Disposal cost	Costs associated with disposal of the asset at the end of its life cycle, including taking account of any asset transfer obligations	ISO 15686
End-of-life cost	Net cost or fee for disposing of an asset at the end of its service life or interest period, including costs resulting from decommissioning, deconstruction and demolition of a building; recycling, making environmentally safe and recovery and disposal of components and materials and transport and regulatory costs	ISO 15686
External costs	Costs associated with an asset that are not necessarily reflected in the	ISO 15686

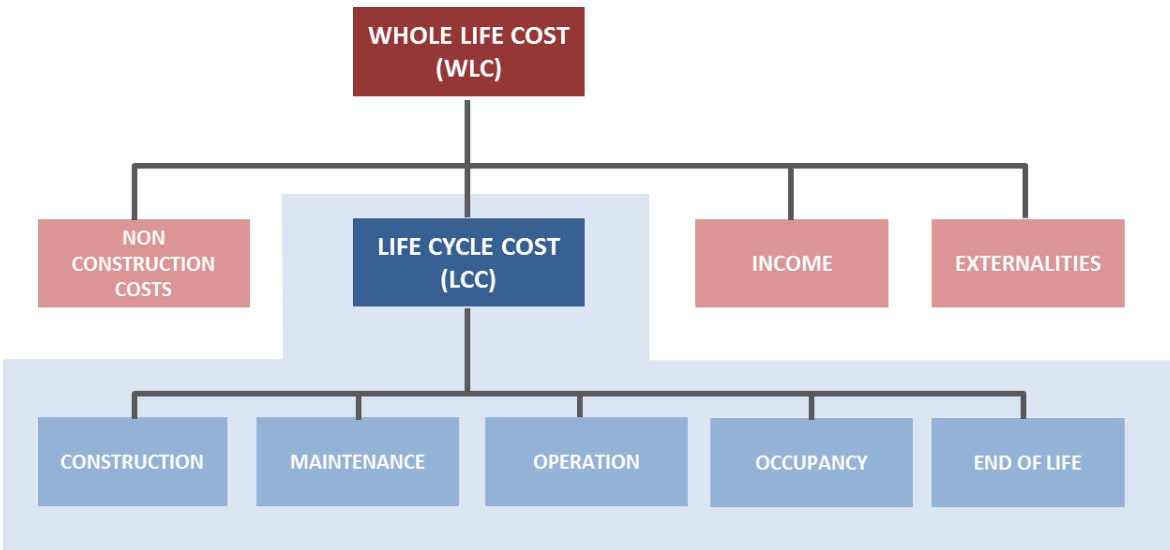
	transaction costs between provider and consumer and that, collectively, are referred to as externalities NOTE These costs may include business staffing, productivity and user costs; these can be taken into account in a LCC analysis but should be explicitly identified	
Maintenance cost	Total of necessarily incurred labour, material and other related costs incurred to retain a building or its parts in a state in which it can perform its required functions NOTE Maintenance includes conducting corrective, responsive and preventative maintenance on constructed assets, or their parts, and includes all associated management, cleaning, servicing, repainting, repairing and replacing of parts where needed to allow the constructed asset to be used for its intended purposes	ISO 15686
Operation cost	Costs incurred in running and managing the facility or built environment, including administration support services NOTE Operation costs could include rent, rates, insurances, energy and other environmental/regulatory inspection costs, local taxes and charges.	ISO 15686
Residual value	Value assigned to an asset at the end of the period of analysis	ISO 15686

6.3 PURPOSE AND POSSIBILITY OF APPLICATION OF LCC

After introducing the main concepts of this methodology through international standard definitions, LCC analysis will now be discussed. It is an interesting and powerful methodology, given its adaptability to many fields as well as to every level of their process. This kind of analysis can be directed towards many scopes and be conducted in a variety of ways in order to reach its aim.

LCC analysis should cover a defined list of costs involving the physical, technical, economic or functional life of a constructed asset over a defined interval of analysis. Life-cycle costing should also be influenced by externalities like as non-construction costs and wider occupancy costs, as well as local, national or international policies, taxes, etc. LCC analysis may include allowances for foreseeable changes, such as changing regulatory parameters. LCC analysis may also form part of a strategic review of procurement routes or objectives, in order to enhance sustainability or improve functionality. Practice can vary between users as to whether only costs borne by the customer for the analysis are taken into account, or whether other costs are also included. (UNI 15686)

Then it becomes evident that this analysis is not predetermined as it depends on the scope and on the client's needs. Anyway a general structure of the costs to be included in a LCC analysis is proposed below, with the relation with a WLC analysis, including other additional items.



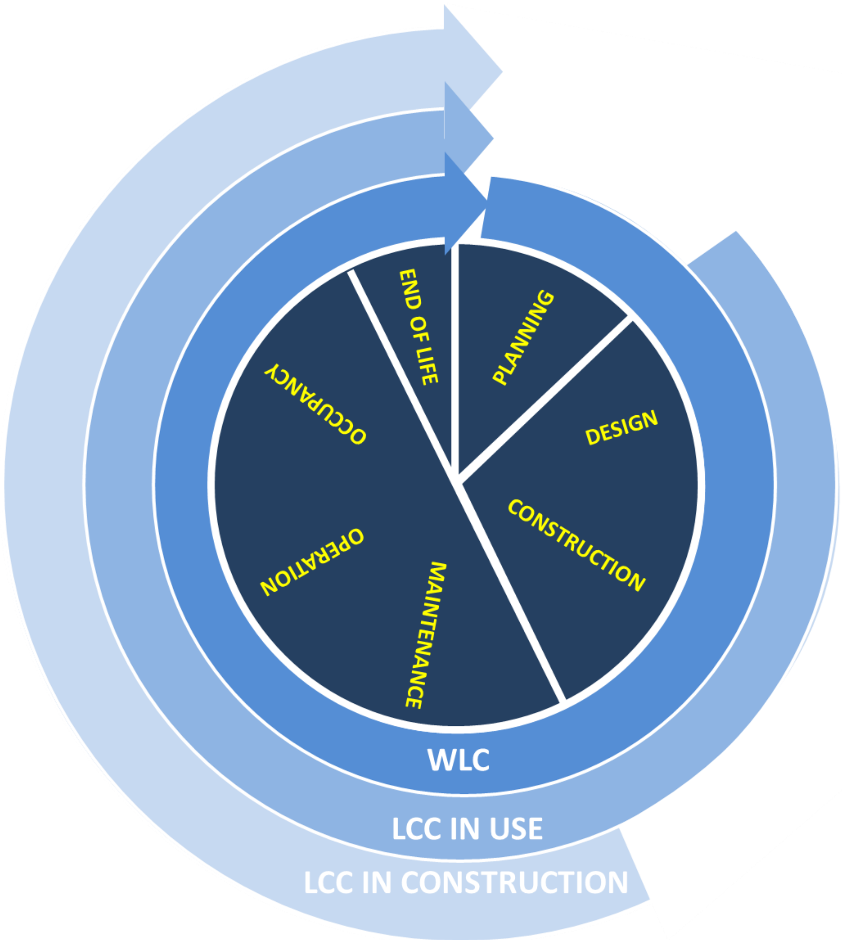
PICTURE 33 RELATIONSHIP BETWEEN LCC AND WLC AND TYPICAL COSTS TO BE INCLUDED - TXP GRAPHIC PROCESSING FROM UNI 15686

According to the International Standard, in case of application to the constructed asset, LCC analysis may be used through the following stages:

- Project investment and planning phase
    - WLC/LCC strategic options analyses

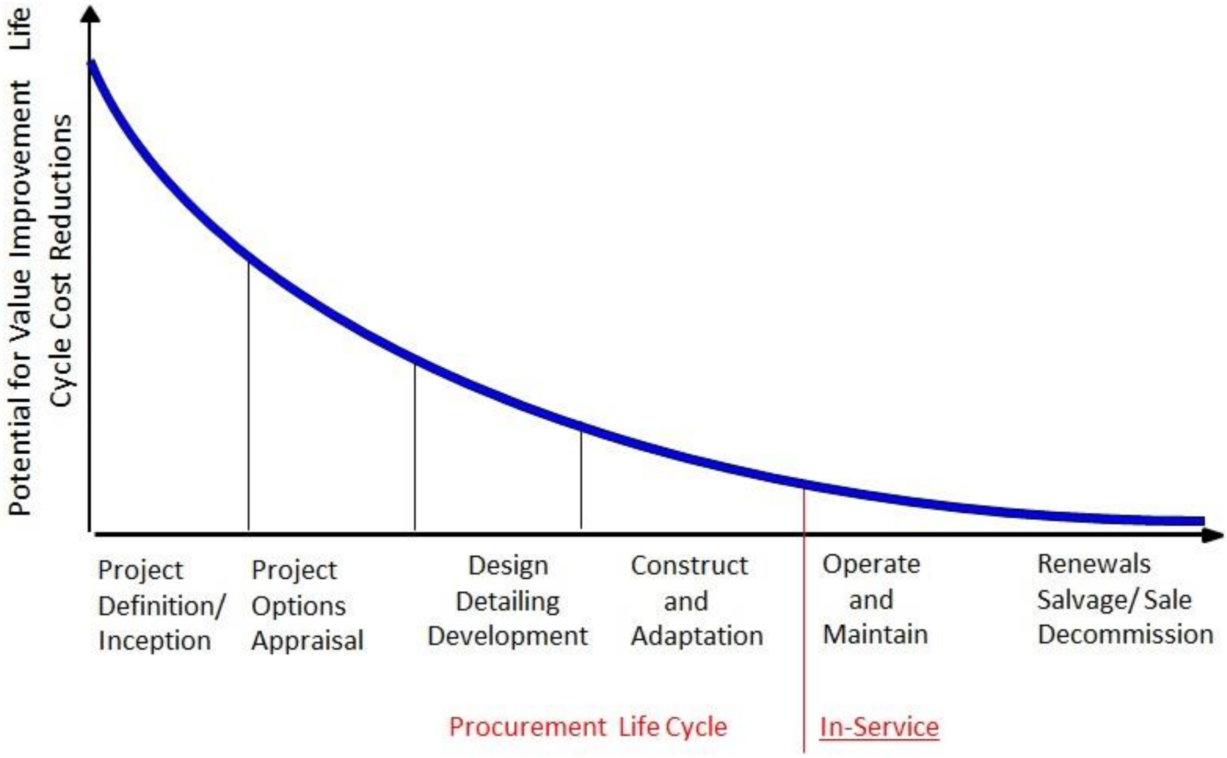
   - Pre-construction
- Design and construction phase
   - LCC during construction, at scheme, functional, system and detailed component levels
- Operation phase
   - LCC during operation (cost-in-use)
   - Post-construction
- Disposal phase
   - LCC at end-of-life

A graphic representation of these possibilities applications of this analysis at different stages of the life cycle of an asset is proposed below, making reference to UNI 15686.



PICTURE 34 LCC UNDERTAKEN AT DIFFERENT STEPS OF THE LIFE CYCLE – TXP GRAPHIC PROCESSING FROM UNI 15686

What is interesting for a designer is that the planning and design phase offers the greatest potential to influence the post-construction costs over the life cycle. As a matter of fact, the opportunity to influence the design and construction options becomes increasingly limited as the process proceeds. As reported by the International Standard, up to 80 % of the operation, maintenance and replacement costs of a building can be defined in the early 20 % of the project design process stages.



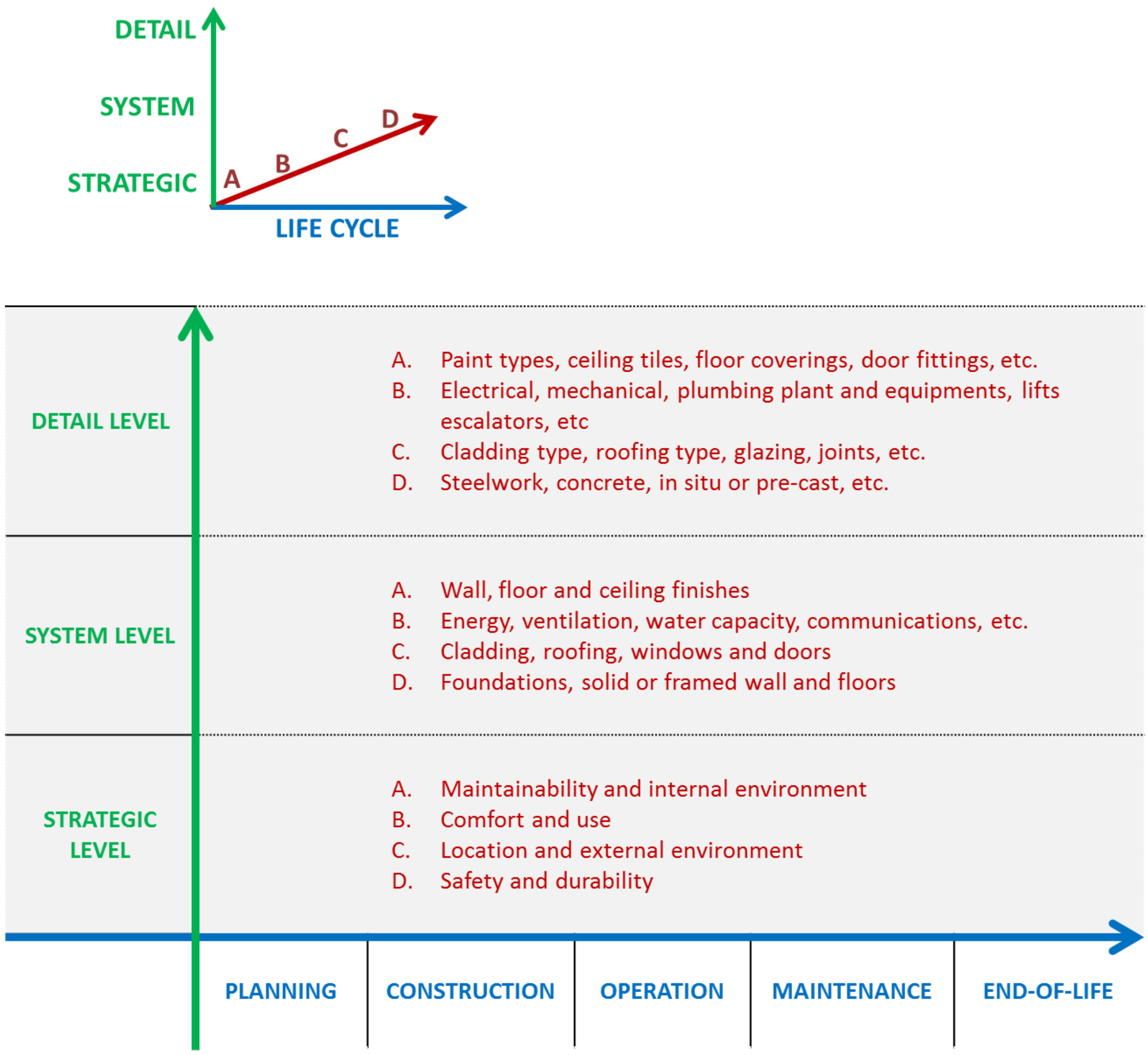
PICTURE 35 SUCCESS IN INFLUENCING SAVINGS TERMS OF LCC IN LIFE - TXP GRAPHIC PROCESSING FROM UNI 15686

According to International Standard, typical decisions informed by LCC analysis are:

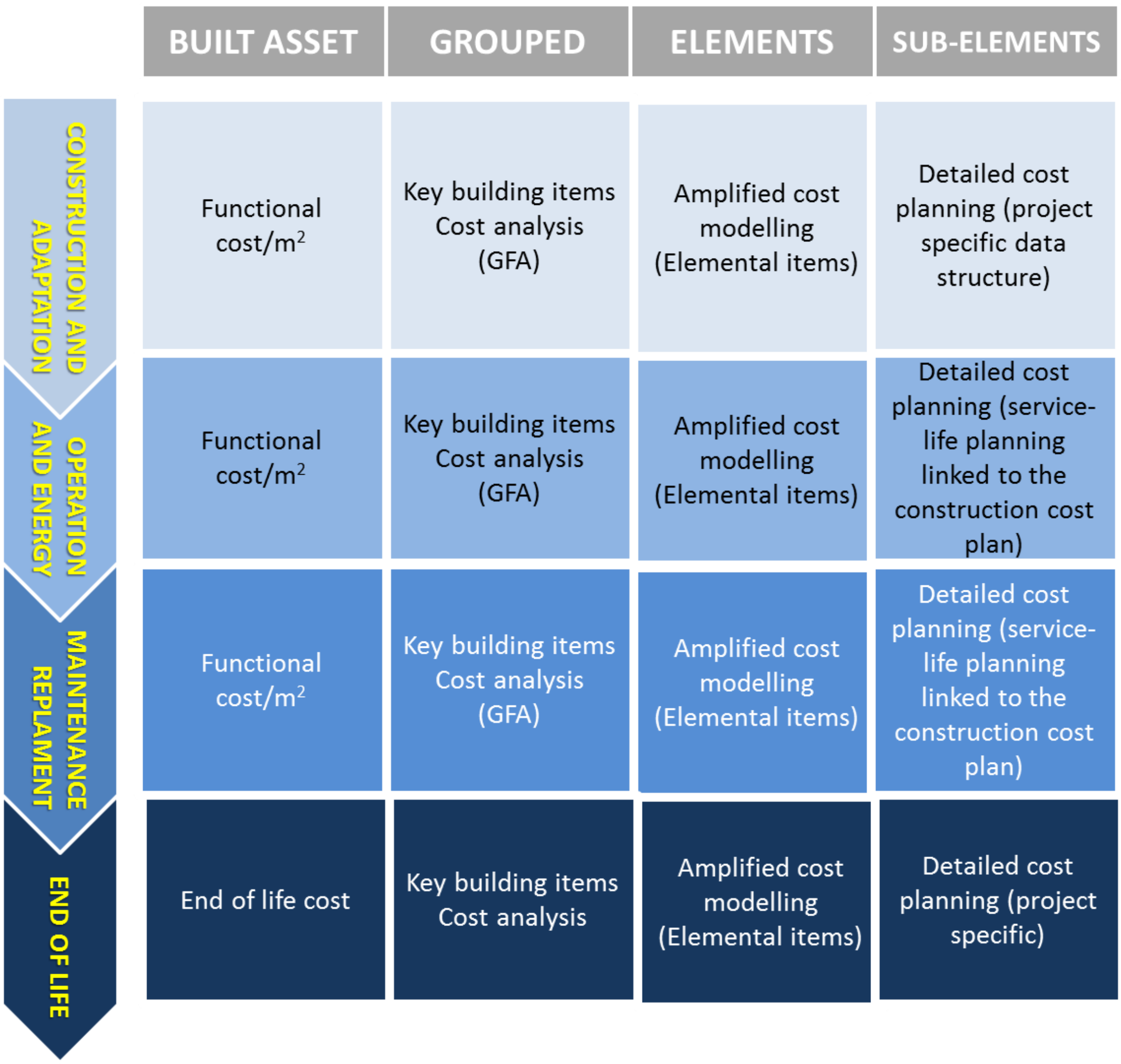
a) Evaluation of different investment scenarios (e.g. to adapt and redevelop an existing facility, or to provide a totally new facility) at the investment planning stage,

b) Choices between alternative designs for the whole or part of a constructed asset during the design and construction stage (asset, system or detailed element level LCC analysis),
c) Choices among alternative components, all of which have acceptable performances during the construction or in-use stages (component-level LCC analysis),
d) Comparison or benchmarking analysis of previous decisions, which may be at the level of individual cost headings (e.g. energy costs, cleaning costs) or at a strategic level (e.g. open plan versus cellular office accommodation),
e) Estimation of future costs for budgetary purposes or for the evaluation of the acceptability of an option on the basis of cost of ownership.

Depending on the stage of the life cycle at which the analysis is performed and according to the main purposes of the analysis itself (e.g.: strategic or detail purpose), it is necessary to tune the LCC in order to fit the objectives. An example of cost items issue of the computation have been suggested by the UNI 15686-5 and have been summarized in the following two schemes. The two pictures together show that the more detailed decisions the analysis has to inform, the more in-deep information about costs have to be collected, in relation to each of the life cycle stages under analysis.



PICTURE 36 DIFFERENT LEVELS OF ANALYSIS AT DIFFERENT STEPS OF THE LIFE CYCLE – TXP GRAPHIC PROCESSING FROM UNI 15686



PICTURE 37 TYPICAL LEVELS OF ANALYSIS WITHIN EACH KEY LCC CATEGORY - TXP GRAPHIC PROCESSING FROM UNI 15686

Given the scope of application of the methodology, as explained in the previous pages, it can be carried out both at a strategic level or at a detailed level as well. In the first case, the LCC makes use of industry-average or benchmarks (parametric estimates). In the second case, the LCC makes use of specific estimates and forecasts. The degree of detail and information available are related to the phase of the process to which the analysis is applied. The general principle that determines the level of detail at which calculations of LCC are made should be the corresponding level of detail employed to calculate acquisition costs. (UNI 15686)

For instance, an initial cost analysis, made at a rough level, should be based on the functional unit (e.g. cost per bed) or total area of the asset (e.g. cost per square metres) or on the number of people accommodated.

In particular, according to the standard, values can be derived from:

a) A direct estimation from known costs and components,
b) Historical data analysis from typical applications (e.g. bills of quantities),
c) Models based on expected performance, averages, etc.,
d) Best guesses of future trends in technology, market and application.

According to picture 30 non-construction costs positive and/or negative externalities are items that usually are not included in LCC, being instead considered as part of WLC. They should be included if the stated initial purpose makes it necessary. For what concerns the private industry it is very important to include revenues (UNI 15686). Airport companies are definitely part of this category. Then for instance future income streams may be included in a WLC analysis but should not, generally, be present in an LCC analysis. Future income streams can form a subsidiary part of an LCC analysis in the form of negative costs.

Moreover, these points must considered in order to carry out the analysis (UNI 15686):

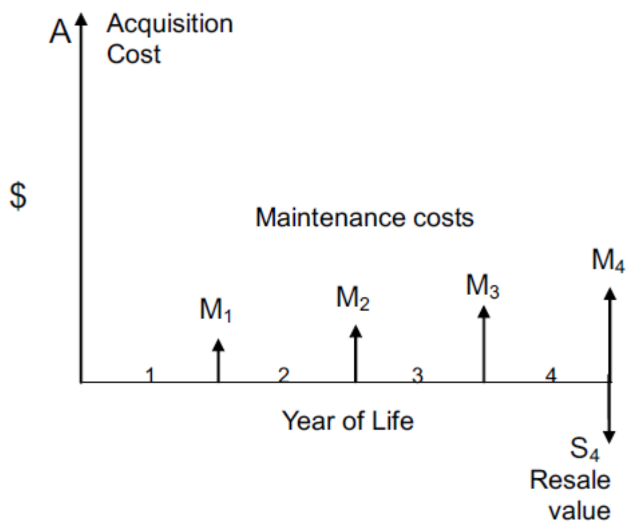
- Costs in an LCC analysis have to be clearly indicated in real vs. nominal, and present vs. discounted. In particular, real and discounted costs should be used.
- The period of analysis should be based on the specific project requirements, which may be over the life cycle of the asset.
- The type of discount rate, either real or nominal, should be distinguished.

6.3.1 LCC ANALYSIS

According to the definition by ISO 15686 part 1, the Life Cycle Cost methodology is a technique which enables comparative cost assessments to be made over a specified period of time, taking into account all relevant economic factors both in terms of initial capital costs and future operational costs. In order to go in deep with LCC, Present Value, discounting and Net Present Value must be introduced.

6.3.1.1 PRESENT VALUE

In LCC analysis, the Present Value method is applied in most cases. In short, the PV (Present Value) represents the amount of money that is to be invested today to pay for initial and future costs. The value of money will have decreased in the future and costs are discounted to a Present Value when the initial investment is made (Sterner, 2002). The first step to calculate the Present Value is to forecast a cashflow, which is simply a list of all the expenditures and incomes sorted by date of occurrence (Fawcett, 2011). A cashflow can be for ease of computation summarized in a cashflow diagram, as the one reported below. Then, through discounting, the Present Value is derived from the cashflow, by applying a percentage discount rate.



PICTURE 38 SAMPLE OF CASH FLOW DIAGRAM - SOURCE HASTINGS 2015

As a consequence, the Net Present Value (NPV) is the sum of the Present Values of a series amounts received or expended over a number of years (Hastings, 2015).

6.3.1.2 TIME PREFERENCE AND DISCOUNTING

Why to work with the concept of discounting? The answer lies in time.

Time is an essential feature when referring to a cashflow analysis. People give more value to a benefit received today than to one received in the future. Similarly, they believe a cost to be heavier if it must be payed immediately, rather than in the future. Time preference can be regarded as an empirical fact (Fawcett, 2011).

The discount factor is the proportion by which an amount is reduced to obtain its equivalent value one year earlier. Then it is:

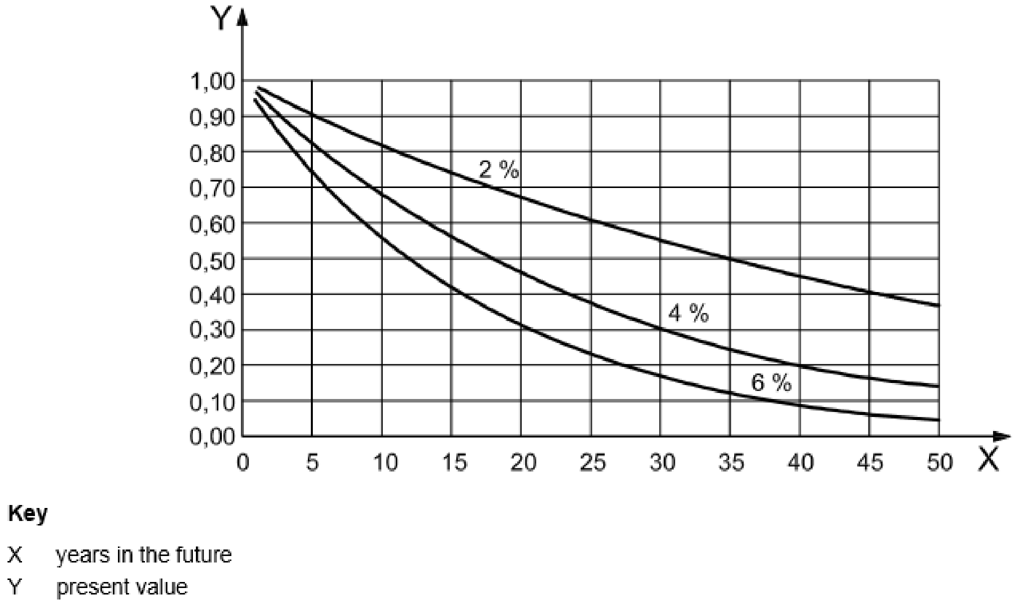
$$p = \frac{1}{(1+r)}$$

Where *r* is the interest rate.

Discount factors take into account:

- Inflation
- Time value
- Risk of the investment

The discount factor can deeply influence the final result of an LCC analysis, as shown in the diagram below, where different rates of discounting have been applied to the same cashflow.



PICTURE 39 PRESENT VALUE OF ONE MONETARY UNIT AT A DISCOUNT RATE OF 2 %, 4 % OR 6 % - SOURCE UNI 15686

6.3.1.3 NET PRESENT VALUE

Life Cycle Costing and Whole Life Costing can be both achieved through an NPV (Net Present Value). NPV becomes then the core of both an LCC and WLC analysis. The Net Present Value is the sum of the present values of a series amounts received or expended over a number of years. It is calculated as follows (Hastings, 2015):

$$NPV = V_0 + pV_1 + p^2V_2 + \cdots p^nV_n$$

Where:

V_n amount at year n

p discount factor

Then a general basic model (Sterner, 2002) for LCC is the following:

$$LCC = I_0 + \sum_{t=0}^{N} O * PV_{sum} + \sum_{t=0}^{N} M * PV_{sum} - S * PV$$

Where:

$PV_{sum} = \frac{(1+r)^t - 1}{r*(1+r)^t}$ $PV = \frac{1}{(1+r)^t}$

I_0	Initial costs
O	Operation costs
M	Maintenance costs
S	Salvage value
PV_{sum}	Present value sum
N	Length of study
t	Time variable
r	Discount rate

6.3.2 LCC IN EUROPE

Despite the potential of this methodology, in Europe there still is no specific legislation that requires life cycle costs to be taken into account (even in procurement procedures). Yet, according to the current and proposed public procurement directives there is the option to adopt LCC.

A number of European countries developed their own national standards for LCC, even before UNI 15686 standard arose; first among them were northern European countries. A notable example is Norway; its LCC standard NS 34546 is generally compatible with 15686 Part 5. Indeed, it influenced the development of the Joint Nordic Classification that was one of the models for the UNI standard (Davis Langdon, 2010). In the UK, a specific BS (British Standard) is used along with a number of guidance documents aimed for example at procuring construction and a requirement to demonstrate best value. In Germany, a Guide for Sustainable Building was implemented in March 2001 for application to all Federal buildings; cost estimations have to consider operating and maintenance costs as well as construction costs. Finland, Sweden, Ireland, Luxemburg and the Netherlands also have a policy or guidelines on LCC (TG4 Final Report 2003).

In the general framework for enhancing sustainability, Europe sees LCC as a crucial part of this whole. Many initiatives have been undertaken by the European Commission in order to make this methodology widespread and friendly to every industrial field, with the inclusion of the construction field. A part of these actions have been addressed to the GPP (Green Public Procurement), by virtue of its deep connection with LCC/WLC analysis.

Some of the main sources developed in Europe, that have been taken into account during the research path in order to better focus on LCC/WLC methodology are:

Literature			
Name	**Source/ Author**	**Description**	**Year**
LCC in construction	Task group 4	Connected to the European initiative "The Competitiveness of the Construction Industry" (1997), a task group has explored LCC in construction in order to make recommendations about possibilities of integration into European policy making. TG 4 addressed a common methodology for European application of LCC, before UNI 15686 Part 5 came into force.	1997
Joint Nordic Proposal for Classification of LCC	Norwegian Directorate for Public Construction and Property management	In 2001 a research and development project, LCC for Buildings and Civil Structures was undertaken in the Nordic countries. The project aimed at identifying a common model for LCC analysis; to promote the use of LCC analysis for building and constructed asset; to point out the environmental impacts.	2001-2005
Procurement Guide: Whole-life costing and cost management	UK Office of Government Commerce	LCC manual is a part of a ready-to-use series concerning procurement, addressed to British contracting authorities, named Achieving Excellence. This specific handbook indicates the main issues to be considered in order to effectively use an LCC in GPP	2003

		process.	
Life-cycle costing	Davis Langdon	Davis Langdon was commissioned to study the different national approaches to LCC. Then a European common methodology for life-cycle costing for constructed assets was developed. A number of case studies shows the possibility of implementation of this common approach.	2006-2007
UNI EN ISO 15686	International Standard Organization	This is the international standard dealing with service life planning of building components or buildings. It assesses the general framework, addressing the procedures for service life management, for performing Life-cycle costing, for considering environmental impacts.	2008
Buying Green	European Union	This is a EU ready-to-use guideline for public offices or any other individual interested into performing a procurement aimed at sustainability and then including an assessment of economic performance in the life cycle or in the service life. It indicates the main issues to be considered in order to effectively use an LCC in GPP process.	2015
European projects			
Name	**Source/ Author**	**Description**	**Year**
Project LCC-DATA	SINTEF - Stiftelsen for	The main barrier to a real application of LCC is usually the	2006-2009

	industriell og teknisk forskning ved Norges tekniske høgskole Norway	difficulty in collecting the necessary data. This project has the aim of reducing this obstacle and creating a European web-based database for benchmarking buildings' in-use costs	
Available at: https://ec.europa.eu/energy/intelligent/projects/en/projects/lcc-data			
Cileccta	Cileccta EU project members	This project has been financed by the EU and led by Norway. The aim was to bring together academics and industries all over Europe in order to develop a pan-European tool for LCC. Beside the set-up of an automatized tool for LCC, seminars and web didactic modules have been edited for training to the methodology itself and to the tool. The seminars have been attended for the research purpose.	2009-2013
Available at: http://cordis.europa.eu/project/rcn/93939_en.html			
Study on a LCC calculation tool	EC	European Commission, in order to enhance the use of LCC in GPP has financed a first study for the set-up of a spreadsheet tool for the calculation of LCC, tailored at the moment for electricity-using products.	2015-2016
Available at: http://ec.europa.eu/environment/gpp/pdf/SF_SSSUP_ELCC.xlsm			

6.4 THE NEW ITALIAN REGULATION PUBLIC CONTRACT CODE

In 2016 the new Public Contracts Code become law. While it does not specifically require a mandatory use of the LCC methodology in a tender process, it includes the issue in

articles 95 and 96, providing this option (not compulsory) and shortly describing the methodology. Article 95 – Contract Award Criteria, and Article 96 – Life Cycle Costing.
The Article 96 describes recall the contents of Directive 2014/24/EU and they clearly make reference to the European Union documents concerning the common methods for life cycle cost analysis.
Directive 2014/24/EU in particular recalls LCC at: Article 67 - Contract Award Criteria and Article 68 -Life-cycle costing. Article 67 reminds that the most economically advantageous tender should take into account a cost-effectiveness approach, such as life-cycle costing, that is shortly described in Article 68.

6.5 DATA COLLECTION

Life cycle costing has to rely on different inputs and information. The functional units of these different types of data usually are cost/unit.

Langdon (2011), Flanagan et al. (1987) and Boussabaine and Kirkham (2005) listed three possible categories of data sources for LCC. The source chosen for the original proposal of this thesis is highlighted in yellow:

Data source	Notes
Data released by the actors of the building process	These data can for instance be released by: • Suppliers and manufacturers; • Testing bodies; • Institutions and Association i.e.: Building Research Establishment (BRE), American Society of Civil Engineers, etc. (Langdon 2011)
Forecasting models	Data are calculated through mathematical models and statistical techniques. Suggested path in case the data is not available.
Historical data series	In case there is a funded system for storing data, related to the specific case object of analysis

Moreover, Langdon (2011) provides a list of possible sources of data, but mainly belonging to the UK area:

- Project agreed life expectancies (UK-BCIS - Survey of Life Expectancies)
- Manufacturers, Suppliers and Trade Associations l Research Organisations (UK - BRE, CIRIA, TRADA)
- Test Houses and Certification Bodies
- British and European Standards
- Research papers and reports
- UK - CIBSE Economic Life Factor codes
- UK – BCIS – Building Cost Info Service (BMI – Building maintenance info)
- UK - HAPM, BPG (part of BRE) and BLP Component Life Manuals
- UK - Occupiers Property Database (OPD)
- UK – BRE - Green Guide to Building Specification

In the case of airport companies, it is necessary to note that the **data are mainly produced within the airport operation management structure** and through internal human resources efforts. Indeed, airport companies rely on their own databases of historical series. This important element highly reduces the common criticalities connected to the collection of data usually being a barrier for the application of LCC. This is confirmed by the contents of the following paragraph.

6.6 APPLICATION OF LCC IN AIRPORTS

A life cycle view is necessary in airport planning, given the weight of the investments involved and the long-term perspective that affects the infrastructures, under evident uncertainty conditions. In construction industry, a life cycle approach has yet been included in the planning and design process with difficulty, and the regulatory framework does not make it compulsory, either. Similarly, in the airport planning and design phases, a life cycle approach is not routine work. There is an implicit reference to time and to future growth, due to capacity requirements and to the investments programme. But

there are not methodology and procedure for including Life Cycle Cost within project design process.
Nevertheless, some research efforts have indeed tried to include the LCC issue in the planning, design and maintenance activities.

LCC is included in the output report and methodology of the Project 07-07, which has been conducted within the Airport Cooperative Research Program (ACRP), a research programme proposed by the Federal Aviation Administration (FAA) and aimed at progress in the field of civil aviation. However, the main product is a step-by-step guide for leading professionals in a business driven design evaluation, rather than a cost oriented one. In this framework, in order to evaluate the options of refurbishments, renovation, replacement of terminal facilities, a four-step process is proposed. There is only one evaluation phase and the process should be located in the phase of masterplanning and strategic planning in order to be effective. LCC is included as one of the analysis to be undertaken in this very structured and complex evaluation model.

Another interesting case is the one of Toronto and Atlanta airport. Their airport companies have implemented the very first approach to Life Cycle management and to Total Cost of Ownership in the American framework of asset management. The two experiments have been reported in the International Transport Forum "Expanding Airport Capacity: Competition and Connectivity-the case of Gatwick and Heathrow", OECD (Organisation for Economic Co-operation and Development).
LCC was used as a methodology to guide terminal facilities management and maintenance. In both experiences, the main results have been:

- The effectiveness of a Total Cost of Ownership approach in facilities management
- The use of **internal data (historical databases)** and **internal** human resources and **competences** to finalize any cost analysis

LCC analysis has been applied in the US especially to airport runway pavements, as reported by the Applied Research Associates (2011) "Life cycle cost analysis for airport pavements Final Report" Airport Asphalt Pavements Technology Program. **Internal data** and resources and **in-house tools** make this application quite easy and effective. In this case LCC analysis is used to direct the choice of the best (wisest economic decision) airport pavement design in a life cycle perspective. The research project led to the identification of a methodology for pavements LCCA and a tool proposal for its implementation in current practice.

7. THE EVOLUTION OF LIFE CYCLE COSTING

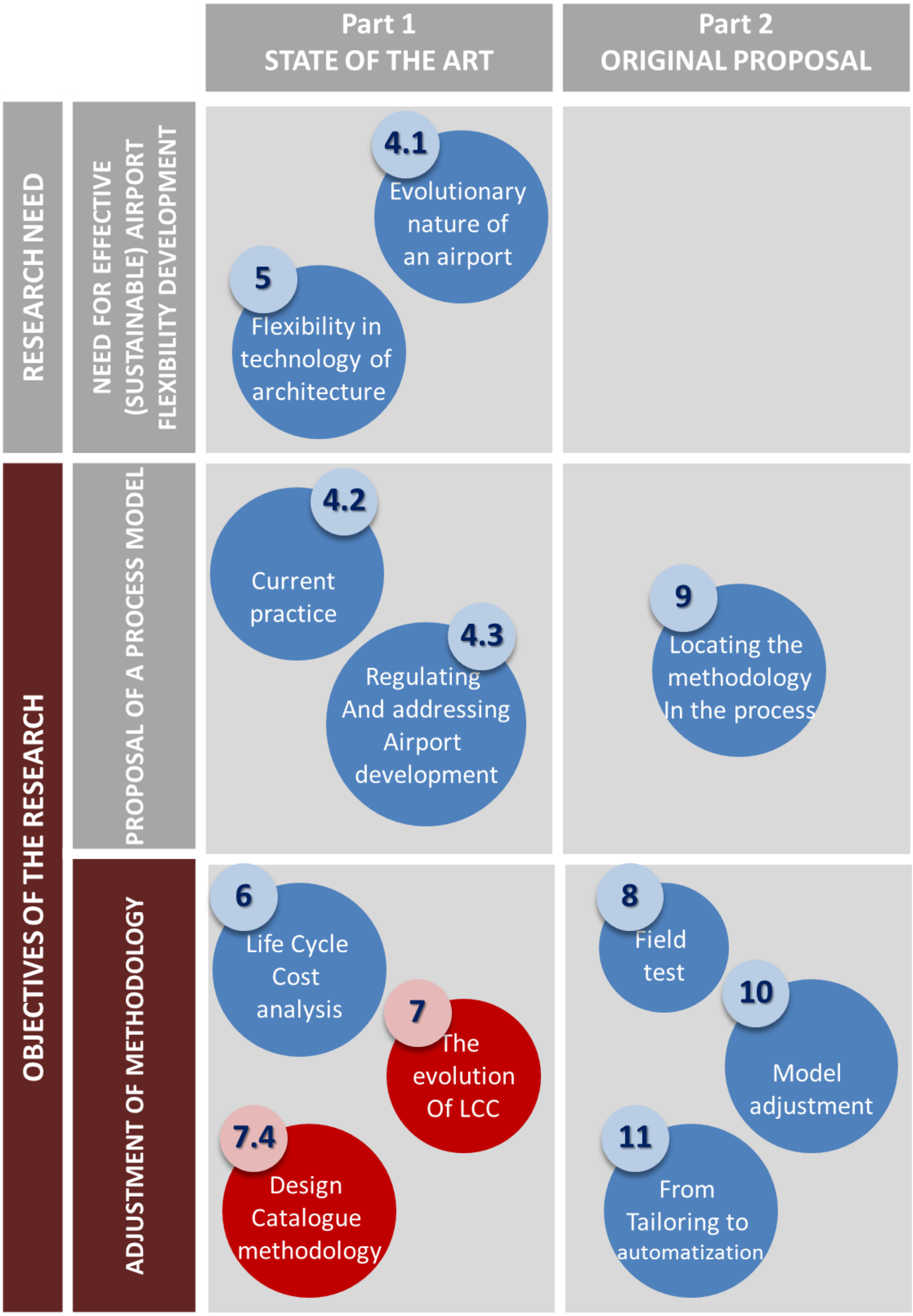
Chapter objectives

In Chapter 7 the reader will understand and learn:

- Uncertainty and flexibility issues in LCC
- The life cycle options concept
- The expected Net Present Value issue
- The basis of Design Catalogue methodology

Chapter Keypoints

Following chapter 6, this chapter introduces the issue of the "new generation" of LCC, that understands uncertainty and accepts a result that it cannot be determined but just expected. Accepting the certainty of uncertainty seems necessary to answer through "flexibility", in order to recognise the importance of lifecycle options, a concept deriving directly from economic real options.
In this evolution of life cycle costing, that accepts uncertainty and proposes flexibility, the Design Catalogue methodology is located.


Part 1
STATE OF THE ART
Part 2
ORIGINAL PROPOSAL
RESEARCH NEED
NEED FOR EFFECTIVE (SUSTAINABLE) AIRPORT FLEXIBILITY DEVELOPMENT
4.1
Evolutionary nature of an airport
5
Flexibility in technology of architecture
OBJECTIVES OF THE RESEARCH
PROPOSAL OF A PROCESS MODEL
4.2
Current practice
4.3
Regulating And addressing Airport development
9
Locating the methodology In the process
ADJUSTMENT OF METHODOLOGY
6
Life Cycle Cost analysis
7
The evolution Of LCC
7.4
Design Catalogue methodology
8
Field test
10
Model adjustment
11
From Tailoring to automatization

7.1 UNCERTAINTY AND FLEXIBILITY

Standard Whole Life Costing (WLC) is going to be overtaken be a new approach to WLC (Fawcett, 2006). WLC "**pretends**" to **take a snapshot today of something** that will happen, or better **that could happen**, in the future: indeed, the future is uncertain.

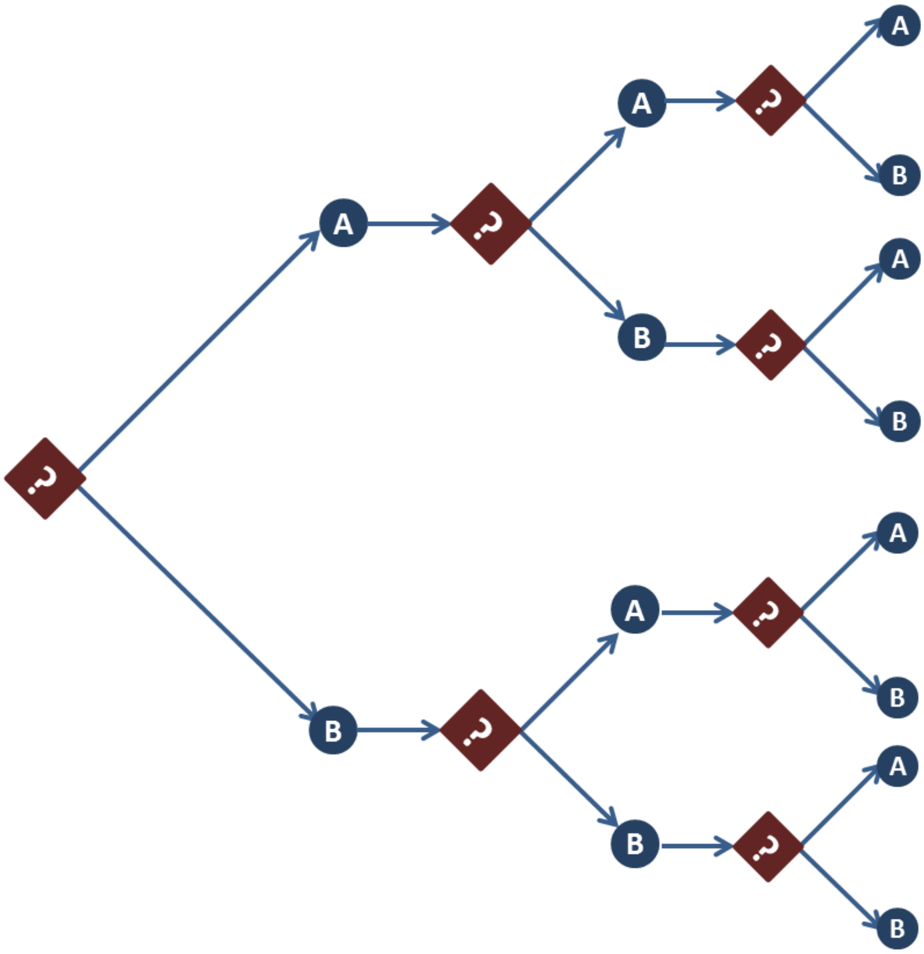
When using traditional WLC to support decision making decision makers rely on results of an analysis that may not be confirmed by future events. The new approach to life cycle costing considers that decision makers could make decisions in the future, relying on up-to-date information, rather than today.

Given this framework, Fawcett and Ellington examine the life cycle options approach to property and WLC building and use the expression "New Generation WLC". They underline that this departure is new and has a high potential, since it can generate a number of tools to make design decision making more effective.

The project design answer to a future scenario that is accepted as not predictable is in flexibility. Flexibility in design enables a system to change easily in the face of uncertainty (Fricke and Schulz 2005). If a construction product is flexible, it is easy and possible to make it change. Why? Because of Real Options: they provide the right, but not the obligation, to change a project in the face of uncertainty (Trigeorgis 1996).

7.1.1 LIFECYCLE OPTIONS

Today, the designer has to implement multiple project design options. Tomorrow, decision will be operated by managers and only one alternative will be chosen.



PICTURE 40 THE SEQUENCE OF FUTURE DECISIONS: LIFECYCLE OPTIONS – TXP GRAPHIC PROCESSING FROM FAWCETT 2011

What is an option? When making a selection, a manager decides between two or more **alternatives**. When holding an **option**, the manager defers the selection between alternatives to a later date (Fawcett, 2006). Options are possibilities of future decisions; then all alternatives are options until the final decision. Options are also referred to as "real options", borrowing this expression from finance.

Options thinking means that is necessary, when designing a new building or asset, to think not only of the physical asset, but also of the opportunities for further development. The opportunities for responding to future change (to new situations or new demands) **are lifecycle options** (Fawcett, 2006). Lifecycle options may not be exercised; usually constructive or technological redundancy provide the opportunity for further development in the future, but this does not necessarily happen during the life of an asset.

In particular, options give the designer and the decision maker the right, but not the obligation, to change a project in the face of uncertainty (Trigeorgis, 1996).

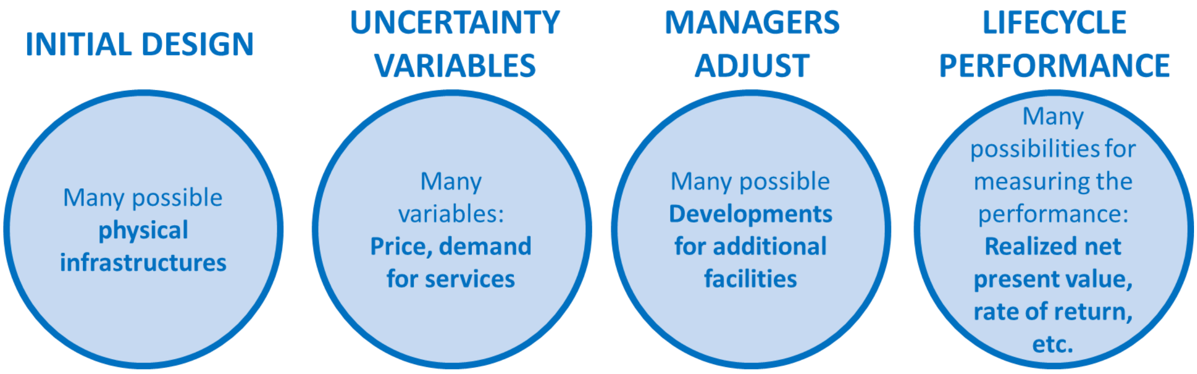
Options exist "on" a system, involving higher-level managerial decisions like abandoning, deferring until favourable market conditions, expanding/contracting/reducing capacity, deploying capacity over time, switching inputs/outputs, and/or mixing all the above (Trigeorgis, 1996). Options "in" a system are technical engineering components enabling options in deployment and operations (Wang, 2005). Options are characterized by a strategy (or type) and an enabler in design (or mechanism) (Mikaelian, 2011).

7.2 Including flexibility in design process

While there is the opportunity to include uncertainty in WLC computation, using it as a tool to inform and guide design, on the other hand research proposes ways to include uncertainty in design process and to actually make design teams face it.

Systems assets are characterized by a high degree of technical complexity, social intricacy, and elaborate processes fulfilling important functions in society (ESD, 2011). Dynamic socio-technical elements like markets, operational environment, regulations, and technology play a significant role in their success or failure (Braha, 2006). Given the long life of systems (+20 years), they face much uncertainty at strategic, tactical, and operational levels (Cardin, de Neufville, 2013).

A typical approach in engineering design and complex project evaluation is to simplify the full analytical problem: designs are often optimized for the most likely projection of major uncertainty drivers (Braha, Minai, and Bar-Yam 2006; Eckert et al. 2009). Typical project evaluation approaches do not account for the fact that system operators will react periodically to enhance the system performance (Trigeorgis 1996). The complexity given by the number of inputs and variables is represented in the picture below.



PICTURE 41 SUMMARY OF THE ANALYTICAL PROBLEM FOR DESIGNING COMPLEX PROJECTS– TXP GRAPHIC PROCESSING FROM CARDIN 2013

Given uncertainty of the future, **flexibility in design** enables a system to change in the face of uncertainty (Fricke, 2005). The flexible design of an asset allows decision makers to effectively face changing environments and conditions (de Neufville, 2011).

The lifecycle performance of an asset is significantly improved by including **design uncertainty and flexibility**. Still, designing for uncertainty and flexibility is a process not yet widespread in industry, which therefore needs a proper guidance (Cardin, 2013). Scientific efforts are being made to create support to guide designers in including flexibility in their projects.

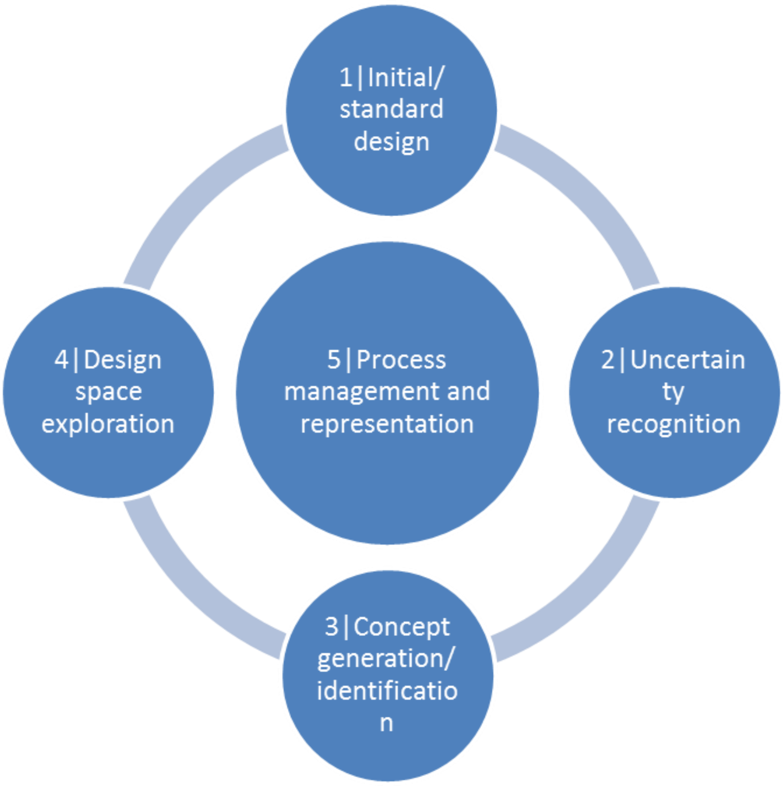
Nevertheless, it is not sufficient to desire flexibility in a system. One needs to enable it concretely in the design and to manage it in operations. (Cardin, 2013)

Cardin (2013) proposed a 4-step process, in order to support the design for flexibility, while recognizing uncertainty. The taxonomy is summarized in the picture below; it is defined in order to help designers with design process management, and it is further explored in each of the five items/steps.

The starting point for a flexible design, according to Cardin (2013), is an initial baseline design. It is defined by making reference to customer design requirements. Uncertainty issues can be then identified both through formal approaches, in case of presence of historical data, and by relying to managers' experience, in case historical data are not sufficient or reliable enough. In Cardin (2013) procedures and references for designers are properly explored and addressed by the author. Designers at this point have to understand where to focus design effort for flexibility by:

A) Generating strategies for flexibilities
B) Identifying where to embed flexibility in design and management.

Finally, designers examine the design space for the most valuable design configurations and management decision rules, in order to achieve the best lifecycle performance and more efficient designs. The process should be managed by the designer but at the same time inputs from many other disciplines are needed and a cooperative working environment is needed. Interaction between professionals by different disciplines can be implemented and exercised through specific activities and games.



PICTURE 42 OVERVIEW OF THE PROPOSED TAXONOMY OF DESIGN PROCEDURES FOR FLEXIBILITY – TXP
GRAPHIC PROCESSING FROM CARDIN, 2013

A proposal for flexibility design management from R. de Neufville is included, integrated and enriched by Cardin's taxonomy of design procedures for flexibility. The process proposed by de Neufville is explained and dedicated to designers too. It includes:

- Step 1: Recognition of the main uncertainty issues (forecasts are ***always*** wrong)
- Step 2: Identification of the solutions and of the elements which, together with design flexibility, can answer to uncertainties
- Step 3: Evaluation of different alternatives of flexible design
- Step 4: Planning for possible implementations of the flexibilities

Flexibility brings benefits in lifecycle performance which are measurable through an economic assessment, specifically the Expected Net Present Value (ENPV)

7.3 EXPECTED NET PRESENT VALUE

The previous chapter expanded upon Net Present Value. Now, Expected Net Present Value (ENPV) must be introduced. Expected Net Present Value adjusts to uncertainty by calculating NPVs under different scenarios and then by probability-weighting them to obtain the most likely NPV.

Instead of relying on a single NPV, ENPV is calculated for a number of scenarios. Then, the probability of occurrence of scenarios is estimated. In the end, NPVs are weighted in relation to their probability. The expected NPV is the sum of the weighted NPVs:

$$ENPV = \sum p * NPV_{scenario}$$

Where: NPV scenario is the NPV in a specific scenario; p is the probability of occurrence of each scenario. To consider uncertainty in scenarios renders the eNPV more reliable than the traditional NPV.

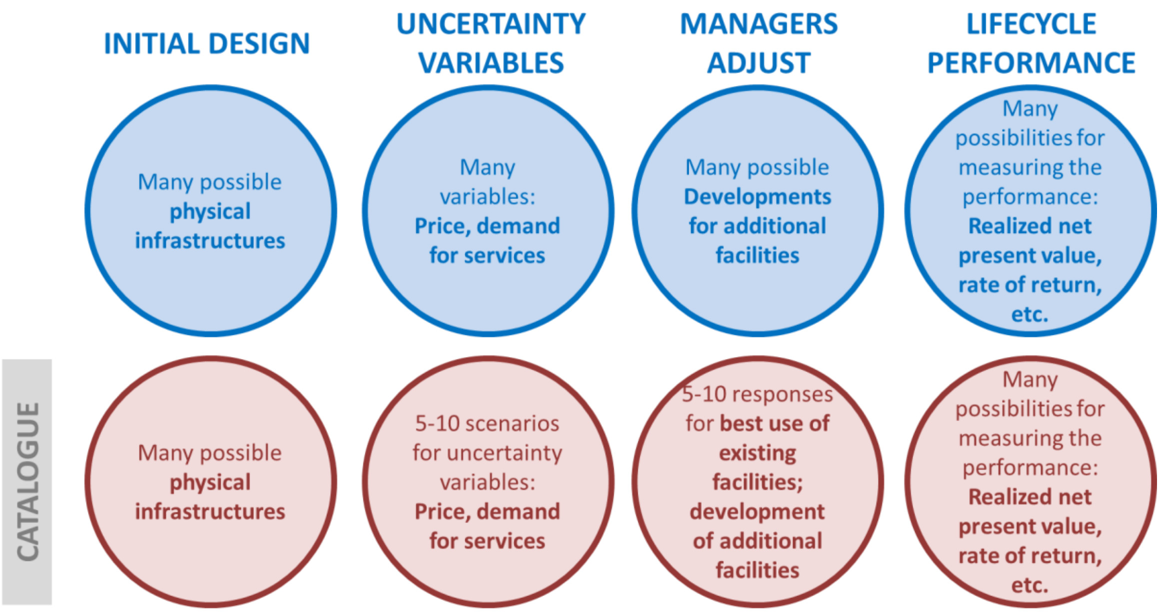
7.4 Design catalogue methodology

The analysis of the lifecycle performance of a system under uncertainty consists in producing design outputs for each possible scenario. This means that a huge effort is required to gain flexibility in design, in terms of time and analytical resources, which makes this technique not widely used.

Cardin and de Neufville (2013) addressed the issue of including flexibility in design by proposing a set of five operating plans for the lifecycle of a system that run quite well with a range of uncertainty scenarios. The Design Catalogue approach is addressed to designers, in order to achieve an explicit consideration of flexibility and effectiveness in lifecycle performance of design, with efficiency in time and resources effort.

This methodology has been applied to a specific case study (a parking garage) by Cardin e de Neufville. The methodology and the steps made during this application have been described in their recent literature, and are being summarized in this paragraph. The Catalogue methodology tries to come up with uncertainty and with the evidence that a “clear picture” can never be given on the future but possible “future scenarios” may well be available. Then it is being recalled in Part 3, where the original proposal is described, consisting of the adaptation and then application to an airport terminal of the methodology itself.

The proposed methodology is a simplification that allows the inclusion of flexibility in design. It relies on a representative range of possibilities small enough to be manageable analytically, and broad enough to enable a more informed analysis of the design problem (Cardin, de Neufville, 2013). In particular, the Catalogue methodology produces a limited number of operating plans; that is to say, possible combinations of variables and decisions that managers could make to manage the system over its lifecycle. The operating plans are produced starting from a limited number of uncertainty scenarios: one operating plan for each scenario. In this way, the catalogue contains the flexible design alternatives best facing each scenario.



PICTURE 43 COMPARISON BETWEEN FULL ANALYTICAL PROBLEM VS A DESIGN CATALOGUE APPROACH FOR DESIGNING COMPLEX PROJECTS – TXP GRAPHIC PROCESSING FROM CARDIN 2013

Cardin (2013) proposes and analyses additionally a specific case study. This methodology works in five steps:

1. To develop a basic model for measuring lifecycle performance:
   This step consists in developing a basic model for assessing the quantitative lifecycle performance. The Net Present Value model is used and a model is proposed for a specific case study, which relates design variables and design parameters. In particular: NPV is defined as the sum of discounted cashflow; revenues and capped by capacity of the system, where both capacity and demand are defined. Costs are considered as the sum of initial costs and operation.
2. To find representative uncertainty scenarios affecting lifecycle performance:
   The designer should address a suitable set of scenarios representing the major uncertainty sources for the lifecycle performance. The possibility to expand capacity is addressed in the case study as the main flexibility requirement; the demand growth is therefore the main uncertainty source. The scenarios defined in the case study are five, representing different demand growths, alongside the most likely deterministic demand scenario modelled in step 1. At the moment

there is no systematic approach to select a representative set for uncertainty scenarios, besides relying on expert inputs.

3. To identify and generate potential sources of flexibility in design and management. The definition of sources of flexibility consists in anticipating the possible decisions that could be made by managers during the lifecycle of the asset. This means formulating decision rules and design variables that simulate the evolutionary nature of the asset. "Design Space Exploration" refers to an abstract combinatorial space, made of physical design variables and decision rules to face uncertainty and exercising flexibility.
   Decision rules and design variables are summarized in a design vector for the case study of a parking garage: [a1-4, a9-12, a17-20, dr, ft, f0]. The components are described below:

TABLE 5- FLEXIBILITY VECTOR COMPONENTS IN CARDIN, DE NEUFVILLE (2013) CASE STUDY

Component	Typology		Description
	Decision rule	Design variable	
a_{1-4}	X		Expansion allowed in years 1-4?
a_{9-12}	X		Expansion allowed in years 9-12?
a_{17-20}	X		Expansion allowed in years 17-20?
dr	X		Years with lack of capacity (demand exceeds capacity) passed before expanding?
f_t		X	Number of floors added in expansion?
f_0		X	Number of initial floors?

These decision rules represent alternatives to risk-averse, risk-neutral, and risk-seeking decision-makers. Picture 43 shows the values that decision rules and design variables can assume at different levels.

4. For each uncertainty scenario, find the most appropriate flexible operating plan and construct the catalogue using the aOFAT (adaptive One-Factor-At-a-Time) fractional factorial algorithm.

The aOFAT sequence by Frey and Wang (2006) is used to define the five operating plans. The initial design and exploration sequence are selected randomly; the baseline operating plan is described for the specific case study by the vector [a1-4, a9-12, a17-20, dr, ft, f0] = [No, No, No, 3, 3, 6]. The design catalogue defined in the sequence, in this case study, is:

DVs and DRs	Op. Plan 1	Op. Plan 2	Op. Plan 3	Op. Plan 4	Op. Plan 5
a_{1-4}	Yes	Yes	Yes	Yes	No
a_{9-12}	No	Yes	Yes	Yes	Yes
a_{17-20}	No	No	No	No	Yes
dr	3	2	2	2	4
f_t	2	2	2	1	1
f_0	6	6	4	4	4

PICTURE 44 EXAMPLE OF DESIGN CATALOGUE – SOURCE: CARDIN 2013

5. Assess lifecycle performance improvement – if any – using the design catalogue as compared to the baseline design under uncertainty:
   This step simulates the ability of the system operator to choose between different flexible operating plans, based on demand observations.

7.5 PROCEDURES TO GENERATE FLEXIBILITY

The flexibility in the final product should be achieved in the early phase of concept ideation; then it should be maintained throughout the project design development. With simple and intuitive procedures that include flexibility in the concept idea the entire lifecycle performance of systems can be improved.

Many studies were conducted on concept generation processes, whose principles can stimulate designers to explore different perspectives on the design and its potential uses. According to Cardin (2012) the effort in classification of concept generation processes led to:

❖ Shaw et al. (2000; 2002) classified Idea Generation (IG) techniques either as intuitive or logical, E.g.:

  - Free undirected brainstorming (Osborn 1957) is an example intuitive germinal technique
  - TRIZ (Altshuller 1973) is a logical, history-based approach.
- The review by Knoll and Horton (2010) shows that ideation techniques can be classified in accordance with three cognitive principles: Analogy, Provocation, and Random changes of perspective. Analogy uses existing knowledge to generate new ideas. Provocation challenges the underlying assumptions of the creative task. Random relies on external stimuli unrelated to the task.

Later, Cardin et al. (2012) explored the opportunities afforded by making a guided brainstorming addressed to generation of flexibility. This procedure would improve anticipated lifecycle performances and the satisfaction of designers. Experiments with a variety of participants have been conducted; participants worked on a simplified system design problem.
An experiment compared the current designers' training in flexibility with a specific training in the same field given to a limited number of them. It consisted in a short but effective lecture about the necessity of including flexibility in design. Afterwards, a free ideation procedure was compared to a guided one.

The results was measured through the number of flexible design concepts generated; their anticipated lifecycle performance improvements; the designers' satisfaction with the procedure. The final result suggested that:

- A ***guided procedure for flexibility*** can generate more flexible design concepts than a usual free and undirected brainstorming
- These generated concepts give a better lifecycle performance, ***up to 36% more than a common benchmark design***
- An ***explicit training on flexibility*** is effective on design procedure; and it makes designers better acquainted with flexibility.

In particular, the focus of the whole experiment was on:

- **Education to flexibility**

The training lesson was esteemed by designers involved in the experiment a good starting point and an easy tool to generate lifecycle performance in design

- **Ideation mechanism used to stimulate creativity**

  Guided brainstorming was appreciated; it consists in a structured process to direct the creativity of designers

7.5.1 GUIDED BRAINSTORMING

The experiment carried out by Cardin et al. (2012) proposed a structured brainstorming. The designers involved have been directed through design concepts formulation and through thinking and discussing on the following topics that have been posed and highlighted to them in this specific order:

1. Identification of sources of uncertainty
2. Identification of the possible strategies that could enable the system to change and adapt to the uncertainty scenarios addressed before
3. Identification of design solutions that could enable the required flexibility
4. Identification of possible decision about the possibility of exercising said flexibility during the life of the asset

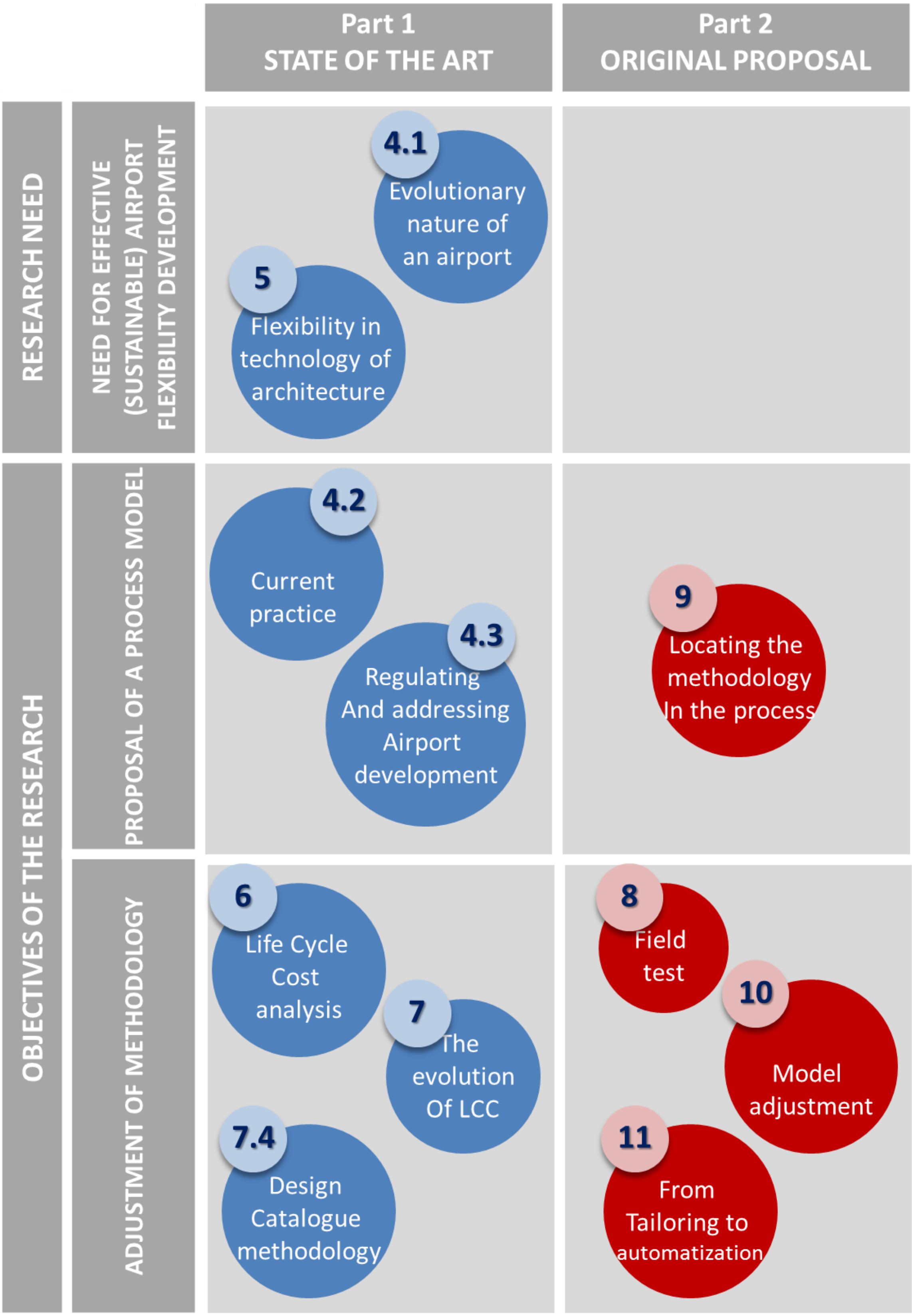
PART 2

ORIGINAL PROPOSAL

In short…

In Part 2 the reader will understand and learn:

- The background of the field test
- The proposal of a process model for including a life cycle perspective for flexibility achievement
- The tailoring to the airport terminal test case of the algorithm to be used in the Design Catalogue methodology
- The implementation of it into a tool
- The test of the tailored algorithm and of the tool using the input data collected concerning the test case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8. Field test

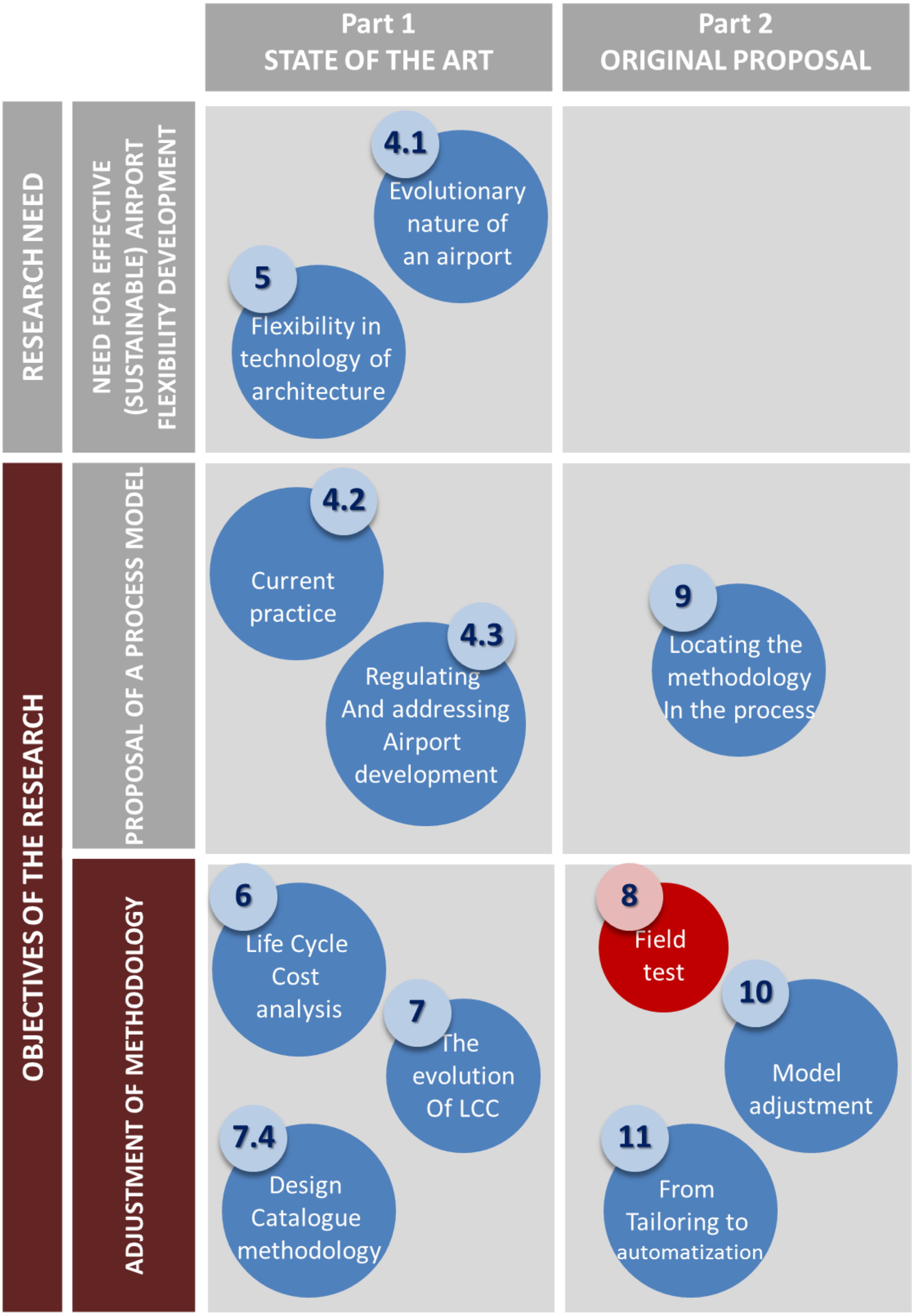
Chapter objectives

In Chapter 8 the reader will understand and learn:

- The main issues of the chosen test case

Chapter Keypoints

The field test case of a new terminal has been chosen. The test case is planned to accommodate up to 50 million passengers at the end of works, through a layout distribution articulated in an “H” shape.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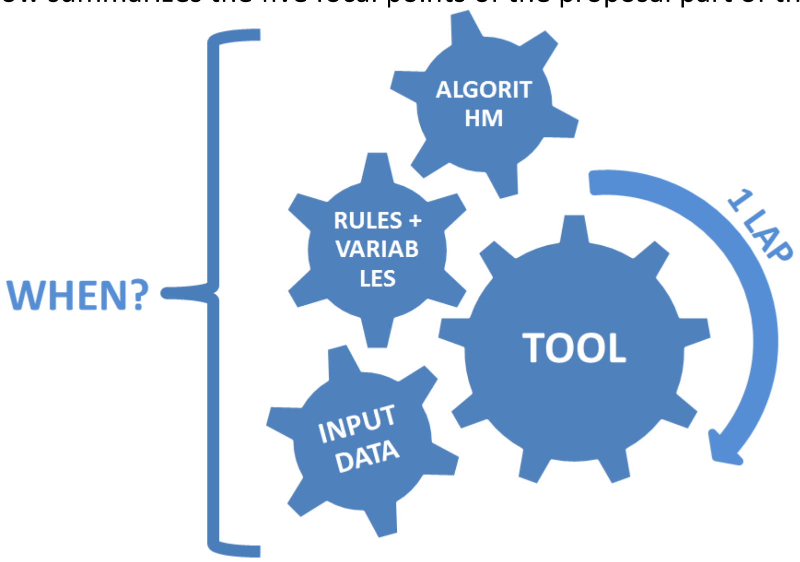
8.1 SYNOPSIS

Starting from the theory of the Catalogue, the research proposal has been managed through five core issues:

- A set of algorithms has been proposed, tailored on a specific test terminal, as a model for measuring the lifecycle performance of the test terminal itself according to the Catalogue.
- Beside, a set of decision rules and planning variables, tailored on the test terminal, has been studied. These two focal points can be identified in the first and third steps of the whole procedure of the Catalogue listed and described in Part 1.
- Moreover, a data collection has been managed, concerning the specific test terminal and the four kind of necessary information for measuring its performance: system data; traffic data; revenues; costs.
- Then, a tool was set up, based on the algorithms, rules and variables tailored before. In order to complete it, 1 lap of the tool itself has been necessary, in order to adjust it while being created. For the completion of the lap the data collected before were used as inputs.
- The use of the Catalogue methodology, and then the use of the proposed model and tool, have been located into the process: a concept of process model has been studied.

The synopsis below summarizes the five focal points of the proposal part of the research:



8.2 WHY THIS OBJECT FOR THE FIELD TEST?

The effort for tailoring the model, to be used for measuring the performance, was carried out on a specific Italian airport terminal test case. Equally, the proposal of the set of decision rules and planning variables and the data collection were all implemented according to this specific test terminal, that this chapter introduces.

The choice of this specific object for the field test was informed by:

- The opportunity to learn by field experience with accessibility to data and visibility on and a step-by-step monitoring of the traditional planning process adopted
- This is the only case of a new Italian airport terminal to be built *ex novo*, thus being suitable for the research purpose and coherent with the research objectives
- The terminal development process of the test case is currently at the planning phase: the research explores the potential of locating the use of the whole Catalogue methodology at said phase; then the opportunity to observe closely this phase of the process is even more interesting
- This terminal is planned for an airport infrastructure which is the 7th in Europe and the 1st in Italy for passenger traffic. This makes the simulation representative of international hub infrastructures, and more significant than minor Italian cases. In particular the model implemented for the Catalogue computation, explained in Chapter 10, includes items of cost, revenue and infrastructure inputs (e.g.: m^2 of commercial areas, energy consumption, etc.) that are common income and cost items in every terminal operating and processing passengers and Commercial Aviation flights. While the choice of this object makes easier future generalizations for said reasons, anyway generalizations of the model should be explored through a scientific validation, starting from the results of this research through further research effort, as explained in Part 3.

8.3 General introduction of the object of the field test

The new airport terminal that has been considered is currently at the planning phase of the whole process. It is going to increase the capacity of an existent terminal system composed of four terminals and seven boarding areas. The test terminal is going to be built in a new area close to the current infrastructure and it will be provided with all necessary civil and urbanization works: access roads, related aprons, two more runways, a people mover.

The first driver of any planning activity are passenger traffic demand forecasts, as explained in Part 1. The traffic is the main input to the performance evaluation in the life cycle, given it is the uncertainty factor. The scenario adopted in order to set up the tool (and then run the life cycle model) is a linear scenario. It consists of a linear interpolation of the main traffic forecasted values and represents a linear growth coherent with the growth forecasted for the test terminal. This issue of traffic inputs and of tool set up are further explored in Chapter 11.

The test terminal was planned with an "H" shape, with a central processor and four piers. This shape has been adopted because it ensures the best effectiveness in airside operations, given the planned location for the new runways and aprons. Moreover it ensures the best land use and a good expandability.

The environment inside this "H" box, the Units of Airport Terminal and the envelope itself are going to be designed properly in the further design phase, in accordance with the requirements addressed by the contracting authority. These requirements have been pointed out in the planning phase and include: capacity of each UAT (Unit of Airport Terminal); comfort of users; environmental sustainability; comfort of elderly passengers and PRM (Passengers with Reduced Mobility); rationality and ease of passengers flows, etc. It becomes apparent, then, that the final user satisfaction is the main aim of the entire planning activity.

Flexibility -or better expandability- has been identified as a desirable requirement, during the decision process of the planning phase. But flexibility has not been clearly addressed given expandability was sought without a proper method. The gut feeling and the experience of managers (Fawcett, 2011) was the main guide even in this case. No specific reference to uncertainty of future passenger's demand has been considered in planning the requirements to address and direct the further design. Only an articulation in two different building phases has been set up, in order to cope with changes in current forecasts following intuition of high management based on today trends. During the research period it has been possible to have visibility on the planning decision process of the test terminal and this information was collected. In the end the two phases were thus defined:

- Phase 1: From 2028 to 2034, the terminal will guarantee a capacity for 35 MPPY (Million Passengers Per Year)
- Phase 2: From 2034 to 2050, the terminal will guarantee a capacity for 50 MPPY.

The total capacity that the new terminal will have to guarantee has been established during the planning phase. Capacity has been specifically defined for each unit of the terminal, in order to provide the designer with clear-cut guidelines. The demand that the capacity will have to respond to was fixed on the basis of the definition of Level of Service (LoS). It sets a standard for the performance required by each environmental unit, in compliance with IATA (International Air Transport Association) international standards. In particular, the planning activity has disposed that the test terminal will ensure 535.000 m^2 of gross floor area at the end of the second phase. Each UAT has been further properly dimensioned for the forecast number of passengers and in accordance with the requirements of the activities to be accommodated.

8.4 BOUNDARIES OF THE FIELD EXPERIENCE

Chapter 10 and 11 describe the tailoring of the model to this specific test terminal; the data collection; the set up of the tool. Making reference to their contents, this paragraph explains the reader the borders and boundaries of this field application.

The field experience has been necessary to:

- understand and study the planning and design process of an airport terminal, with reference to the state of the art;
- collect data, by having access to databases and documents, and by having the possibility to take information directly from the professionals;
- have access to traffic historical data and forecasts;
- monitor the ongoing planning process and learn from the main decisions of the airport company about the new terminal development.

The field experience does not allow any direct comparison between an approach through Catalogue and traditional one (adopted by the company), since the planning process is still ongoing. Then, the field experience does not allow a comparison with the real final behaviour at the end of life, given the test terminal has to be built and a comparison could be done at the end of its lifecycle. The field experience has not consisted into a real interference into the decision process of the airport company, since the test terminal is a huge investment for the upcoming years and every decision about it is informed by a dedicated team of professionals and consultants, and then taken by the high management of the company and its holding group.

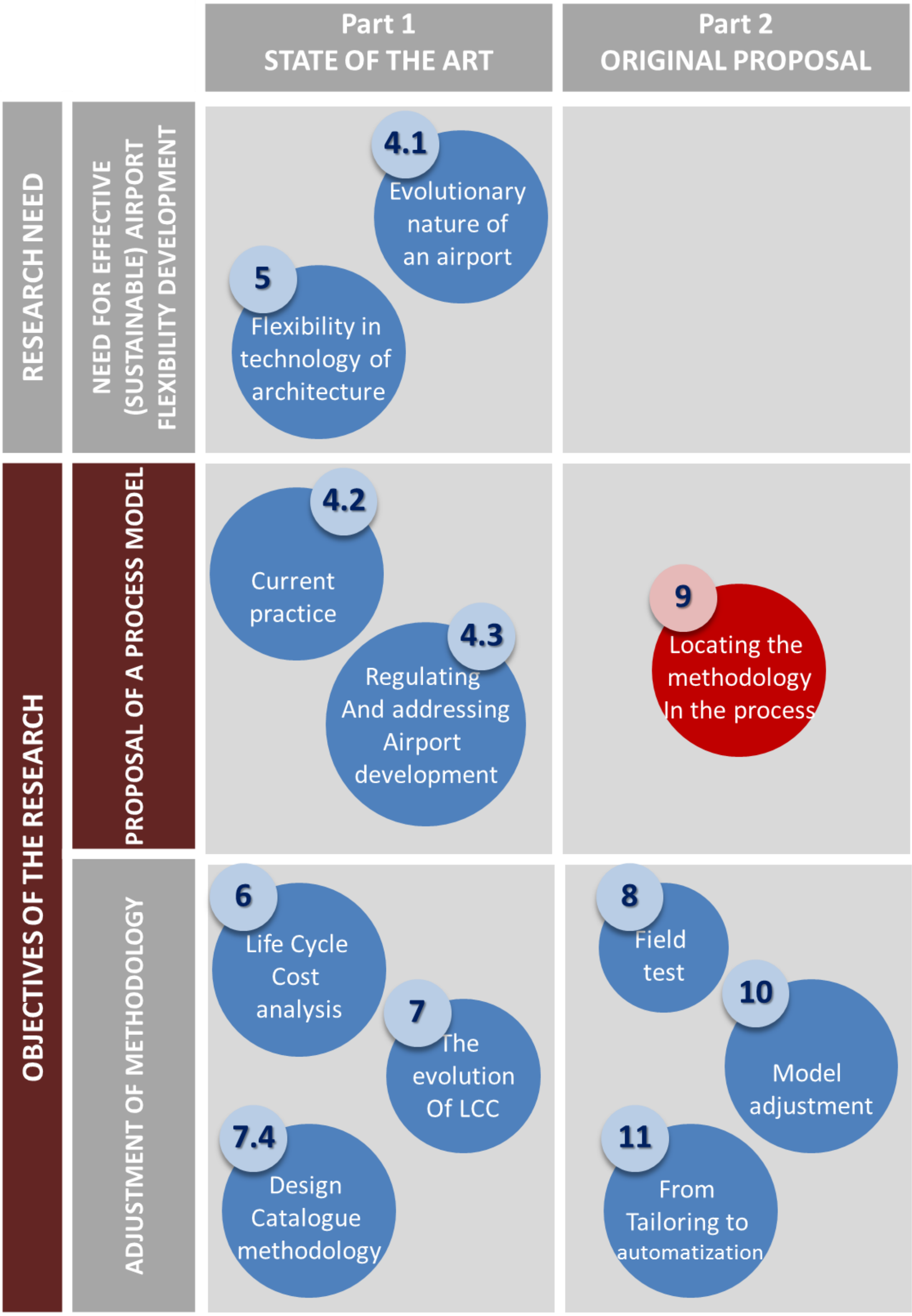
9. LOCATING THE METHODOLOGY IN THE PROCESS

Chapter objectives

In Chapter 9 the reader will understand and learn:
- The main characteristics of the process concept proposed by this research, referred to the airport terminal development

Chapter Keypoints

The Catalogue methodology can aid both professionals and managers approaching the planning phase toward the definition of terminal design requirements. Indeed Life Cycle Costing can help in early conception identifying the main issues of a proper design brief, for achieving flexibility in the final product. Furthermore, time and cost items can be the inputs for the later phases of the process, according to the adoption of advanced tools for design process management (e.g.: 5D BIM).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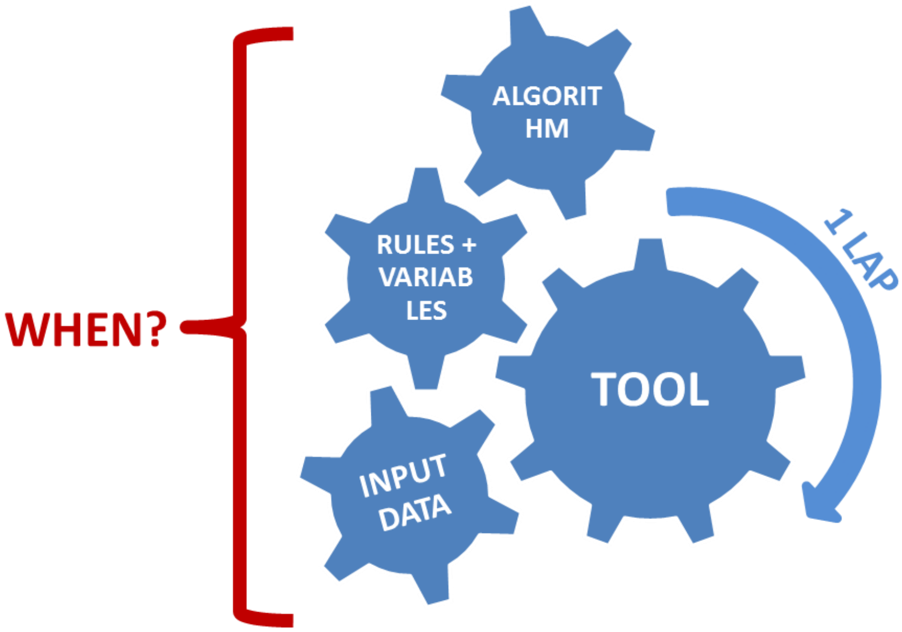
9.1 Introduction

This chapter aims at proposing a process concept for the introduction of a lifecycle perspective, in order to maximize cost effectiveness of the asset, starting from the planning activities and ending with the end of the asset's life. This concept locates the use of the Catalogue, more in general, and then the adoption of the model tailored in the test case, as integral part of the Catalogue methodology, to be implemented by the final user. The synopsis recalls the main issues of the original part of this research; in red the issue of this chapter:



The Design Catalogue, introduced in Part I, is a methodology to face uncertainty in the life cycle of infrastructures. Therefore, in chapters 10 and 11 it is going to be tailored to a test terminal and its life cycle. Why is it interesting to test this methodology out on airport terminals? Because it highlights elements of uncertainty; it defines items enabling flexibility during the lifecycle of the infrastructure; lastly, it produces a Catalogue of effective project design answers to probable uncertainty scenarios, making cost effectiveness a parameter of evaluation.

The Catalogue methodology facilitates the definition of design requirements and performance inputs in order to include flexibility in the new architectural product. From the point of view of both the planner and the designer, the application of this methodology can function as the starting point to design an infrastructure that can cope with possible unexpected changes.

First, this paragraph properly locates the use of Catalogue methodology during the pre-construction, giving the Catalogue a precise role in the whole process, with reference to airport terminal planning and design and its actors.

The Catalogue also provides aids and inputs to the operation phase, since operative plans are, by definition, tools for facing the unexpected changes to infrastructure management while the architecture product becomes operative.

Lastly, the next pages will also include the proposal of a starting point for the integration of time and cost effectiveness in the whole life cycle management, as a cause for reflection and further research.

9.2 When and For Which Purpose?

Airport terminal design management starts at planning phase, as anticipated in Part 1. In the planning phase, after the definition of the general framework of all the future works needed in the whole airport, the contracting authority defines the requirements of every single work, including those performed on terminals. At this phase –planning - the design brief, that is the main document addressing the designer and regulating the relationship with the contracting authority, is defined.

As a matter of fact, the life cycle of an airport terminal starts when the air transport demand compels the airport company to devise a new planning action. At this stage, every capacity and architectural input, together with times and costs expected for construction, is included in the design brief by the airport planner. The airport planner acts together with and on behalf of the contracting authority. The design team receives the planning inputs contained in the brief and develops the design documentation. **Errore. L'origine riferimento non è stata trovata.**5 summarizes the main items of a traditional standard process in a flow chart.

Lately, airport companies have begun to require Building Information Modelling (BIM) in design. Airport companies are indeed becoming increasingly receptive to the benefits of BIM in the design and construction phases, and, above all, in the operation phase. When the contracting authority requires from the designer the use of BIM technology, a 3D BIM model for construction is delivered to the contractor. It must be updated and integrated with any information acquired on the construction site. The final 3D model, as it has been improved with all the new information, becomes the basis for the infrastructure and life cycle management by the airport company within the operation phase.

The current practice in airport terminal design management is summarized in the flow chart below. Alongside each stage the proper output document is identified.

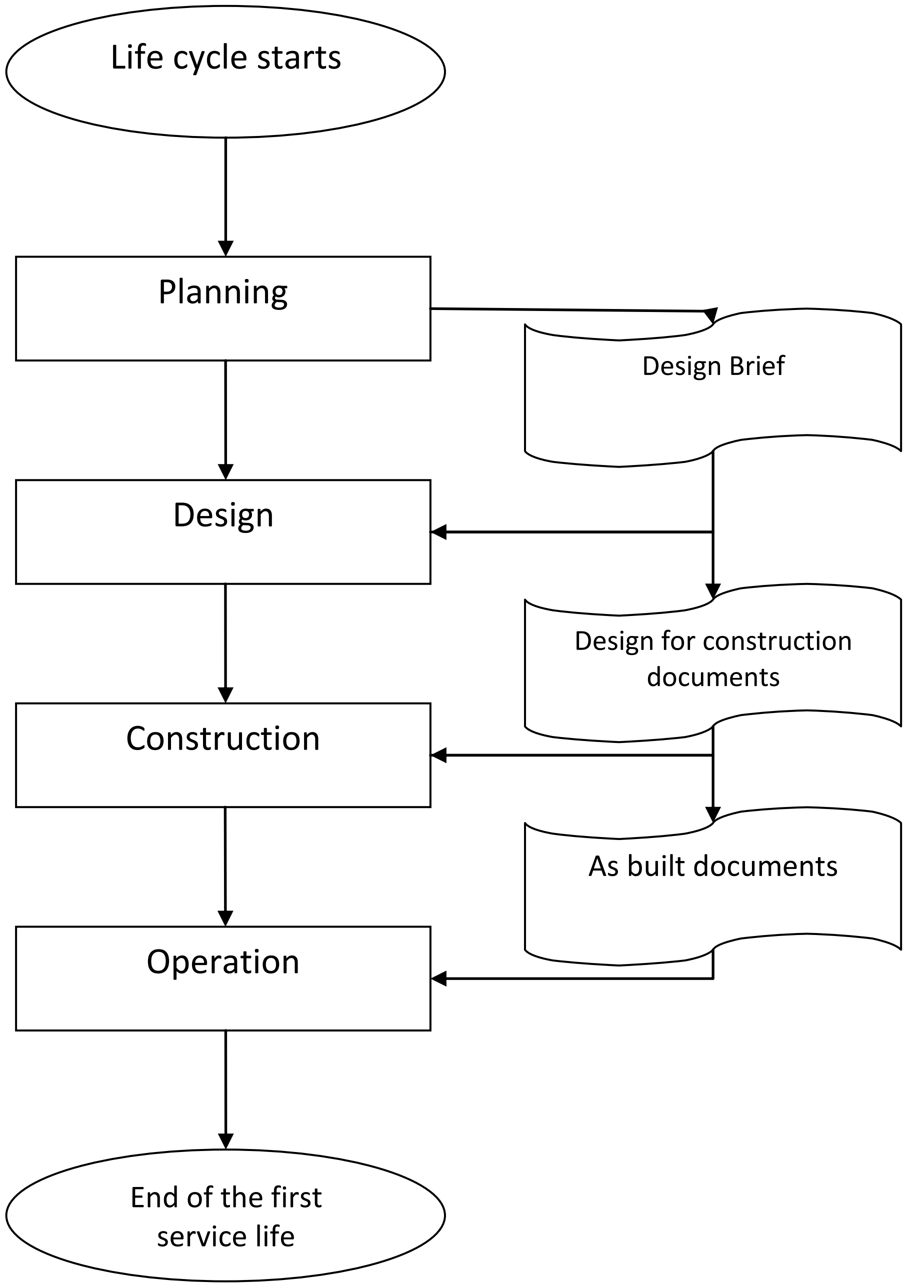
With reference to this framework, the Catalogue methodology should be applied to airport terminal design process during the early **planning phase**.

In particular, in keeping with the Italian planning process and its regulation throughout the Economic Regulatory Agreement (ERA) phase, the Catalogue would be a helpful tool in the definition of:

- Development plan / Masterplan
- Design Brief
- Feasibility study
- Environmental Study scenarios
- Interventions timing
- Other

Given the correlation with the early planning phase and the research aims when applying said methodology to terminal architectural design, it would be more correct to rename “Design Catalogue” as “Planning catalogue”.

In order not to create an overlapping of terms, a clear difference will be maintained from this moment on between design and planning. Planning Catalogue is, for all intents and purposes, a tool for airport terminals planning management. It follows that “Design Catalogue” will be from now on named “Planning Catalogue”.



PICTURE 45 GENERAL FLOW CHART OF THE STANDARD PROCESS – TXP ORIGINAL GRAPHIC ELABORATION

9.3 WHICH CONNECTION BETWEEN PLANNING AND DESIGN THROUGH THE CATALOGUE?

As stated in the previous paragraph, the Catalogue methodology should be applied at the planning phase.

By introducing the Catalogue methodology into airport terminal design management and exploring its potentials, in accordance with the process identified in the previous flow chart (**Errore. L'origine riferimento non è stata trovata.**5), some integrations to the process are now proposed and are shown in Picture 466.

IN PART 1, THE RELATIONSHIP BETWEEN AIRPORT TERMINAL PLANNING AND DESIGN WAS ACCURATELY DESCRIBED. AN AIRPORT TERMINAL PLANNING ACTION IS IN FACT THE VERY FIRST STEP IN THE DESIGN OF A TERMINAL. INDEED, BY PROVIDING THE DESIGN TEAM WITH ALL THE INPUTS AND FORMULATING ALL THE PROPER REQUESTS, THE FIRST ARCHITECTURAL DESIGN CONCEPT IS ADDRESSED; THE FIRST PLANTS AND CIVIL WORKS EVALUATION IS MADE. THIS ENTAILS THAT THE APPROACH TO LIFE CYCLE DESIGN MUST BE APPLIED IN THIS PHASE, IN ORDER TO BENEFIT OF THE MAXIMUM EFFECT AND SAVING THROUGH THE LIFECYCLE, ACCORDING TO THE DIAGRAM IN

Picture 34 and Picture 35.

The output of a Catalogue has been explained in Part 1. Then for the purpose of this chapter, the Catalogue approach supplies the planner and later the designer with a clear picture of the possible future evolutions and configurations of the terminal, in relation to different probable traffic scenarios. The approach also estimates the possible timing of future configurations.

By applying the methodology, the airport terminal planner will be able to define a number of clear inputs to the design, in order to ensure an efficient behaviour of the final operating terminal. The catalogue will be translated into design requirements and technical specifications for the project design layout, plants, materials, production addressing the flexibility need.

The output of the catalogue methodology should be then elaborated, finalized and included in the design brief (*Documento Preliminare alla Progettazione - DPP*). This is the main input to the design phase and it should contain any requirement for flexibility by architectural design, flows and capacity allocation, costs and timing management. Such document, enriched with flexibility requirements that planners could deduce from the catalogue output, will be from now on referred to as “Integrated Brief”.

A proper Integrated Brief gives a complete summary of the requirements to the designer. A 5D Building Information Modelling could be adopted in order not to lose information about times and costs and to integrate the catalogue planning options within the whole lifecycle, starting from the design phase until operation.

A 5D BIM is a 3D BIM model linked to:

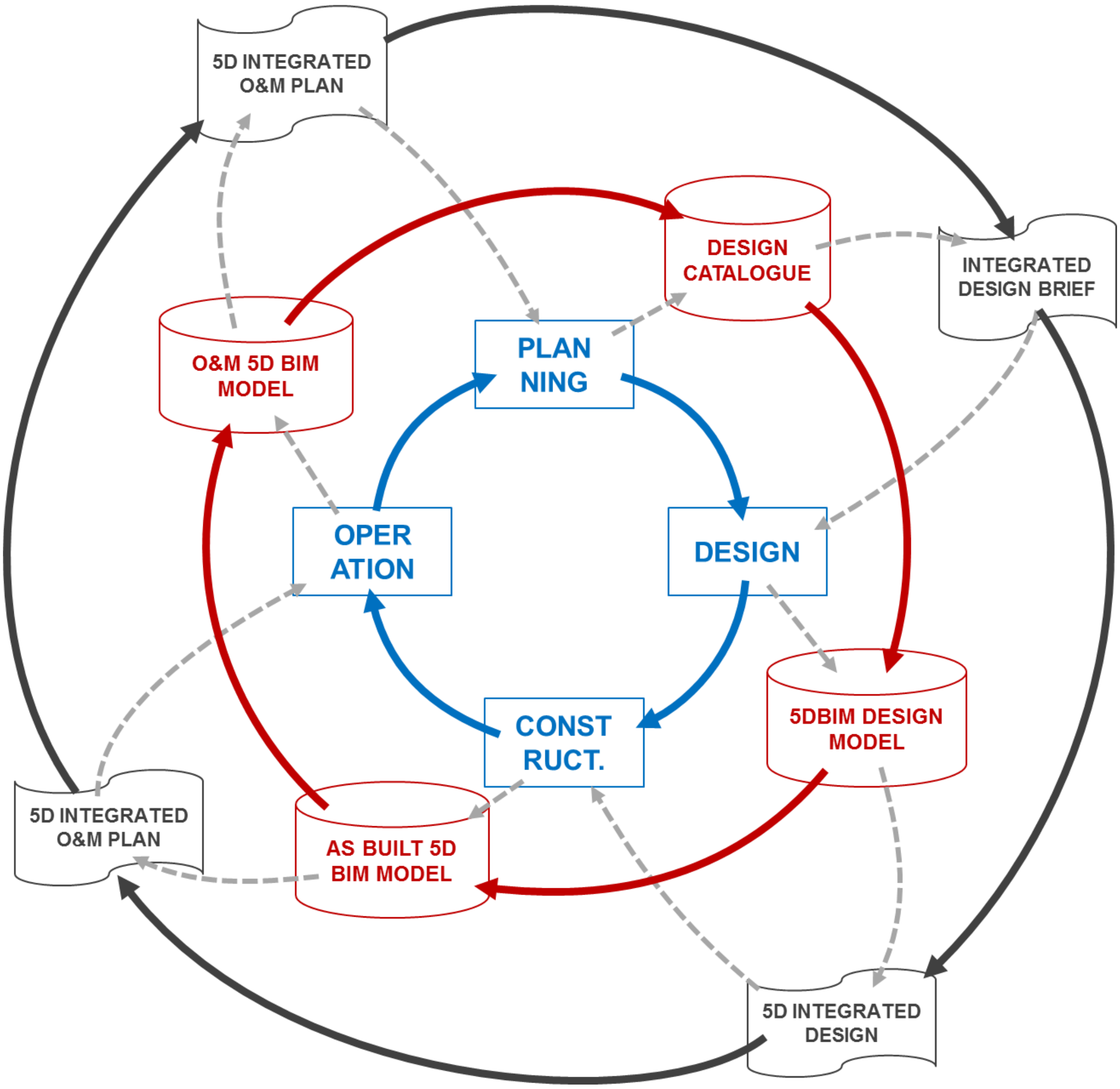
- Scheduling (time-related information, 4D BIM)
- Costs (cost-related information, 5D BIM)

This paragraph is intended to be a starting point for further research. Indeed, more effort is required to explore the concrete possibilities of application of 5D BIM technology, in order to include life cycle performance in design, construction and operation until the end of functional life.

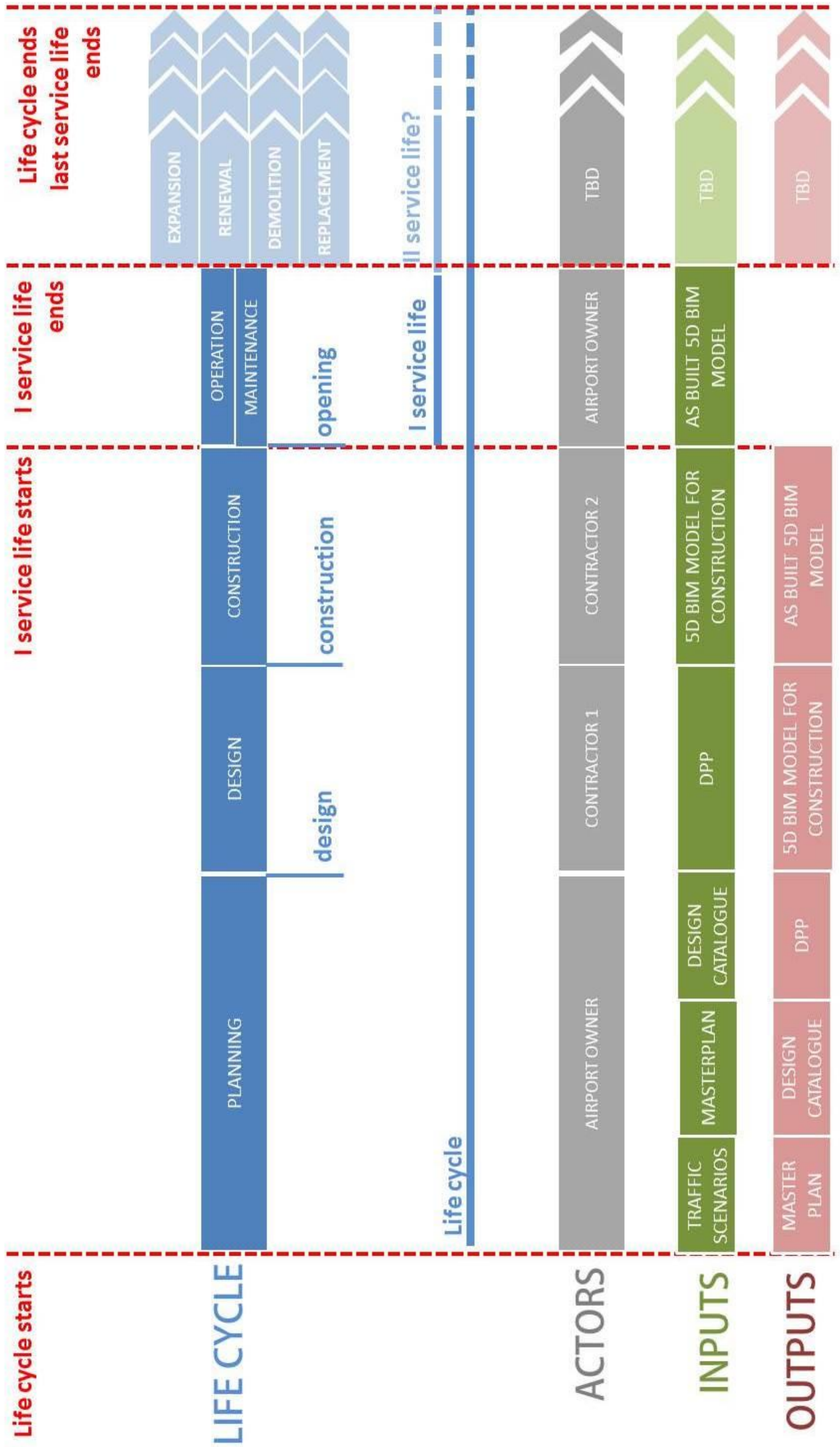
Picture 46 has been studied and proposed in this research in order to summarize these issues in a new circular and twisted flow chart, comprehending the vision of a cyclical process, where the element of time and costs are relevant and included into the tools to be used to produce the documents proper of each life cycle step and leading to the next one.

Then, the planning phase produces an integrated brief by using a Catalogue approach. Then design brief informs the design, which is set up through a 5D BIM model, becoming the input for the construction phase. During construction the model is implemented and delivers a complete tool for the operation phase, aiding during operation by informing decision makers about the performance of the asset in its life cycle.

Errore. L'origine riferimento non è stata trovata. puts together in a line lifecycle phases over one service life, relating them to the input and output documents/information and to the actors.



PICTURE 46 EVOLVED FLOW CHART OF THE PROPOSED INTEGRATED PROCESS: INCLUDING A SUPPORT FOR CONSIDERING LIFE CYCLE PERSPECTIVE – TXP ORIGINAL GRAPHIC ELABORATION



PICTURE 47PROCESS DELIVERING LIFE CYCLE PERFORMANCE IN THE FINAL PRODUCT – TXP ORIGINAL GRAPHIC ELABORATION

9.3.1 POSSIBLE APPLICATIONS OF THE CATALOGUE TO DIFFERENT PLANNING ACTIONS

Airport terminal planning can be described by two main categories of possible planning actions. The first one is a large scale planning, typically requiring long-term effectiveness of the planning action. The second one consists of a small scale planning, typically requiring short-term effectiveness. The main difference is that the first typology of planning action involves great infrastructure developments: expansions, demolitions, major refurbishments. The second typology involves each single Unit of Airport Terminal (UAT) and consists of smaller reconfigurations and refurbishments: increasing capacity of security checks, reconfiguration of check in hall, etc.

Planning Catalogue could be applied to both cases. In this research the large scale application is tested.

TABLE 6 APPLICATION OF THE CATALOGUE TO LARGE AND SMALL SCALE TEST OBJECTS

	Large scale	Small scale	Notes
Main Features			
Scale	Terminal System	Subsystems	
Planning purpose	Programming and planning refurbishment/ extension/ new realization of an airport terminal;	Programming and planning refurbishment/ extension/ new realization of environmental units	
Term of the planning action	Long term	Short/medium term	
Period of analysis	Ca. 30 years	Less than 10 years	
Elements of uncertainty	Future demand for air transport (movs/pax)	Current and future demand for air transport related to future flights allocation*	*in case of airports with more than one terminal; otherwise the uncertainty in a so short period could be not relevant to a concrete application in a managerial field and difference with a standard approach could not be appreciated by airport company

10. MODEL ADJUSTMENT

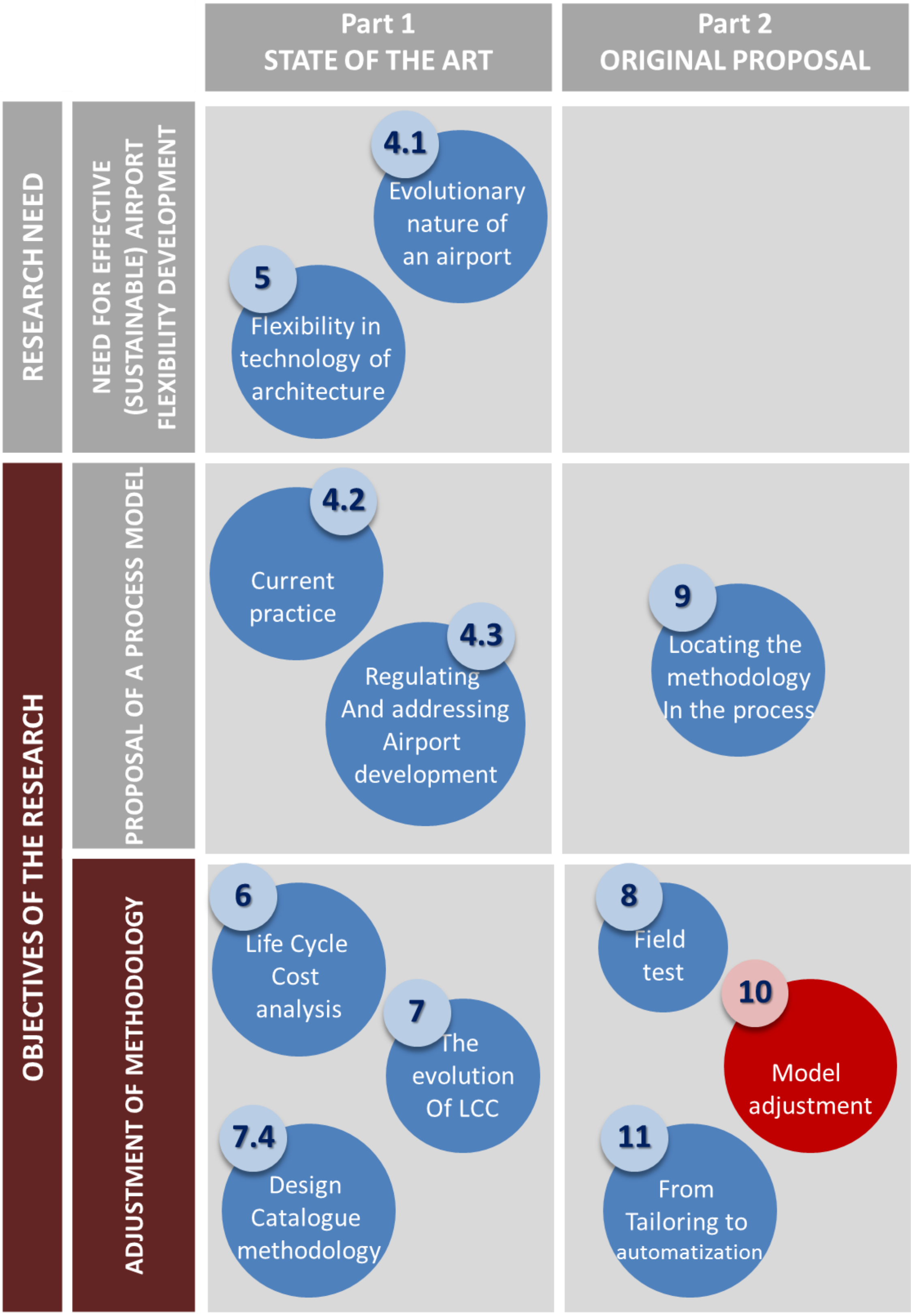
Chapter objectives

In Chapter 10 the reader will understand and learn:

- The model for performance measurement of the test terminal, tailored for application to this airport terminal, according to the requirements of the Catalogue methodology
- The set of decision rules and planning variables tailored to the test terminal, according to the requirements of the Catalogue methodology

Chapter Keypoints

The basic model which is the main step of the Catalogue methodology, starting from the proposal of the case study of Cardin, is tailored to the airport terminal test case.
Moreover, rules and variables are studied on the test terminal, corresponding to the set of values that are involved in the computation, during the aOFAT sequence iteration described in Part 1.
These two issues are examined, tailored and adjusted, making reference to infrastructural and economic items involved in the life cycle of a terminal.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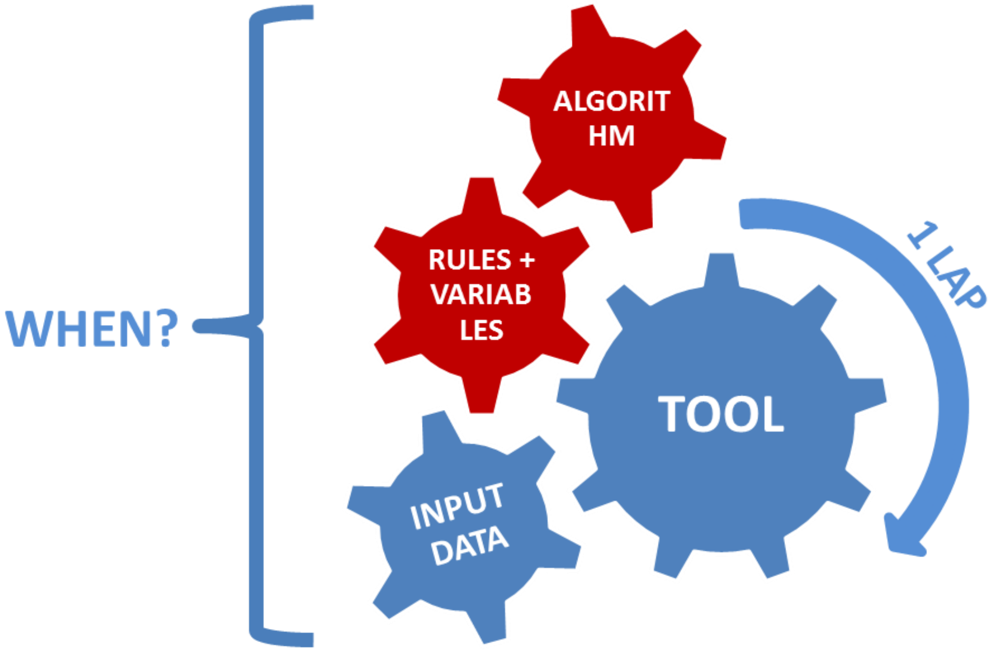
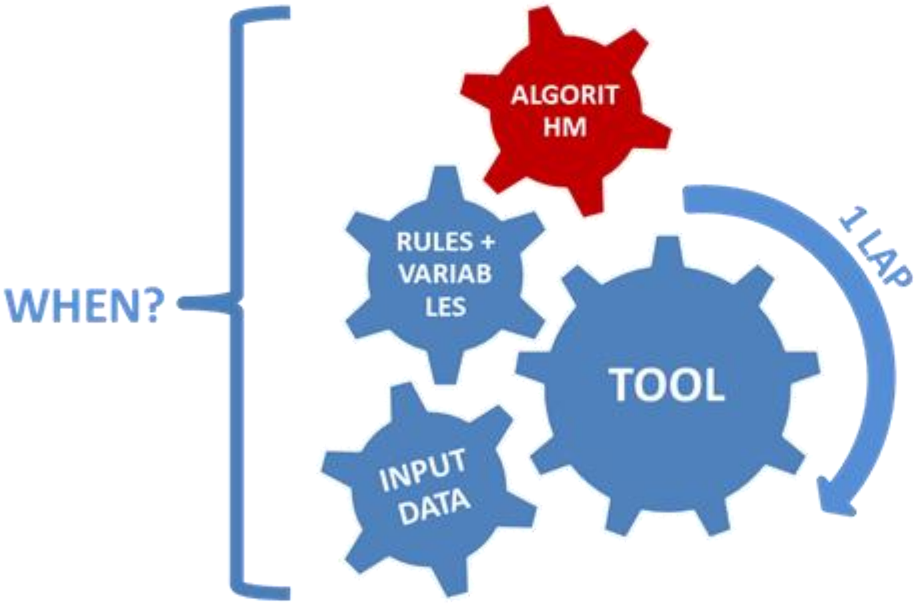
10.1 Introduction



Chapter 9 explored the new process concept, that includes the Catalogue in a renovation of the traditional process flow chart. This chapter (10) explores the effort for tailoring the model to measure the economic effectiveness in the lifecycle of the test terminal, together with the tailoring of the set of decision rules and planning variables for the implementation of the Catalogue. In red the topics of Chapter 10, according to the synopsis of the research proposal part.

10.2 Proposal of algorithms for the catalogue approach



After having located the application of the Catalogue in the whole process and having proposed a process concept in Picture 466, the model for measuring the economic performance and effectiveness of the test terminal in the lifecycle is now proposed and examined. In red the said topic, contained in this paragraph, according to the research proposal synopsis.

10.2.1 THE LIFE CYCLE OF A TERMINAL AND ITS RELATED COSTS

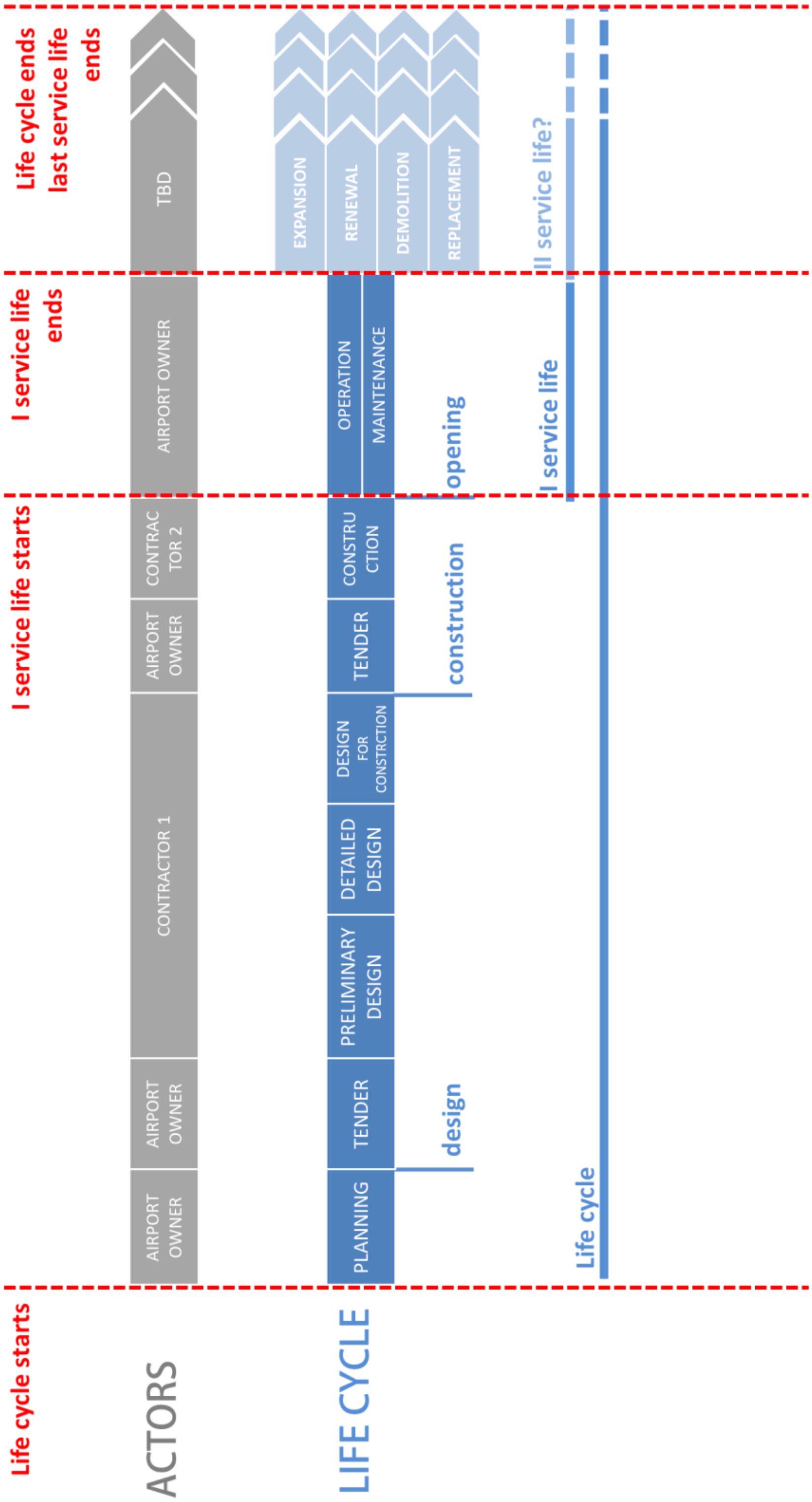
With Part 0 and Part 1, the general framework of the present work has been completed. In order to introduce the proposed model adjustments, an insight of the life cycle, actors and costs of an airport terminal is now summarized, making reference to the literature review of Part 1 and to field experience.

- The lifecycle starts at the beginning of the planning phase. This phase includes the necessary checks for effective needs and requirements for a new airport terminal. Location and capacity of the new building are determined. Access roads and pathways are preconfigured. Apron characteristics are assumed. After total terminal capacity requirement calculation, dimensioning of each terminal unit is carried out; they represent the first and main input for design. Capital costs of the future building are determined as well, in order to guide future design choices.
- While the technical planning phase is taking place, all the necessary tender documents are prepared in order to launch design activities. The tender is driven according to the Italian Procurement Code and European legislation. The new terminal life cycle is described in the design phase too. Design should accept and recognize all the inputs given during the planning phase, giving these data and requirements an architectural shape and a structural formality.
- The construction of the new terminal takes place during the final steps of the design process, where the new building becomes real and evident. However, even before construction and before the building became evident the life cycle was progressing, though silently.
- The airport terminal soon becomes operative, inaugurating the first service life of this new building.
- Architectural shape is completed; furniture and every system and equipment for passengers and luggage processing are working. The terminal comes in full operation. Hundreds of passengers and airport operators pass every day through

each Unit of Terminal (UAT) and make use of every item, equipment, electronical device available. The architectural shape, interior details, functional distribution are constantly put under stress. Therefore, maintenance activities must be programmed alongside operation. As time goes by the performance of the entire building decreases, whereas the number of passengers increases and new technologies become available in the terminal operation market. This period of full operation comes to an end, as the building does no longer respond adequately to the needs.

- At the end of the first service life period depending on the airport owner’s needs and finance an expansion action can occur. Other possible solutions, respectively cheaper and more expensive than expansion, are: renewal, demolition and replacement.
- At the end of each following service life period, life cycle will come to an end.

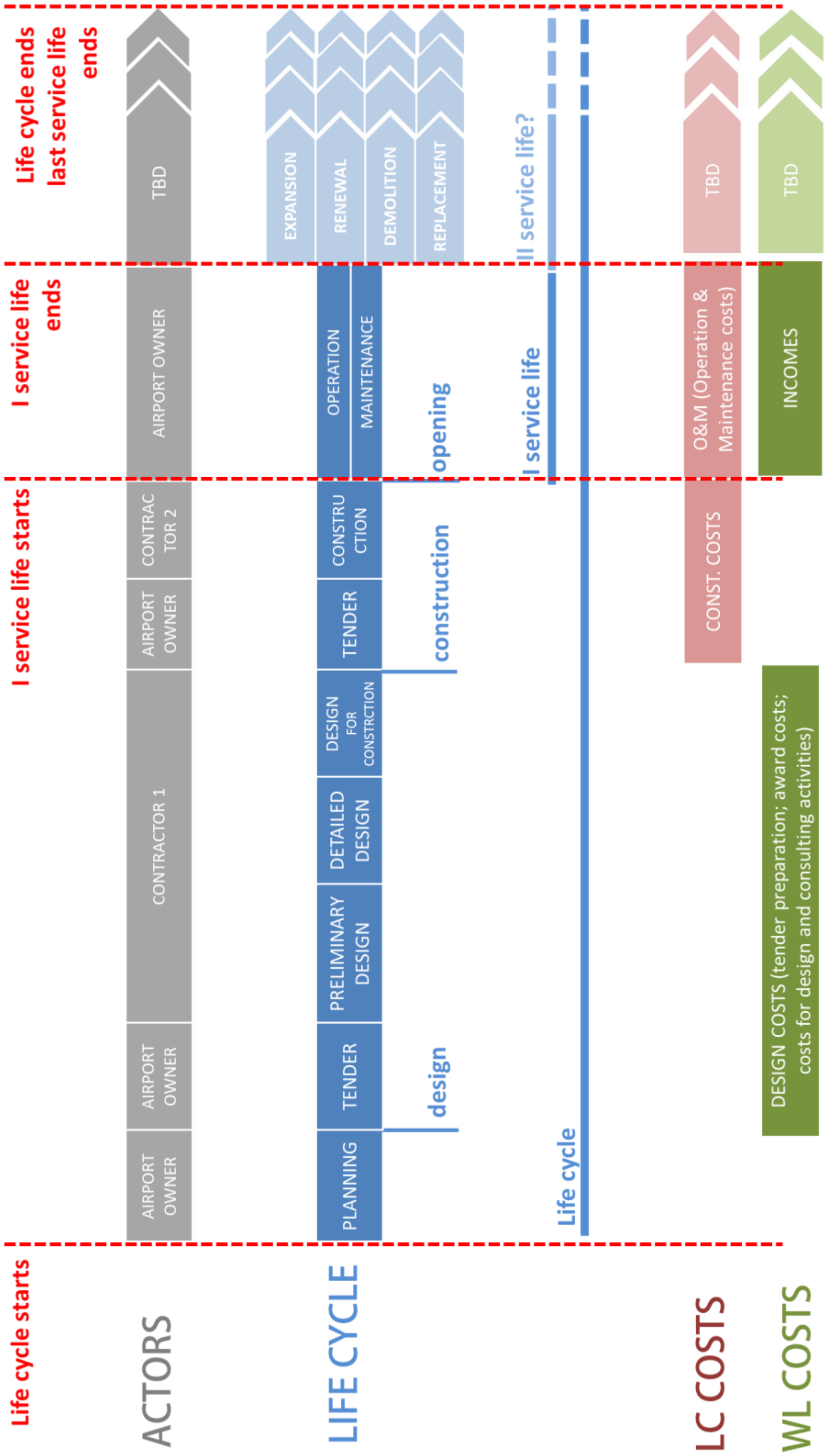
Errore. L'origine riferimento non è stata trovata.8 shows the steps listed and additionally makes reference to a *t0 time*. *t0* is the time of application of the methodology proposed. But at the same time, the methodology consists in a life cycle analysis; so each step is taken into account as a potential input in the calculation. Then, the actors that are owners of every step are highlighted in grey.



PICTURE 48 TERMINAL LIFECYCLE STEPS AND ACTORS - TXP GRAPHIC PROCESSING

Then, in line with the literature and regulations concerning Life Cycle and Life Cycle Costing, for each of the life cycle steps one or more cost factors have been defined.

The main items have been represented in 49. Indeed, in keeping with the International standard (ISO 15686), only macro-economic values should be included in a WLC at the planning phase. This kind of cost analysis should be based on the functional unit (e.g.:cost per bed in case of hotel facilites) or total area of the asset (e.g.:cost per square metres) or on the number of people accommodated. Then the benchmark-level estimate con be retained as a basis for checking against a detailed life-cycle costing analysis (ISO 15686). Moreover, not all the cost categories listed in ISO 15686 are relevant to gain planning flexibility.



PICTURE 49 TERMINAL LIFECYCLE COST AND REVENUE ITEMS - TXP GRAPHIC PROCESSING

10.2.2 TAILORING THE MODEL

Starting from the literature review and the state of the art widely shown in Part 1 concerning LCC, WLC, new generation WLC, the development of a basic LCC model was completed. The model has been tailored to the specific airport terminal presented in Chapter 8 and takes account of every item relevant to the description of the performance of an airport terminal during its lifecycle.

As maintained by literature and regulation (ISO 15686), LCC applied to a planning (initial and strategic) phase should be broad and at a benchmark-level. The analysis entails the formulation of many assumptions concerning its inputs, basing the calculation on parametric values and functional units (e.g.: cost per square meter or cost per number of people –passengers in this case- accommodated).

Broad assumptions may be made at this stage for key variables and may include speculations about future requirements (e.g.: future accommodation needs) and about variables in the cost calculation (e.g.: costs of energy; choice of applied discount rates; etc.). Technical assumptions may also be made about the data included in the calculations (e.g.: timing of cost flows and service life of components) (ISO 15686-5).

Hence, starting from these clear guidelines, the model for lifecycle performance assessment is here summarized:

$$NPV = \sum_{t=0}^{T} \frac{R_t + C_t}{(1+r)^t} \qquad (1)$$

$$C_t = C_0 + C_o + C_m \qquad (2)$$

$$C_0 = C_{const} + C_{flex} \qquad (3)$$

$$C_o = C_{ener} + C_{clean} \qquad (4)$$

$$C_m = C_c * coeff \qquad (5)$$

$R_t = R_{subconc} + R_{pax} + R_{roy}$ (6)

$R_{subconc} = R_{sub\ off} + R_{sub\ vip} + R_{sub\ ret}$ (7)

$R_{pax} = [min(k; D)/2] * tar$ (8)

$R_{roy} = [min(k; D)/2] * roy$ (9)

$k = k_i * A * 4380$ (10)

Where:

R_t	Revenues at time t
$R_{subconc}$	Revenues for spaces subconcessions
$R_{sub\ off}$	Revenues for offices subconcessions
$R_{sub\ vip}$	Revenues for VIP lounges subconcessions
$R_{sub\ ret}$	Revenues for retail subconcessions
R_{pax}	Revenues for passengers tariff
K	Capacity. A=terminal area; K_i=crowding index
D	Demand
tar	Average tariff per passenger (departing)
R_{roy}	Revenues from Royalties
roy	Average royalties per passenger
C_t	Costs at time t
C_0	Costs at time 0

C_{const}	Construction costs
C_{flex}	Costs for acquiring flexibility
C_o	Operation costs
C_{ener}	Energy costs
C_{clean}	Cleaning costs
C_m	Maintenance costs
coeff	Maintenance conversion coefficient

The model was also transposed in the tool implementation, as described and reported in Chapter 11. With regard to sheet C1 of the Planning Catalogue spreadsheet, the model is the key to the main computational relations among the sheet cells. More details about the single cost and revenue items are given in the next paragraph.

WHY WERE THESE REVENUES AND COSTS CHOSEN?

Given the field test object, access to internal databases and to the 2015 Annual Report has shown that the main cost items are, in a decreasing order:

TABLE 7 COST ITEMS ACCORDING TO THE ANNUAL REPORT

N.	Cost item	Notes
1	Renewal of airport infrastructures	2015 Annual Report
2	Construction services	2015 Annual Report
3	Maintenance activities	2015 Annual Report
4	Cleaning activities	2015 Annual Report

5	Professional services	2015 Annual Report
6	Human resources	2015 Annual Report
7	External services	2015 Annual Report
8	Others	2015 Annual Report

Furthermore, the main revenue items are, in a decreasing order:

TABLE 8 REVENUE ITEMS ACCORDING TO THE ANNUAL REPORT

N.	Revenue item	Notes
1	Airport rights (tariffs)	(Aviation revenues) 2015 Annual Report
2	Commercial Subconcessions	(Non aviation revenues) 2015 Annual Report
3	Security services	(Aviation revenues) – not relevant 2015 Annual Report
4	Real estate	(Non aviation revenues) 2015 Annual Report
5	Parking areas	(Non aviation revenues) – not relevant 2015 Annual Report
6	Centralized infrastructures	(Aviation revenues) – not relevant 2015 Annual Report
7	Advertising	(Non aviation revenues) 2015 Annual Report
8	Others	2015 Annual Report

Thus, revenues and costs considered as inputs of the model are the heavier items, written down in the following list:

TABLE 9 ITEMS CONSIDERED

N.	Cost inputs
1	Construction costs
2	Maintenance costs
3	Cleaning costs
N.	**Revenue inputs**
1	Tariffs
2	Commercial subconcessions
3	Real estate

These information is related to an airport of 40M pax and to a system of 4 terminals, and the model has been tailored on it. The airport of the test the 7th in Europe and the 1st in Italy for passenger traffic. This makes the simulation representative of international hub infrastructures, and more significant than minor Italian cases. The most relevant cost and revenue items outlined in this analysis are common to every passenger terminal processing Commercial Aviation flights. While for said reasons this eases the transposition to other terminal cases, the generalization and portability of the model should be scientifically validated as explained in Part 3, related to further research developments.

HOW SINGLE REVENUES AND COSTS ITEMS ARE CALCULATED?

In particular, each one of the economic inputs listed in the previous table results from a specific computation. For clarity, they are specified as follows:

Capacity (over one year)

$$K_t=(A_t/k_i)*16*365 \qquad (10)$$

Where:

A_t Terminal area at time t [m^2]

K_i Crowding Index [$m^2/(m^2/pax)$]

16 daily terminal operation hours

365 terminal operation days out of one year

Demand (Over one year)

Airport company forecasts give an annual demand value per each year.

Revenues

$$R_{pax} = r_{pax} * \min(K_t; D_t) \quad (11)$$

Where:

r_{pax} Average passenger tariff [€/pax]

K_t Capacity [pax]

D_t Demand [pax]

$$R_{sub\ off} = r_{sub\ off} * Ao_t \quad (12)$$

Where:

$r_{sub\ off}$ Unit offices rent price [€/m^2]

Ao_t Offices area at time t [m^2]

$$R_{sub\ vip} = r_{sub\ vip} * Av_t \quad (13)$$

Where:

$r_{sub\ vip}$ Average unit vip lounges rent price [€/m^2]

Av_t Vip lounges area at time t [m^2]

$$R_{sub\ ret}=r_{sub\ ret} * Ar_t \quad (14)$$

Where:

$r_{sub\ ret}$ Average unit commercial rent price [€/m^2]

Ar_t Commercial area at time t [m^2]

$$R_{roy}= r_{roy}*min(K_t;D_t) \quad (15)$$

Where:

r_{roy} Average unit commercial royalties per passenger [€/pax]

K_t Capacity [pax]

D_t Demand [pax]

Costs

$$C_{const}=c_{const}*\Delta At \quad (16)$$

Where:

c_{const} Unit construction cost [€/m^2]

ΔAt Additional area at tim t of construction [m^2]

$$C_{flex}=C_{const}*0.34 \quad (17)$$

Where:

C_{const} Construction cost [€]

0.34 Assumed additional construction value for flexibility acquisition

$$C_{ener}=c_{ener}*cons*A_t \quad (18)$$

Where:

c_{ener} commercial cost of energy [€/kWh]

cons annual unit energy consumption per square meter [kWh/m^2]

A_t Terminal area at time t [m^2]

$$C_{clean}=c_{clean}*A_t \qquad (19)$$

Where:

C_{clean} average annual parametric cost per square meter [€/m^2]

A_t Terminal area at time t [m^2]

$$C_{main}=C_{const}*0.5 \qquad (20)$$

Where:

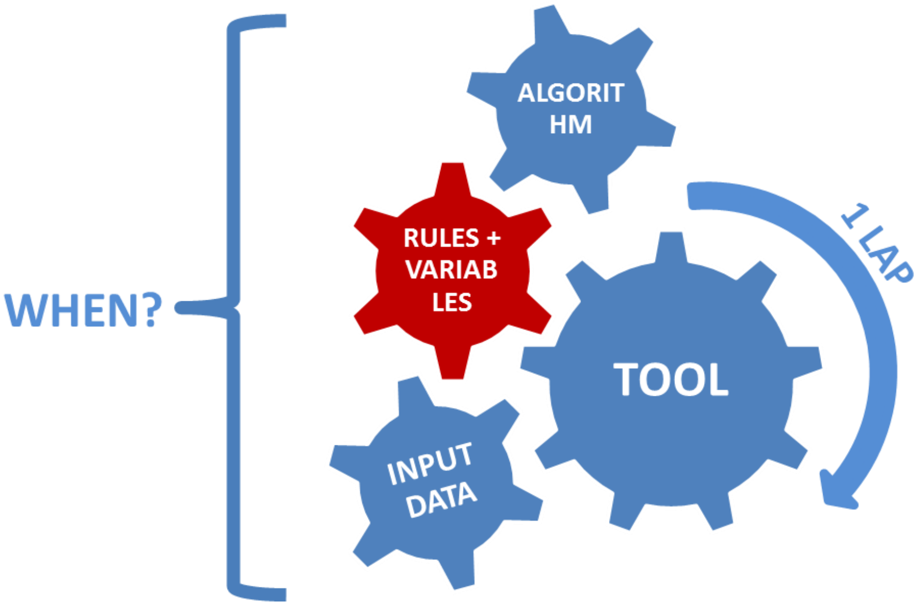
C_{const} construction cost [€]

0.2 conversion factor from construction costs to maintenance costs

Each input to equations (2) and (6) results from the parametric cost values assumed for the test. In presence of some discrepancies in functional units and data available, some of these equations could have been written in different ways. In any case, since these values are related to assumptions made or set of data available for a specific airport company, it follows that similar assumptions and parameters or functional units could be used in other cases and other airport companies, with little differences in functional units depending on the available parameters.

In Chapter 11 data collection is explained and inputs considered for the transposition to a spreadsheet tool are illustrated.

10.3 Proposal of a set of decision rules and design variables



In Chapter 9 the application of the Catalogue was located in the whole process and process concept of Picture 466 was proposed. In Paragraph 10.2 the model for measuring the economic performance and effectiveness in the lifecycle was tailored. Now the set of decision rules and planning variables is proposed. In red the said topic, according to the research proposal synopsis.

10.3.1 TAILORING THE SET OF DECISION RULES AND PLANNING VARIABLES

The identification of a set of decision rules and planning variables, according to the Catalogue methodology, concerns the identification of the possible sources of flexibility in the terminal object of the test.

The set tailored to the test terminal was developed starting from the set proposed by Cardin and De Neufville (2013). The first four decision rules are dedicated to describe the possible approach of the airport management when acquiring new flexibility for the test terminal. The last two design variables describe the possible decisions of the airport management concerning how to acquire the necessary capacity.

The vector proposed by Cardin and De Neufville (2013) for the case of a parking garage is suitable for an infrastructure system which serves the main purpose of accommodating and processing an increasing number of users (cars in their application; passengers in an airport terminal application). Starting from this vector, the decision rules and planning variables have been adjusted to the specific airport terminal case.

Then, given:

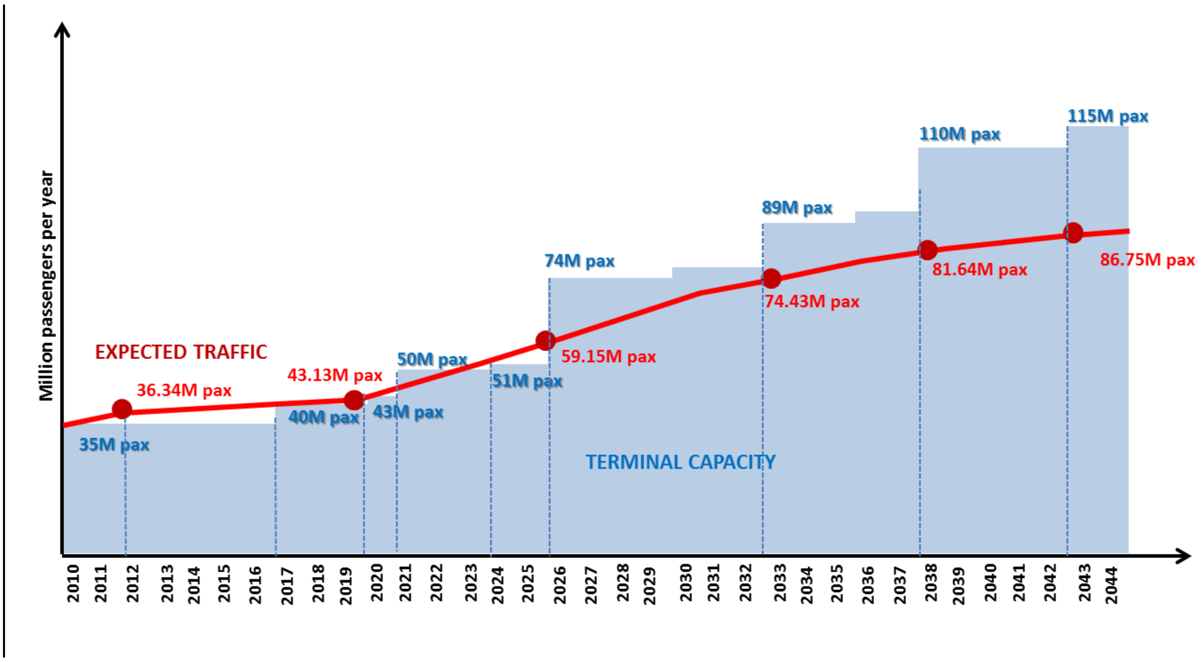
- These considerations,
- The information provided in Part 1,
- The description of the terminal life cycle performance made in Paragraph 10.2
- The nature of the terminal design issue and process,

The vector describing the possible sources of flexibility in the terminal object of the test and considered for the computation is:

$[y_{5\text{-}8}; y_{13\text{-}16}; y_{20\text{-}22}; dr; k_t; k_0]$

The first three decision rules describe the possibility of the airport management to decide whether or not to expand the terminal in the years 5th -8th , 13th -16th , 20th -22nd from the initial terminal construction. The entire interval under analysis ranges from 2028 to 2050. These two limits represent the time-range which the airport company is interested in, for any evaluation of the life cycle performance of this airport terminal case. As a matter of fact, 2028 is the year of entry into operation of the new terminal. Moreover, the airport company Economic Regulatory Agreement with the Italian Civil Aviation Authority is expiring in 2050. Every return on investment after this time is not relevant for infrastructure planning. Therefore, today-2028 and 2028-2050 are the intervals of analysis of this application of the Catalogue. As demand grows and exceeds capacity, even if a real necessity for an infrastructure expansion arose, the airport management could take the decision not to expand. This uncertainty item is described by introducing the three components y5-8, y13-16, y20-22. These components can assume the value of “yes” if corresponding to the decision to expand, or “no” if corresponding to the decision not to expand.

The vector component “dr” represents the possibility of increasing capacity only after a number of years following the demand being exceeded by terminal capacity. This means that, given the economic investment that an expansion entails during those years, expansion decision could be delayed by the airport management. In this period, the terminal operates at a lower Level of Service for a certain number of years and the capacity of its environmental units is stressed until the expansion occurs. The future investments planned by the ERA on entire terminal system of the test airport are shown in picture 50.



PICTURE 50 EXPECTED SATURATION OF THE FIELD TEST TERMINAL SYSTEM – TXP GRAPHIC ELABORATION FROM ADR ERA

The saturation chart of the entire terminal system for the next 30 years shows that investments in infrastructures for acquiring new terminal capacity have been programmed to occur after a number of years of terminal stress and saturation that fluctuates:

- From 2 to 8 years.

Where the highest values correspond only to a recent decisional delay of the airport company, in the light of the uncertainty concerning the renovation of the ERA between the owner and the concessionaire of the airport, and it is not due to technical decisions making. So, the "dr" component has been fixed in three levels:

- 2 years,
- 4 years,
- 6 years.

2 years correspond to a risky attitude of the decision maker, while 6 years correspond to a prudent attitude of the decision maker and 4 years is a compromise between the two.

The last two components of the vector are the planning variables. The "kt" (standing for capacity at time "t") variable describes the square meters that the decision maker could make available for the future expansions of the new airport terminal. The "k0" (standing for capacity at time "0") variable describes the initial terminal area that the decision makers could define for the new airport terminal.

In particular, the airport terminal responds to the demand for air transport, that is a forecast number of passengers to be accommodated in the terminal. The answer to this demand is given by additional terminal areas: additional square meters in airport terminal planning translate into additional million passengers per year (MMPY). The conversion from square meters to million passengers per year is made through the Crowding index. Therefore, differently from the Cardin design variables (2013) for a new multifloor carpark, which are expressed as numbers of additional/initial floors, in this field test these variables are expressed into million passengers per year.

The planning history of the terminal object of the test has been explored through interviews and analysis of internal documents. According to the history of decision making of the airport management with regard to this specific terminal case, the initial and additional capacity have been fluctuating during the planning phase between the following values:

I. First hypothesis: Initial capacity: 50M pax; additional capacity: 0
II. Second hypothesis: Initial capacity: 25M pax; additional capacity: 25M pax
III. Final hypothesis: Initial capacity 35M pax; additional capacity: 15M pax

Then, these three levels for the "kt" component were fixed:

- 5M pax
- 15M pax
- 25M pax

Whereas, in the case of the "k0" component, the levels are fixed in:

- 25M pax
- 35M pax
- 50M pax

The table below summarizes the main issues of this paragraph.

Component	Typology		Description	Values
	Decision rule	Planning variable		
Y_{5-8}	X		Expansion allowed in years 5-8?	Yes/No
Y_{13-16}	X		Expansion allowed in years 13-16?	
Y_{20-22}	X		Expansion allowed in years 20-22?	
dr	X		Years with lack of capacity (demand exceeds capacity) passed before decision to expand the terminal?	2 years /4 years /6 years
k_t		X	Terminal capacity added in expansion (pax or m^2)	5 MPPY / 15 MPPY / 25 MPPY
k_0		X	Initial terminal capacity (pax or m^2)	25 MPPY / 35 MPPY / 50 MPPY

In view of these considerations, the rules and variables levels have been summarized as follows:

TABLE 10 PLANNING VECTOR LEVELS

Component	Levels		
	-	o	+
$Y_{5\text{-}8}$	No		Yes
$Y_{13\text{-}16}$	No		Yes
$Y_{20\text{-}22}$	No		Yes
dr	2	4	6
k_t	5	15	25
k_0	25	35	50

The baseline design for this test is a new terminal with:

- Capacity of 50 million passengers per year,
- No possibility of expansion in years 5-8, 13-16, 20-22 from construction
- Possibility of expansion after 4 years of demand exceeding capacity
- Additional capacity of 25 million passengers per year.

In the table above, baseline design characteristics are highlighted in red.

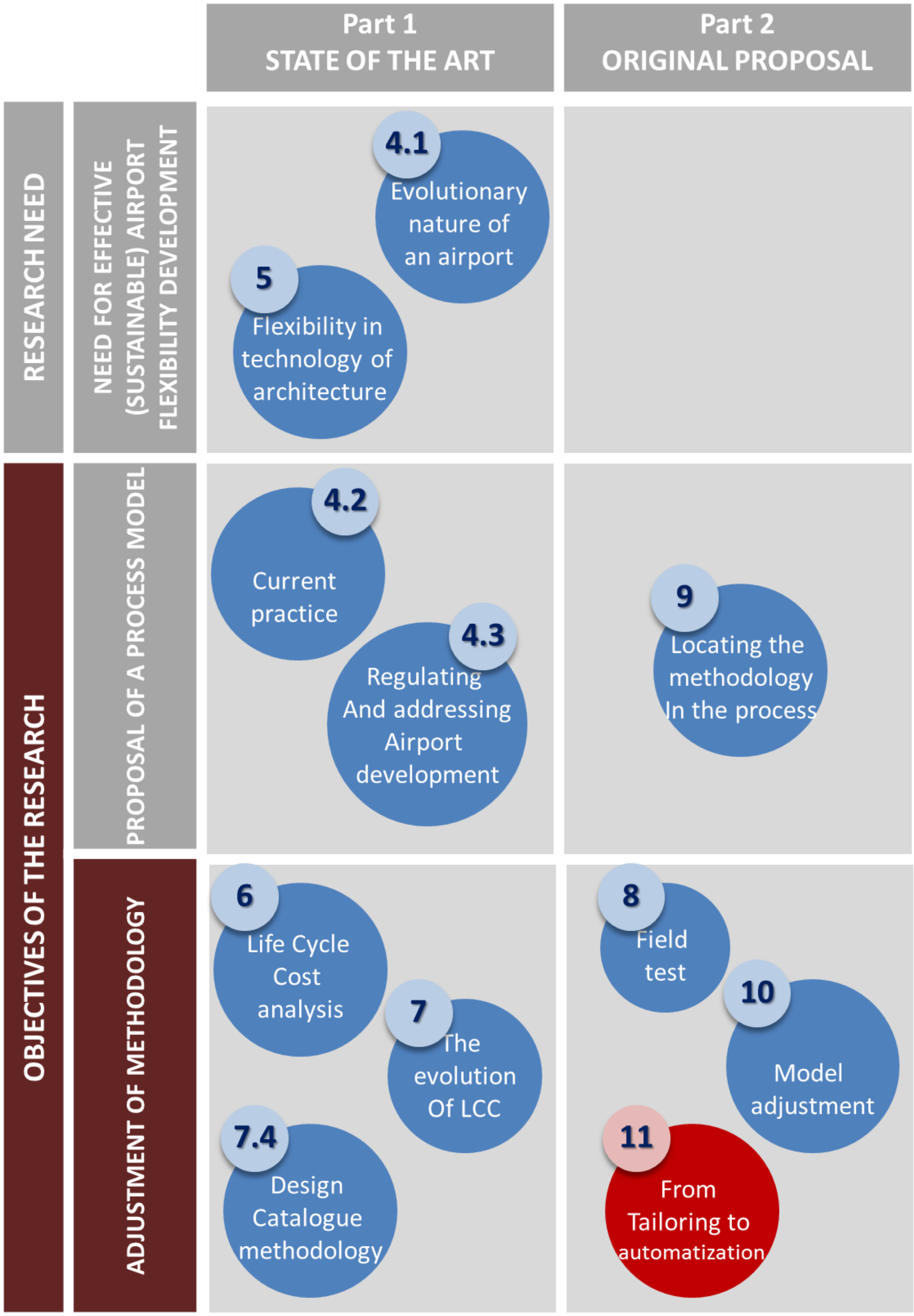
11. FROM TAILORING TO AUTOMATIZATION

Chapter objectives

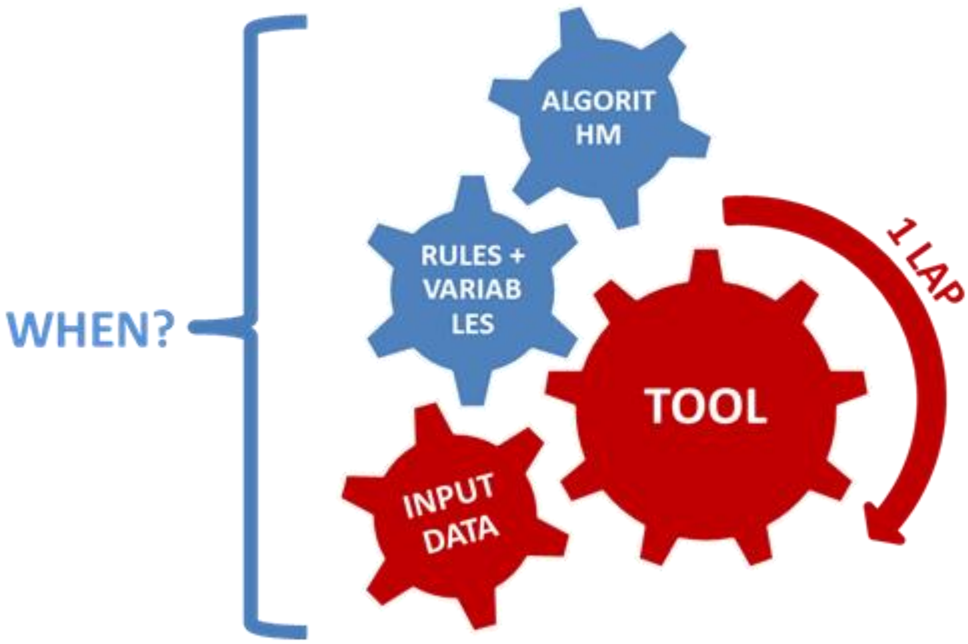
In Chapter 11 the reader will understand and learn:
- The results of the collection of data and inputs to the model managed during this research
- The set-up process of the algorithms of the model in a spreadsheet tool, through one lap of the sheet

Chapter Keypoints

The research lead to the collection of infrastructural and economic data, concerning the test terminal, to be the main inputs to the model.
Then the tailored model for the life cycle performance measurement and the tailored set of decision rules and design variables have been translated into a spreadsheet. The tool has been set up while being tested: one lap has been attempted and arranged by using one traffic scenario, related to the traffic forecasts for the test terminal.

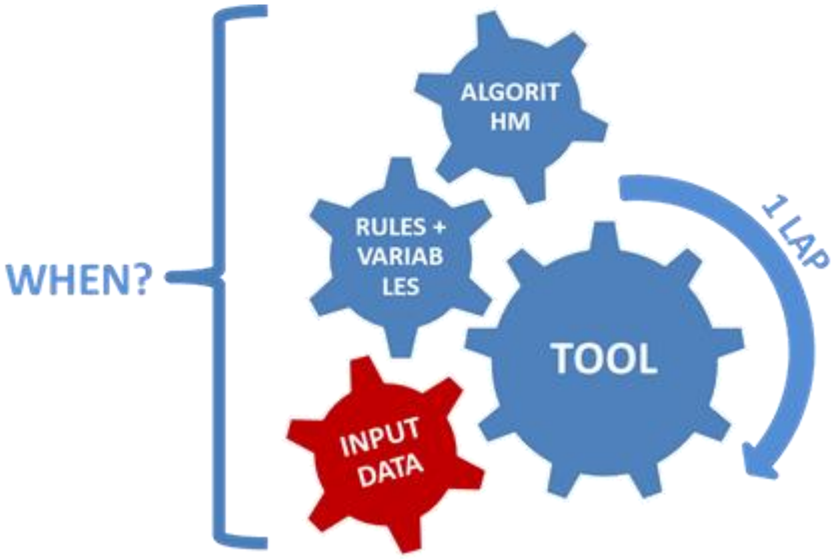

Part 1
STATE OF THE ART
Part 2
ORIGINAL PROPOSAL
RESEARCH NEED
NEED FOR EFFECTIVE (SUSTAINABLE) AIRPORT FLEXIBILITY DEVELOPMENT
4.1
Evolutionary nature of an airport
5
Flexibility in technology of architecture
OBJECTIVES OF THE RESEARCH
PROPOSAL OF A PROCESS MODEL
4.2
Current practice
4.3
Regulating And addressing Airport development
9
Locating the methodology In the process
ADJUSTMENT OF METHODOLOGY
6
Life Cycle Cost analysis
7
The evolution Of LCC
7.4
Design Catalogue methodology
8
Field test
10
Model adjustment
11
From Tailoring to automatization

11.1 INTRODUCTION



In Chapter 9 the application of the Catalogue was located in the whole process and process concept of Picture 46 was proposed. In Paragraph 10 the model for measuring the economic performance and effectiveness in the lifecycle was tailored to the test terminal. Beside a set of decision rules and planning variables was proposed, according to the test terminal. In Chapter 11 the transposition of these algorithms into a tool, by using input data of the test terminal, is proposed. In red the said topic, according to the research proposal synopsis.

11.2 DATA COLLECTION



In Chapter 9 the application of the Catalogue was located in the whole process and process concept of Picture 46 was proposed. In Paragraph 10 the model for measuring the economic performance and effectiveness in the lifecycle was tailored to the test terminal. Beside a set of decision rules and planning variables was proposed, according to the test terminal. In this Paragraph, the data collected are reported; this information has been the input for the test of the spreadsheet tool while being set up. In red the said topic, according to the research proposal synopsis.

In order to collect the necessary data a number of methodologies have been applied. The data collection has been conducted during the adjustment of the model and allowed the transposition of the algorithms to a spreadsheet tool through a testing activity. It also made possible to address the tailoring of the model and its algorithms, in relation to the availability of data and their functional units.

The collection led to the acquirement of the following information:

- Terminal building information:
    - Terminal gross floor area
    - VIP lounges area
    - Retail area
    - Offices area
    - Forecasted TPHP[2] (Typical Peak Hour Passenger)
- Information about expected revenues connected with the operation of the building, in line with the revenue items identified during the Catalogue methodology adjustment phase:
    - Revenues from terminal areas subconcessions
    - Tariff per departing passenger
    - Royalties from sales
- Information about expected costs connected with the life cycle of the building, in line with the cost items identified during the Catalogue methodology adjustment phase:
- Expected average construction costs
- Expected maintenance costs
- Expected energy costs
- Expected cleaning costs

[2] TPHP (Typical Peak Hour Passenger): the peak hour of passenger traffic in the busy day; the busy day is the second busiest day of the average week in the peak month (IATA Manual, 2010)

11.2.1 Report: data collection

Data collection has been conducted before testing the model developed and allowed its transposition to a spreadsheet tool. A filed experience allowed the collection of the computation inputs, related to the test terminal described in Chapter 8.

The data collection report makes a deeper insight into Chapter 3, 8 and 10.

Data collection has been an important part of the research path. Needed data have been determined once the tool had been adjusted to the terminal life cycle and had been implemented. Not all the data collected have been used, given the research delimitations and boundaries.

Data collection methodologies

The main methodologies that have been taken in consideration are (Harrel, 2009):

- Survey:	Pre-determined questions submitted by a form, with closed and/or open questions	NO
- Interviews:	One-on-one discussions between and interviewer and an individual	YES
- Focus groups:	Dynamic group discussions	NO
- Observation:	Data collection where the researcher remains external	YES
- Extraction:	Collection of the data from existing documents that includes a work of abstraction of the desired information from the source	YES
- Secondary data sources:	Collection of the data from existing sources (data bases)	YES

Beside each one of the methodologies a yes/no note has been written down, in case the specific methodology has been adopted in the end.

In the further paragraphs different types of data that have been collected will be analysed. According to the tool requirements, there are two types of numbers:

- System parameters: data describing the system that the Catalogue intends to examine
- Economic data: data describing costs and revenues expected

SYSTEM PARAMETERS

An example of computation data has been reported in the following table. It is a part of the sheet C1 of the Planning Catalogue tool implemented. In particular it belongs to the first iteration of the aOFAT Sequence (the complete name of the sheet: "C1|NPV input|aOFAT #1").

The purple descriptions are the ones that have to be adjusted from one aOFAT sequence to another. So they depends from the system data collected at the beginning of the tool test, but they not necessarily correspond to the data collected, according to the Planning vector combinations matrix: they are a function of the total built area of the terminal.

TABLE 11 SAMPLE OF SYSTEM PARAMETERS ROWS; EXTRACT OF PLANNING CATALOGUE, SHEET C1

	Description	Unit	Value
Input table			
System parameters			
	Energy consumption	kWh/m^2	222
	Initial area	m^2	270.000
	Expansion area	m^2	54.000,00
	Initial VIP lounges area	m^2	3750
	Expansion VIP lounges area	m^2	750
	Initial retail area	m^2	23750
	Expansion retail area	m^2	4750
	Initial offices area	m^2	0
	Expansion offices area	m^2	0
	Crowding index los C	m^2/pax	63

ENERGY CONSUMPTION:

Adopted value: 222 kWh/m^2

Description:	This parametric number describes the energy consumption for each square metre of terminal area in the case study. The consumption, expressed in kWh/m^2, comprehends supply for electricity, cooling and heating of the terminal area.
Collection methodology:	Interview
About data collection:	The engineer Head of Airport Systems and plants Planning division, directly working on the airport object of this test, has been interviewed by the author. After introducing to him the research aims, boundaries and issues, the interview has been addressed to understand if a parametric value measuring the annual energy consumption for the entire current terminal system of the airport exists. This annual value could in fact easily be extended to the case study. The person interviewed, while considering the proposed methodology a good option, stated that could supply the specific numbers forecasted for the terminal of the case study. These numbers has in fact been used for its future plants dimensioning: - Annual energy consumption for cooled square meters and electricity: 140 kWh/m^2 - Annual energy consumption for heated square meters: 82 kWh/m^2

TERMINAL AREA (INITIAL AND EXPANSION):

Adopted value:	Values of initial and expansion terminal area vary, according to the aOFAT Sequence iteration

Description: Initial terminal area describes the square meters built at the beginning of the system life cycle.

Expansion terminal area describes the square meters that are going to be added at the end of each service life.

Collection methodology: Extraction

About data collection: These two areas are deduced from the final total gross floor area that is going to be built. The total gross floor area has been extracted from the Masterplan Report:

- Final total gross floor area: 535.000 m^2

VIP LOUNGES AREA (INITIAL AND EXPANSION):

Adopted value: Values of initial and expansion VIP lounges area vary, according to the aOFAT Sequence iteration

Description: Initial VIP lounges area describes the total square meters of lounges built at the beginning of the system life cycle.

Expansion VIP lounges area describes the total square meters of lounges that are going to be added at the end of each service life.

Collection methodology: Interview

About data collection: The engineer conducting terminal capacity checks, directly working on the airport object of this test, has been interviewed by the author.

After introducing to him the research aims, boundaries and issues, the interview has been addressed to understand the adopted practice for lounges dimensioning in a completely new terminal.

The person interviewed explained that, when dimensioning the total amount of lounges required, a parameter of square meters per million passengers per year is used. The parameter used for dimensioning lounges of the test terminal has been:

- VIP lounge area: 150 m^2/MPPY

RETAIL AREA (INITIAL AND EXPANSION):

Adopted value: Values of initial and expansion retail area vary, according to the aOFAT Sequence iteration

Description: Initial retail area describes the total square meters of retail built at the beginning of the system life cycle.

Expansion retail area describes the total square meters of retail that are going to be added at the end of each service life.

Collection methodology: Interview

About data collection: The engineer conducting terminal capacity checks, directly working on the airport object of this test, has been interviewed by the author.

The person interviewed explained that, when dimensioning the total amount of retail required, a parameter of square meters per million passengers per year is used. The parameter used for dimensioning lounges of the case study refers only to the departing passengers, not to the total of departures and arrivals:

- Retail area: 1900 m^2/MPPY

CROWDING INDEX:

Adopted value: 63 m^2/pax

Description: The index evaluates the terminal crowding, relating the total operative terminal area to the number of passengers that pass through the terminal in the peak hour.

In the Planning Catalogue tool, it allows the translation of total terminal square meters into capacity (number of passenger hosted).

Collection methodology: Extraction

About data collection: The 63 value of the index correspond to a Level of Service (LoS) C, usually adopted for dimensioning new terminals. This evaluates the overall terminal total area performance.

This average value has been abstracted from the total final operative area and the final Typical Peak Hour Passenger (TPHP) number, expressed in the Masterplan Report:

- Final total gross floor area: 535.000 m^2
- Final retail area: 47.500 m2
- Final VIP lounge area: 7.500 m2
- TPHP (50 million pax - 2034): 16.686 pax/hour

Revenues

Income values are necessary to make an assessment of the economic performance of a plan. An airport terminal is source of these main revenues:

- Revenues from terminal spaces subconcessions, regulated by Civil Aviation Authority;
- Revenues from terminal spaces subconcessions, not regulated by the Civil Aviation Authority
- Royalties from retail/ food&beverage sales in the terminal
- Average tariff per passenger processed through the terminal

Each of these items describes the performance of an airport terminal, according to its area and to its capacity or demand.

TABLE 12 SAMPLE OF REVENUE VALUES; EXTRACT OF PLANNING CATALOGUE, SHEET C1

	Description	Unit	Value
Revenue (Cash value)			
R_t	**Revenues**	**eur**	**/**
$R_{subconc}$	Subconcessions revenue	/	/
	Vip lounges subconcessions	eur/mq	900
	Offices subconcessions	eur/mq	250
	Retail subconcession (if considered)	eur/mq	550
R_{pax}	Pax Tarif	eur/pax	15

VIP subconcessions:

Adopted value: 900 €/m^2

Description: Annual price per m^2 of lounges area.

Collection methodology:	Secondary data sources and extraction
About data collection:	This average value has been abstracted making reference to a range of different annual prices of VIP lounges. The prices have been extracted by real estate databases of the airport that will develop the terminal object of the case study.

PASSENGERS TARIFF:

Adopted value:	15 €/m^2 (considering departures and arrivals)
Description:	Average tariff per departing passenger.
Collection methodology:	Interview
About data collection:	An economist conducting annual analysis and adjustments on tariffs, directly working on the airport object of this test, has been interviewed by the author.

After introducing to him the research aims, boundaries and issues, the interview has been addressed to understand if it was possible to calculate a single average tariff value per departing passenger, making reference to the current airport investments and infrastructures.

The person interviewed explained that, when considering a tariff, it is important to consider its forecast too. Tariff is one of the other parameters of this analysis that varies over the years, after passenger traffic. Even in this case, similarly to passenger traffic evolution. there are annual official forecasts, produced by every airport company that can lead to interesting results. ACI releases international benchmarks too. The current tariff on passengers processed in the test airport is of 30 euros per departing passenger. So the value considered in the analysis is:

- Dep. passenger tariff: 30 €/pax; for ease of use in the computation 15 €/pax have been considered for the total of departures and arrivals.

ROYALTIES:

Adopted value:	2.3 €/pax
Description:	Income from the sales of retail and restaurants.
Collection methodology:	Interview
About data collection:	The head of Commercial relations, directly working on the airport object of this case study, has been interviewed by the author.

After introducing to him the research aims, boundaries and issues, the interview has been addressed to understand if it was possible to calculate a parametric value to relate royalties to total terminal area, to total retail area or to departing passengers, making reference to the current situation.

The person interviewed explained that in the Annual Final Report an average value of expense per departing passenger is defined. In 2015 and 2014 it was 12 €/pax. The royalties on passengers' purchases into the terminal building resulted +20% of the total. Then 2.3 €/pax is the average royalty value per departing passenger.

Costs

While revenues depend also on the number of passengers processed by the terminal, costs are related in the computation to the terminal area or to energy consumption and maintenance.

TABLE 13 SAMPLE OF COSTS VALUES; EXTRACT OF PLANNING CATALOGUE, SHEET C1

	Description	Unit	Value
Costs (Cash Value)			
C_t	**Costs at time t**	eur	
C_0	Initial costs	eur	5.200
C_c	Unitarian construction costs	eur/m^2	4000
C_{flex}	Unitarian flexibility costs	eur/m^2	1200
C_o	Operation costs		33,36
C_{ener}	Unitarian Energy costs	eur/kWh	0,15
C_{clean}	Unitarian cleaning costs	eur/m^2	0,055
C_m	Maintenance costs		700
C_m	Unitarian Maintenance costs	eur/m^2	700

Initial costs (and expansion costs):

Adopted value: 5200 €/m^2

Description: Costs for new construction and additional costs for enhancing flexibility.

Collection methodology: Extraction

About data collection: The total cost is composed by the preliminary unit construction cost assumed in the planning phase of the test terminal, plus a

30% in flexibility advantage.

The unit construction cost results from the average of the total construction cost programmed for the whole new terminal of the case study:

- Unit construction cost: 4000 €/m^2

OPERATION COSTS:

Adopted value: 33.36 €/m^2

Description: This item describes mainly energy costs and cleaning costs, even if not relevant.

Human resources and purchase of equipment and devices have not been considered since not directly related to the behaviour of the architectural system.

Collection methodology: Interview and Secondary data sources

About data collection: The major part of this item is the energy cost. Having reduced energy consumption only to electricity supply, made the computation quite easier.

The Head of System and Plants Planning division has been interviewed, as explained in the "System parameters" paragraph. During the interview the issue of the airport cogeneration plant was addressed. In fact given the current performance of the cogeneration plant as airport power source, it has been suggested to adopt the energy commercial cost for the case study:

- Energy commercial cost: 0.15 €/kWh

MAINTENANCE COSTS:

Adopted value:	700 €/m^2
Description:	Unit annual cost for maintenance activities.
Collection methodology:	Extraction
About data collection:	The maintenance cost item required a work of abstraction of the desired information from existing reports. In particular it has been assumed the total investment cost for the case study terminal and its unit cost of 4000 €/m^2. Then the items of investments in new infrastructures and existing infrastructures maintenance have been compared. These items have been extracted from the Annual Report. In the end, maintenance investments are equal to 1/6 out of the new infrastructure works.

CAPACITY AND DEMAND DATA

In order to make the computation effective, it is necessary to track Capacity and Demand. When Demand exceeds Capacity a change in system is operated.

An example of Demand/Capacity tracking has been reported in the following table. It is a part of the sheet C1 of the Planning Catalogue tool implemented, belonging to the first iteration of the aOFAT Sequence (“C1|NPV input|aOFAT #1”).

The values change over time, since they depends on terminal area and on traffic scenarios.

TABLE 14 SAMPLE OF CAPACITY AND DEMAND ROWS; EXTRACT OF THE PLANNING CATALOGUE, SHEET C1

	Description	Unit	Value	Y1	Y2	Y3
				0	1	2
Capacity						
k	Capacity	pax/year		25.028.571	25.028.571	25.028.571
Demand						
D	Demand	pax/year		13.274.295	14.808.434	16.341.816

CAPACITY:

Adopted value: Capacity varies with the total terminal area. Each time an expansion occurs, capacity grows.

Description: Capacity describes the terminal’s ability to accommodate a certain number of passengers.

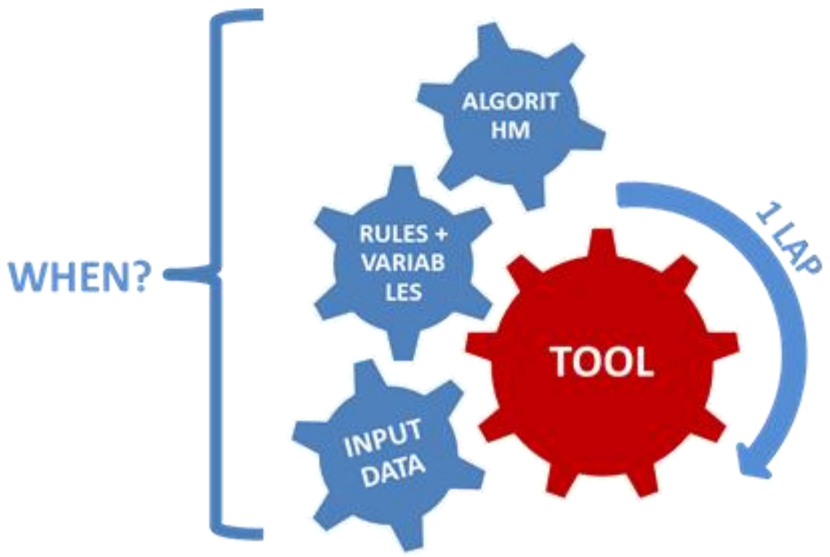
Collection methodology: Extraction

About data collection: Capacity is a function of total terminal area and Crowding index.

DEMAND:

Adopted value:	Demand varies every year, according to traffic scenarios.
Description:	Demand is the future requirement for passenger traffic and for terminal capacity. The Planning Catalogue methodology requires the statement of different traffic scenarios, leading to different Planning Vectors, starting from the traffic official forecasts.
Collection methodology:	Interview and secondary data sources
About data collection:	In this specific test, the linear scenario adopted follows the traffic forecasts. The forecasts for the case study have been extracted from the July 2016 forecast data-base, which is the basis of the Masterplan Report diagrams. The issue of traffic input is further analysed in Paragraph 11.4.

11.3 PRODUCING A TOOL



In Chapter 9 the application of the Catalogue was located in the whole process and process concept of Picture 46 was proposed. In Paragraph 10 the model for measuring the economic performance and effectiveness in the lifecycle was tailored to the test terminal. Beside a set of decision rules and planning variables was proposed, according to the test terminal. In the previous paragraph, the data collected was reported. In this paragraph, the set up of a spreadsheet tool is explained, based on the algorithm model adjusted to the test terminal, and on the set of rules and variables. In red the said topic, according to the research proposal synopsis.

A spreadsheet was set up according to the adjustments made on the model and on the set of decision rules and planning variables. The aim was to maximize automatization, in order to make any further integration easier and faster.

Despite the good level of automatization of the produced tool, a more efficient level of automatization is required in order to make the toolkit suitable for use by external professionals, without losing its flexibility. This should be the aim of further research and of the application of the tool to other cases or tests, as explained in Part 3.

The tool that has been set up is divided into the following sections:

- Index
- A: Planning vector combinations
- B: Demand scenarios
- C1: NPV inputs
- C2: NPV outputs
- D: aOFAT sequence
- E: Planning Catalogue

11.3.1 Report of the tool implementation

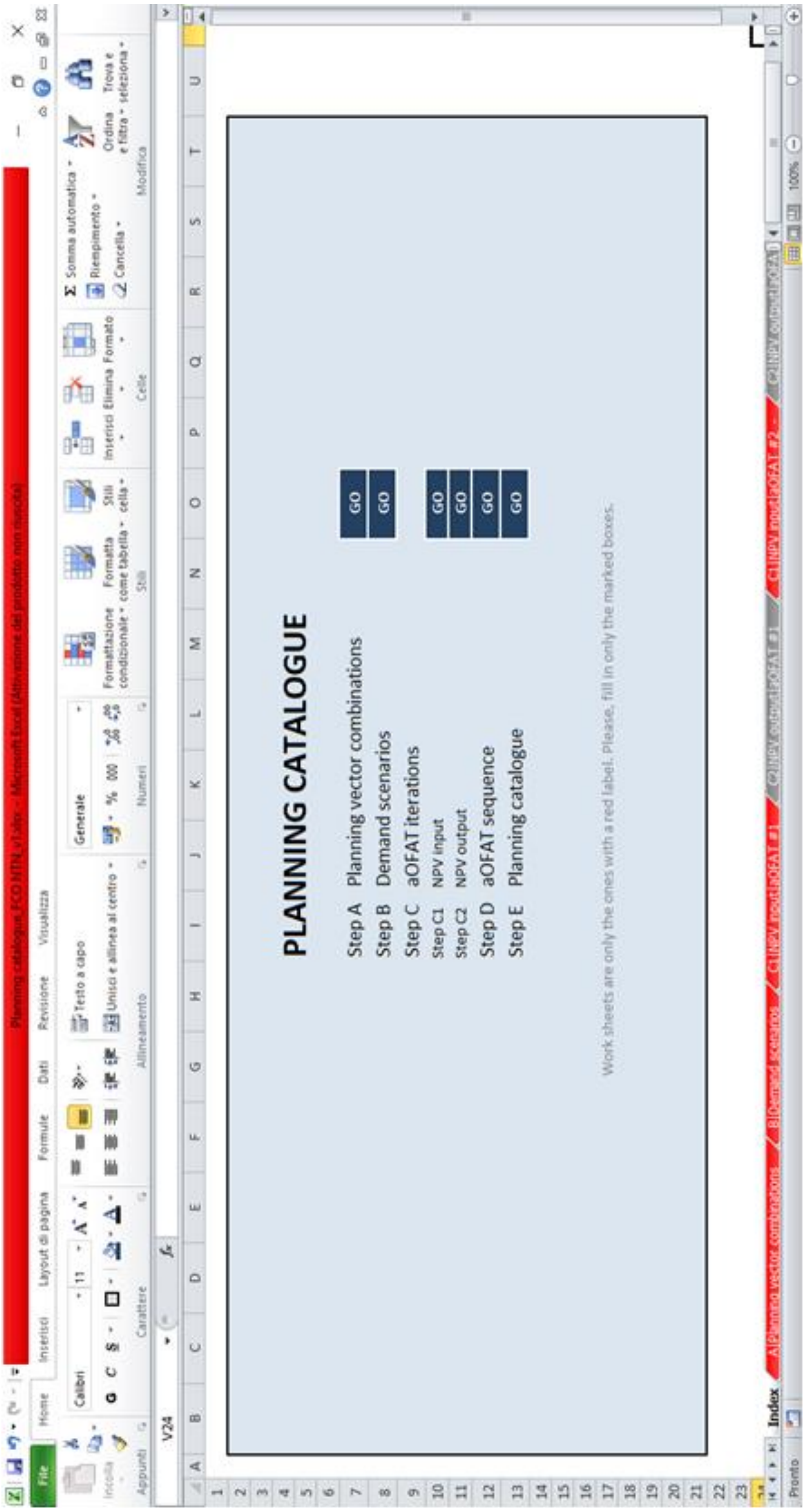
A tool has been set up, based on the LCC model adjusted to the test airport terminal, and while being produced in was tested through the inputs given by a data collection on field.

The tool has been implemented on Excel® spreadsheets.

The use of spreadsheets makes easier the availability of the tool, since it can be processed both via MS Excel® and OpenOffice®. This solution is typically adopted also by research units working for the Airport Cooperative Research Program, pertaining to the Transportation Research Board of the National Academies. Indeed ACRP often releases free tools set up on spreadsheets for the common use of Airport Companies worldwide, together with the proper un-locking code in order to make any customization by the users possible and easy. This makes these tools widespread, accessible, customizable.

This paragraph is making a deeper insight into Chapter 8, 9 and 10.

The sheets have been set up while being tested. During the test amendments and refinements have been done, gradually that the test went on. More research can be done in order to make the spreadsheet more automatized, without losing its customizability at the same time and to give it a better interface. These issues are recalled even in Part 3, and here summarized. Indeed, as explained in the paragraph dedicated to Sheet C1, this window of the spreadsheet (C1) at the moment requires that the user recognizes when the rules and variables make the "expansion" possible. In this way, the user can intervene with handy inputs in the C1 sheet making a change in the computation. This should be better highlighted to the users, before he uses the sheets; otherwise this operation should be made more automatized.



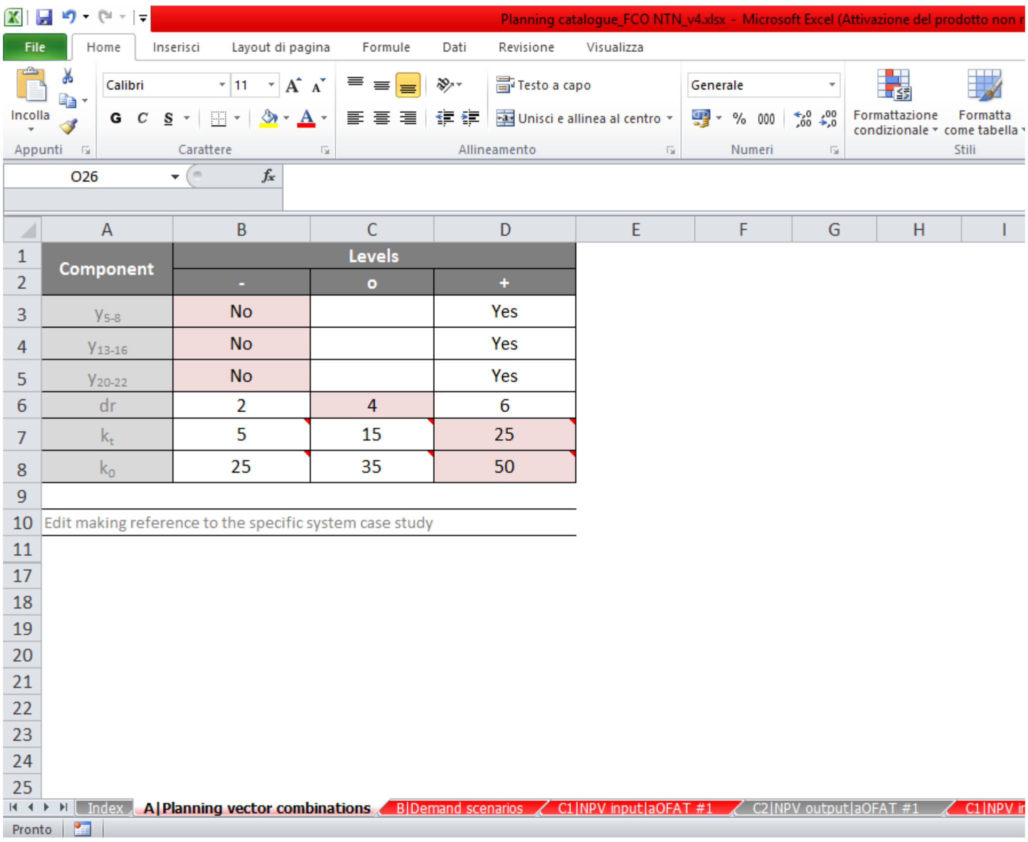
PICTURE 51 CATALOGUE SPEADSHEET, INDEX

SHEET A: DEFINING THE PLANNING VECTOR POSSIBLE COMBINATIONS

The first window is dedicated to the set up of the variables and rules necessary for the analysis. In order to make the spreadsheet easily adjustable and customizable, even during the test, these cells have not been locked.

There are not computational relations between cells in this sheet, but connection with the further sheets have been established in order to make this table's values leading the whole tool.

For ease of use, boxes representing the baseline design are highlighted in light red.



Component	Levels		
	-	o	+
y_{5-8}	No		Yes
y_{13-16}	No		Yes
y_{20-22}	No		Yes
dr	2	4	6
k_t	5	15	25
k_o	25	35	50

PICTURE 52 CATALOGUE SPREADSHEET, SAMPLE OF PLANNING VECTORS COMBINATIONS

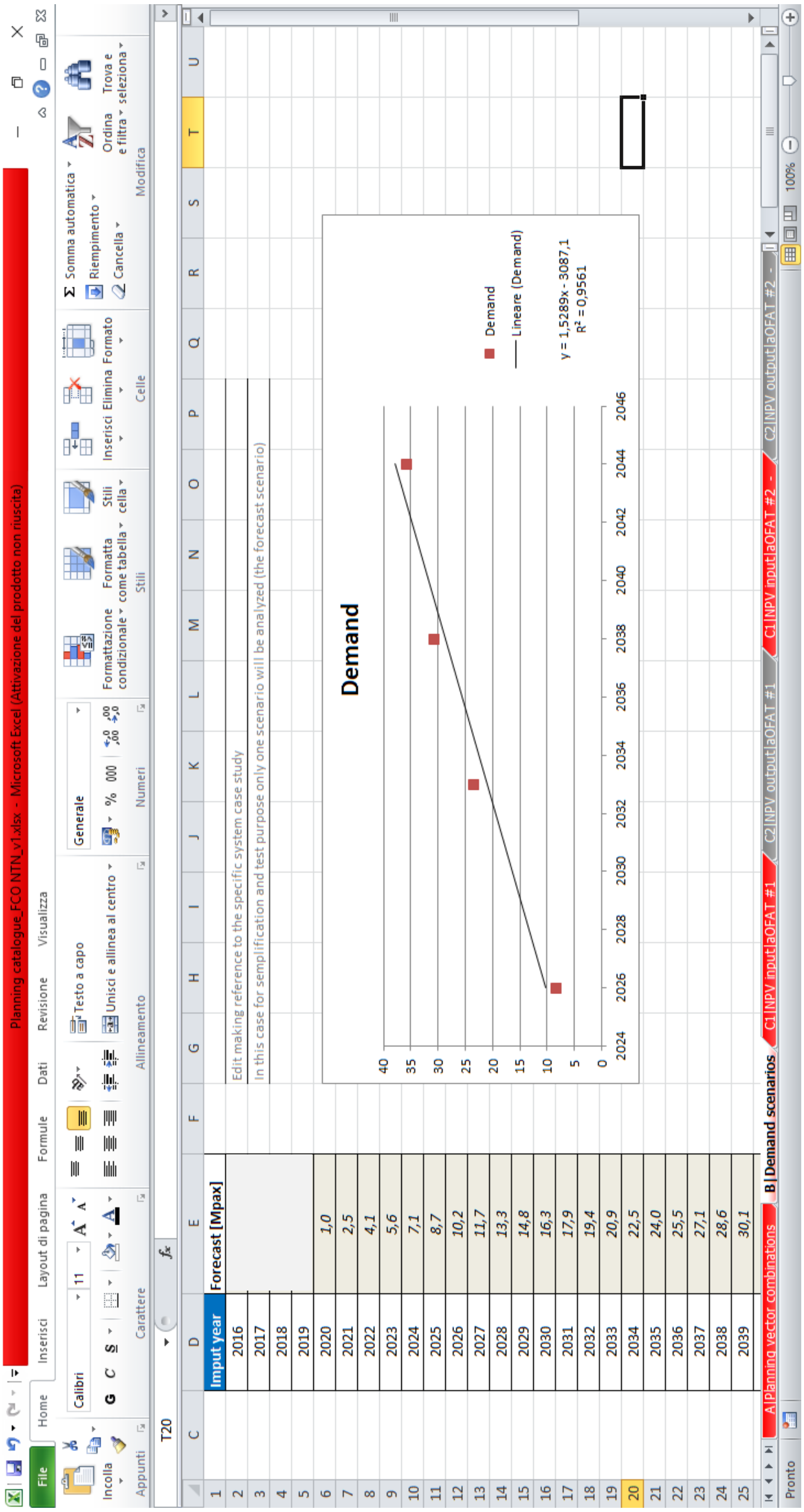
SHEET B: DEFINING UNCERTAINTY SCENARIOS

In this test, only one scenario has been analysed. The scenario concerns a linear demand distribution during the study period, which traces the up to date traffic forecasts. The issue of traffic input is further analysed in Paragraph 11.4.

This consists of a work sheet for the collection of demand data, with no computation input. A chart supports the graphic comprehension of the traffic distribution.

Connections between the demand cells corresponding to the test years and the further sheets (C1 sheet) have been established. Indeed in C1 the traffic is continuously compared with demand, in order to calculate the revenue and cost outputs.

In a complete execution of the computation this sheet has to be changed and adjusted in function of the other different demand scenarios.



PICTURE 53 CATALOGUE SPREADSHEET, SAMPLE OF UNCERTAINTY SCENARIO: LINEAR GROWTH

SHEET C1: DEFINING THE INPUT FOR EACH AOFAT ITERATION

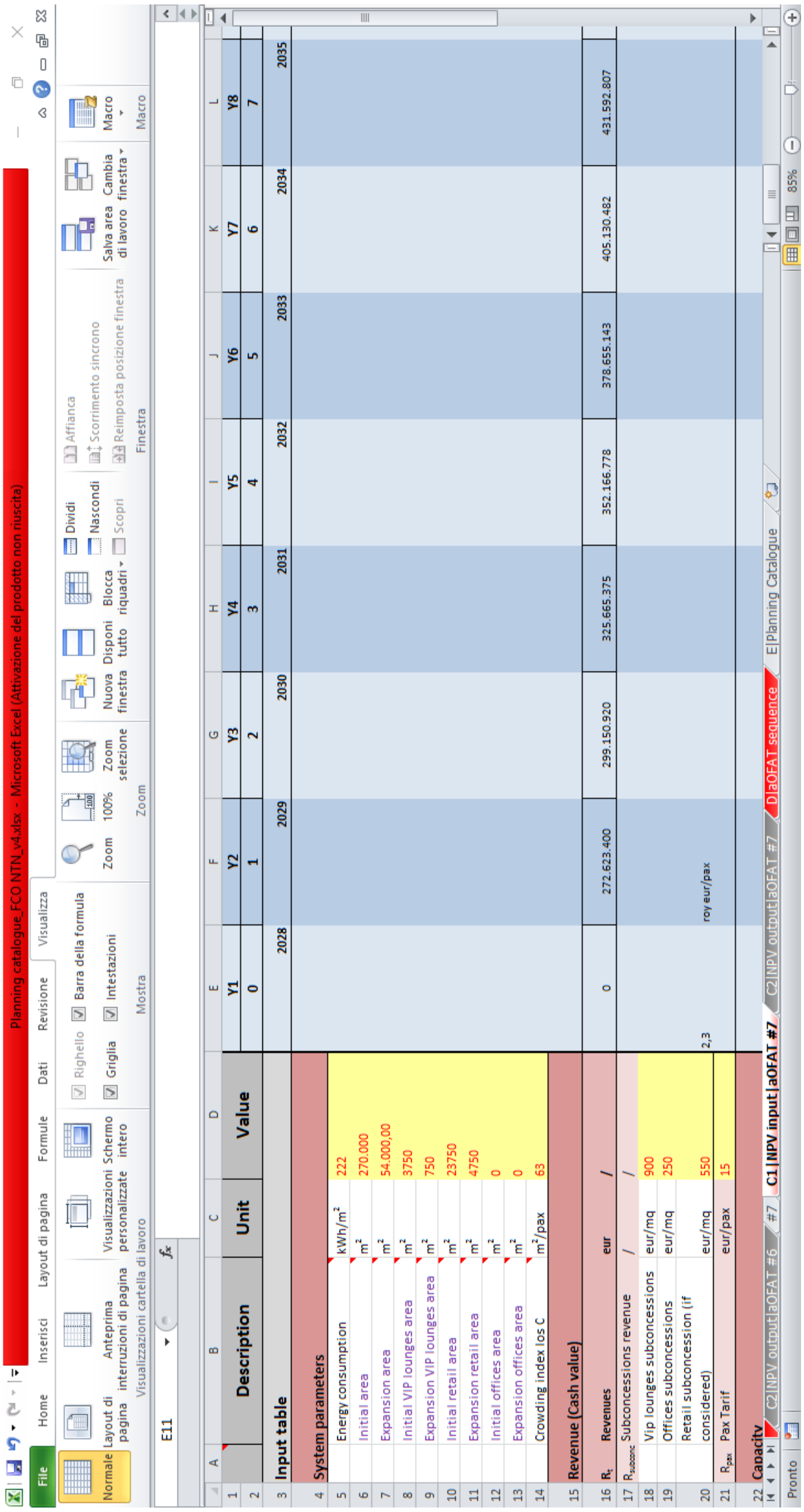
The C1 spreadsheet is the input part for the NPV computation executed in sheet C2. It uses values of the previous sheets: planning vector values (sheet A) and traffic values (sheet B); then it adds numbers concerning costs, revenues and system parameters. Each NPV computation measures the performance of a specific variable or rule of sheet A; this computation corresponds to each one of the aOFAT (adaptive one-factor-at-a-time) iterations of the entire aOFAT sequence. Then, for each demand scenario, one aOFAT sequence has to be developed, with its own NPV assessments for any iteration of the sequence.

The input table has been divided into five groups, concerning the typology of information and data input:

- System parameters;
- Demand;
- Capacity;
- Revenues;
- Costs.

Part of this information is determinate and does not change over time; or it is the basis for further data to be extracted through proper calculations. On the left side yellow boxes have to be filled (handy input) with this kind of information. Whereas on the right side timeline accommodates the data changing over time.

The computational relation between the time-scanned blue boxes and the fixed yellow ones is the real core of the NPV computation. At the same time a complete automation of the sheet is not easy. In fact at the moment it is required that the user of the spreadsheet understands when the rules and variables make the “expansion” possible, in order to intervene in the C1 sheet making a change in the computation. This occurs for these time-scanned blue rows: capacity; revenues; costs. In fact they all are affected by any change in square meters over time. A more flexible interface in this case would be helpful for the final user, that could avoid mistakes in computation and consequent loss in time. Otherwise the user should be informed before approaching the computations in this sheet. Further research would be helpful in this way.



PICTURE 54 CATALOGUE SPREADSHEET, DEFINING INPUTS FOR THE FIRST ITERATION

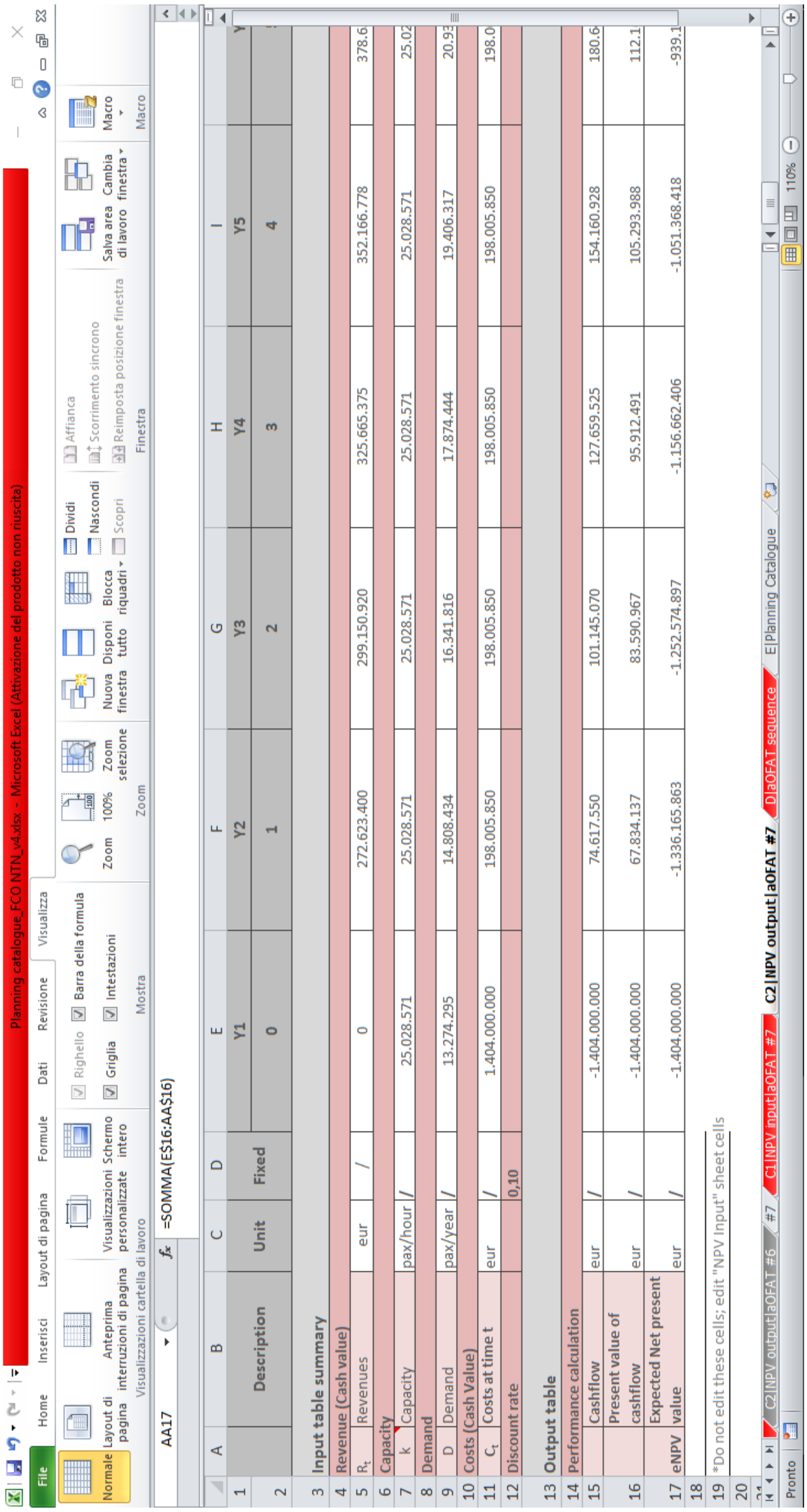
SHEET C2: NPV OUTPUT FOR EACH AOFAT ITERATION

The C2 spreadsheet is the output part of the NPV computation. It acquires all the necessary input information from sheet C1. Again, each NPV computation measures the performance of a specific variable or rule. So beside a C1 sheet, a C2 has to be repeated for any iteration of the aOFAT sequence related to every scenario.

The user does not have to work on this window, since it is entirely computerized. Every change in C1 determines a change in C2, with an up to date NPV. The sheet indeed works as a summary of the results of C1 sheet and calculates the NPV.

Demand, Capacity, Revenues and Costs are recalled from C1 in the first rows.

Then the Cashflow for each year of the timeline is calculated. The Present Value of cashflow is defined. In the end, the expected Net Present Value results.

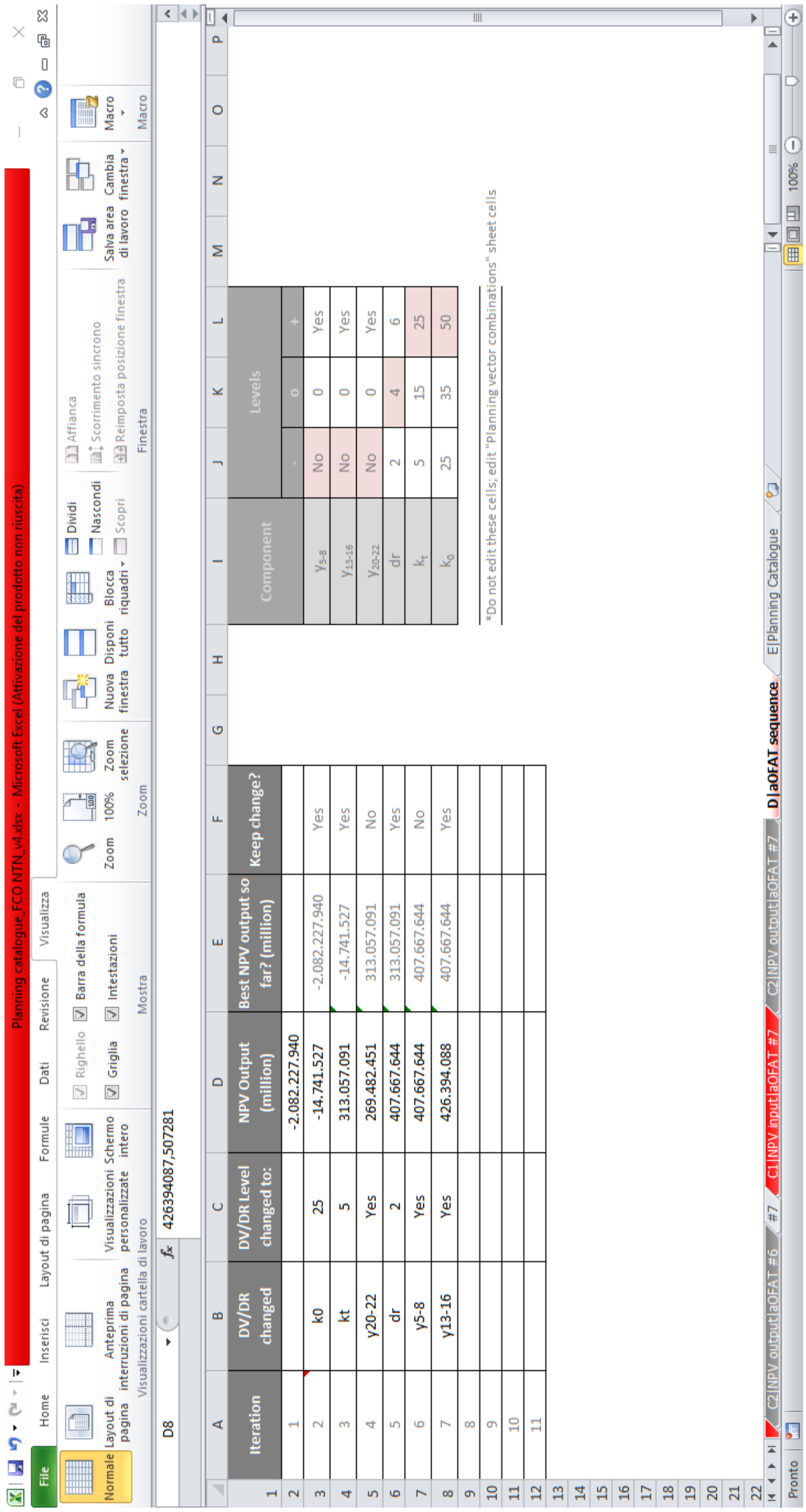


PICTURE 55 CATALOGUE SPREADSHEET, DEFINING NPV FOR THE FIRST ITERATION

SHEET D: aOFAT ITERATION

One iteration routine in function of a single uncertainty scenario is exemplified in the following picture. The execution of one “lap” of the tool allowed a better set up of it, and has been conducted while set up was going on. Then it also allowed to check the applicability rising the catalogue complexity to airport design level. This arrives to functionality check. The full decision support level and the portability issues to other applications are left to future research.

Columns B, C, D, require input by the user. The NPVs resulting from step C has to be reported in column D. It is compared with the best NPV obtained, in column E and F. Columns E and F are computerized and give the user an answer on how to proceed in the aOFAT iteration, through a yes or no answer.



Iteration	DV/DR changed	DV/DR Level changed to:	NPV Output (million)	Best NPV output so far? (million)	Keep change?
1			-2.082.227.940		
2	k0	25	-14.741.527	-2.082.227.940	Yes
3	kt	5	313.057.091	-14.741.527	Yes
4	y20-22	Yes	269.482.451	313.057.091	No
5	dr	2	407.667.644	313.057.091	Yes
6	y5-8	Yes	407.667.644	407.667.644	No
7	y13-16	Yes	426.394.088	407.667.644	Yes
8					
9					
10					
11					

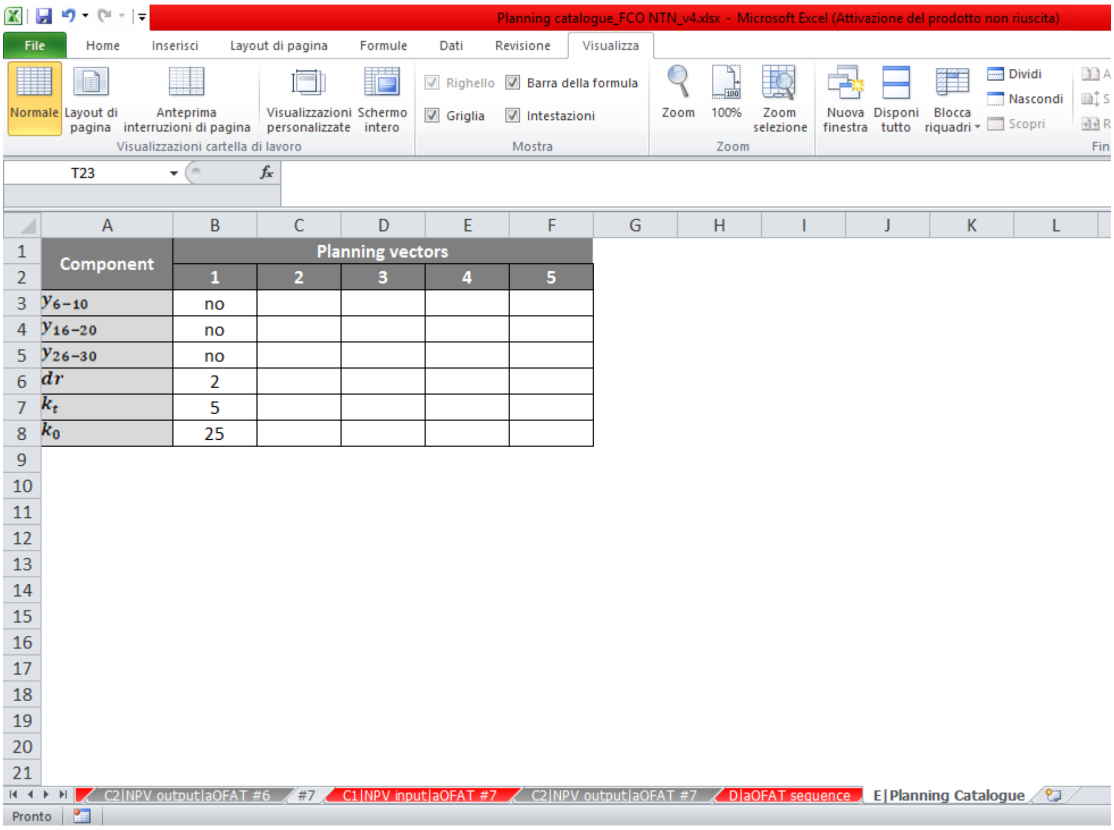
Component	Levels -	Levels 0	Levels +
y_{5-8}	No	0	Yes
y_{13-16}	No	0	Yes
y_{20-22}	No	0	Yes
dr	2	4	6
k_t	5	15	25
k_0	25	35	50

*Do not edit these cells; edit "Planning vector combinations" sheet cells

PICTURE 56 CATALOGUE SPREADSHEET, AOFAT ITERATION

SHEET E: PLANNING CATALOGUE

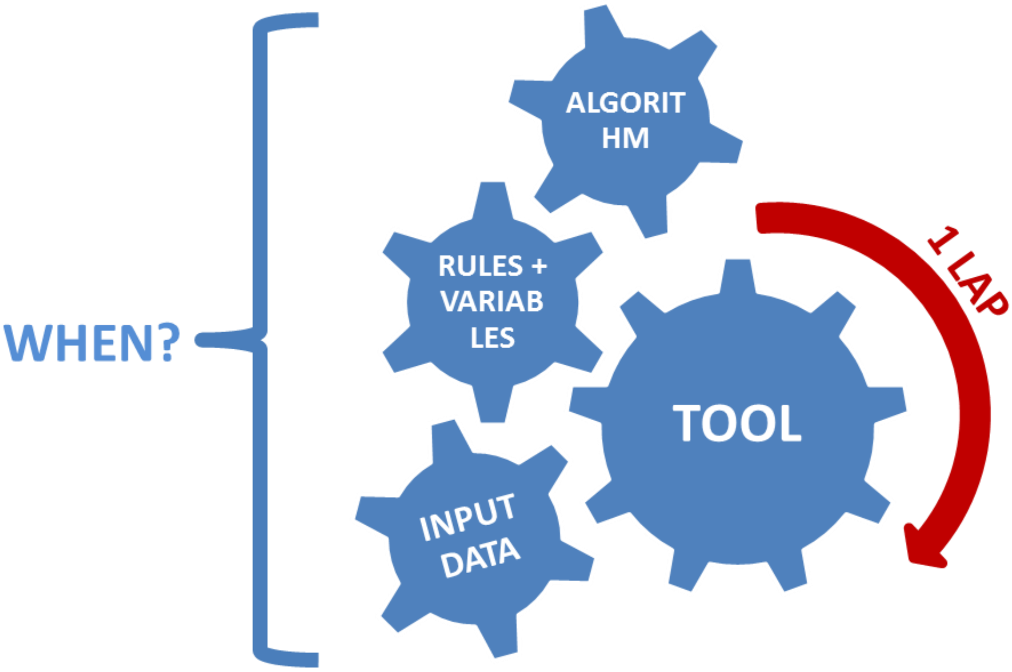
Step E has not a computational purpose. This sheet is not a computational sheet, but has only a report aim. It has to be filled while sequences are completed.



Component	Planning vectors				
	1	2	3	4	5
y_{6-10}	no				
y_{16-20}	no				
y_{26-30}	no				
dr	2				
k_t	5				
k_0	25				

PICTURE 57 CATALOGUE SPREADSHEET, PLANNING CATALOGUE

11.4 Testing the model



In Chapter 9 the application of the Catalogue was located in the whole process and process concept of Picture 466 was proposed. In Paragraph 10 the model for measuring the economic performance and effectiveness in the lifecycle was tailored to the test terminal. Beside a set of decision rules and planning variables was proposed, according to the test terminal. In the previous paragraphs: the data collected was reported; the set up of a spreadsheet tool was explained, based on the algorithm model adjusted to the test terminal, and on the set of rules and variables. In this paragraph is summarized the results of the execution of one "lap" of the tool to functionality check. In red the said topic, according to the research proposal synopsis.

The iteration of the spreadsheet allowed a better set up of it, and has been conducted while set up was going on. Then it also allowed to check the applicability rising the catalogue complexity to airport design level and arrives to functionality check. The full decision support level and the portability issues to other applications are left to future research.

The test has consisted into generating one operating plan for one fixed demand scenarios. In order to better understand this chapter, the reader is returned to Part 1, where the full steps of the Catalogue methodology were properly described.

In order to manage the test, the main inputs have been:

- Infrastructural data
- Economic data
- One traffic scenario fixed starting from the airport forecast.

11.4.1 Traffic scenario considered

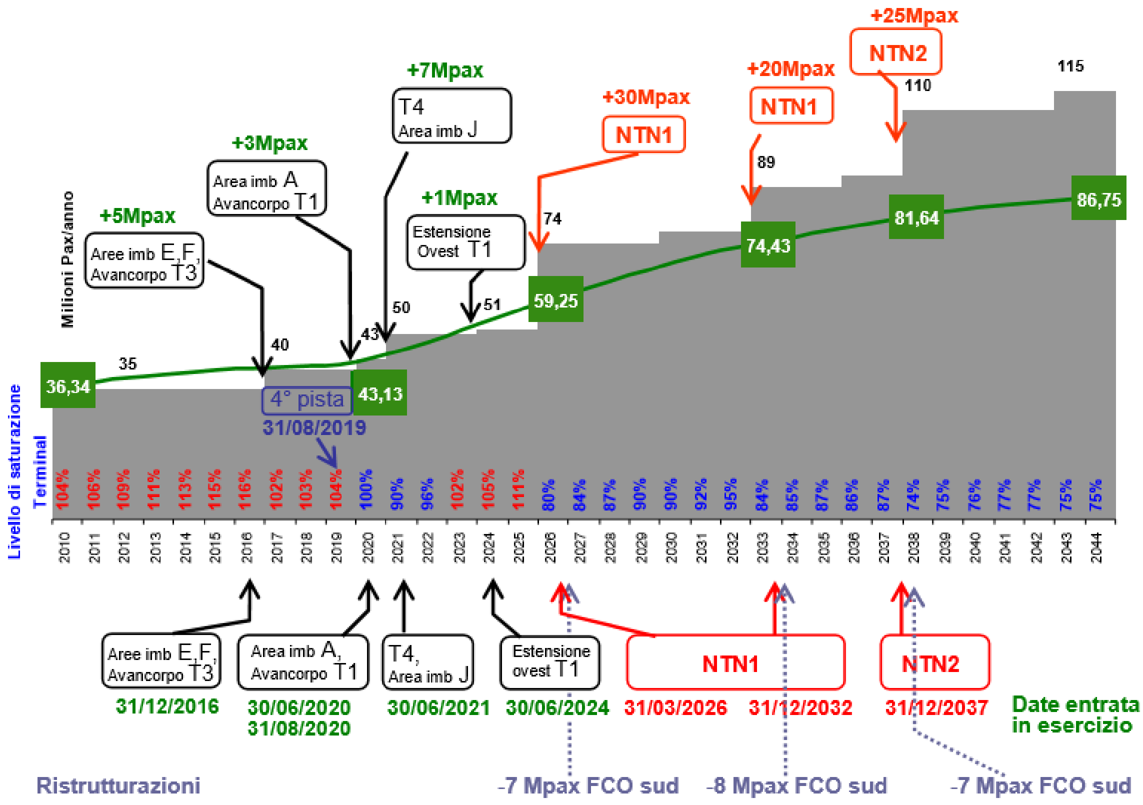
For checking purpose, one scenario is taken in consideration in order to test the model tailored to the test airport terminal and the spreadsheet, verifying the applicability rising the catalogue complexity to airport design level. Then one full iteration of the computation is made and one planning vector is calculated.

A quick digression about uncertainty in airport life cycle is proposed, in addition to the focus proposed in Chapter 4.

As deeply shown in Part 1, given the infrastructural nature and vocation of an airport terminal, the main uncertainty source for the lifecycle performance of an airport terminal is the demand for air transport. Airport companies periodically produce traffic forecasts, for airport management purposes. While only future forecasting is possible for airport companies, the forecasted numbers are not necessarily verified. In the end, identifying a probable set of uncertainty scenarios, as inputs to the Catalogue, means describing the sources of uncertainty for the lifecycle performance.

The traffic forecast for the airport of the terminal object of the test is summarized in the picture below, together with the related programme for capacity expansion that should cope with accommodation of forecasted demand.

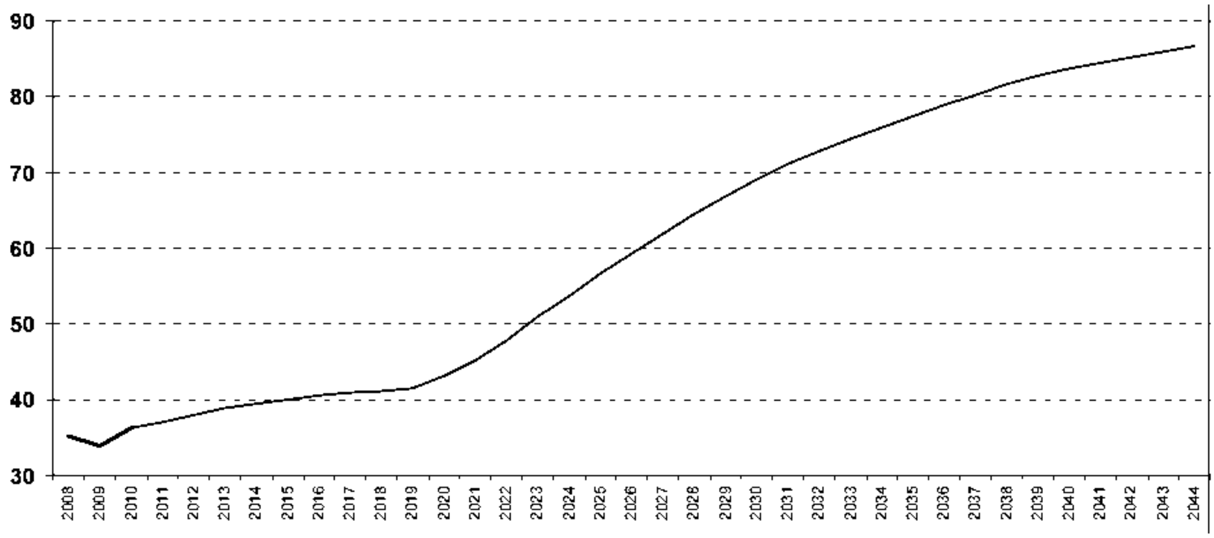
The scenario adopted in the test represents a linear growth in passengers, in accordance with what depicted below.



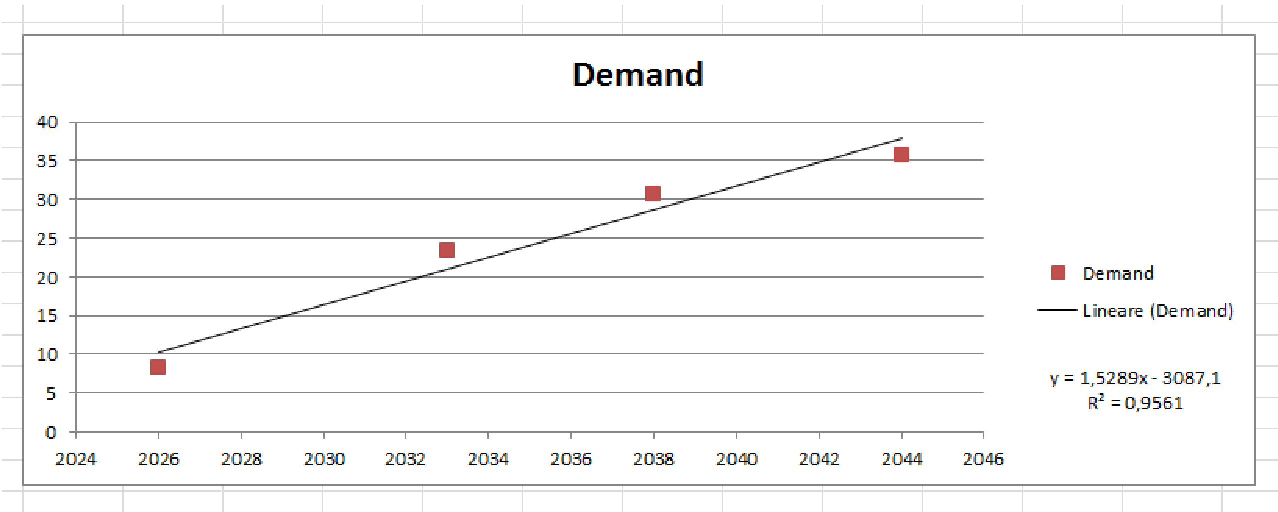
PICTURE 58 AIRPORT TRAFFIC FORECAST ACCORDING TO ECONOMIC REGULATION AGREEMENT

In red NTN stands for a completely new terminal infrastructure, to be constructed within the next decades and object of the test, corresponding to the test terminal described in Chapter 8. Then the graphic explains that while in 2022 forecasted passenger traffic exceeds capacity, a few years later the construction of the New TN can deliver an additional capacity. The green line represents the traffic forecast, that is what is interesting for us since it represents the expected growth in passengers.

Picture 5959 and **Errore. L'origine riferimento non è stata trovata.**60 represent the traffic forecast of the airport company and the linear growth scenario considered for this test.



PICTURE 59 PASSENGER TRAFFIC FORECASTS FOR THE TEST AIRPORT



PICTURE 60 LINEAR PASSENGER TRAFFIC SCENARIO CONSIDERED

11.4.2 PERFORMING THE CHECK

Picture 61 shows the 7 iterations that was conducted during the test. Starting from the linear traffic scenario,

a. The input data were put in the tool

b. For each of the planning rules and variables, the Levels that they could assume were varied one at the time; the order of variation was a random order

c. According to the one traffic scenario considered (linear growth), the NPV was defined for each planning rule/ variable level assumed

d. If the NPV resulting was lower than the previous one, the level of the planning rule/variable under consideration was varied; otherwise the level was kept and became a milestone of the final planning vector

At the end of each iteration, the final planning vector was defined, which was the best vector in terms of performance responding to the scenario in consideration (linear growth). The iteration due to the changing of planning rules/variables levels were 7 in total, as shown in Picture 6161, before reaching the definition of the whole vector (of 5 numerical components).

Iteration	DV/DR changed	DV/DR Level changed to:	NPV Output (million)	Best NPV output so far? (million)	Keep change?
1			-2,08		
2	k0	25	-14,74	-2,08	Yes
3	kt	5	313,05	-14,74	Yes
4	y20-22	Yes	269,48	313,05	No
5	dr	2	407,66	313,05	Yes
6	y5-8	Yes	407,66	407,66	No
7	y13-16	Yes	426,39	407,66	Yes
8					

9					
10					
11					

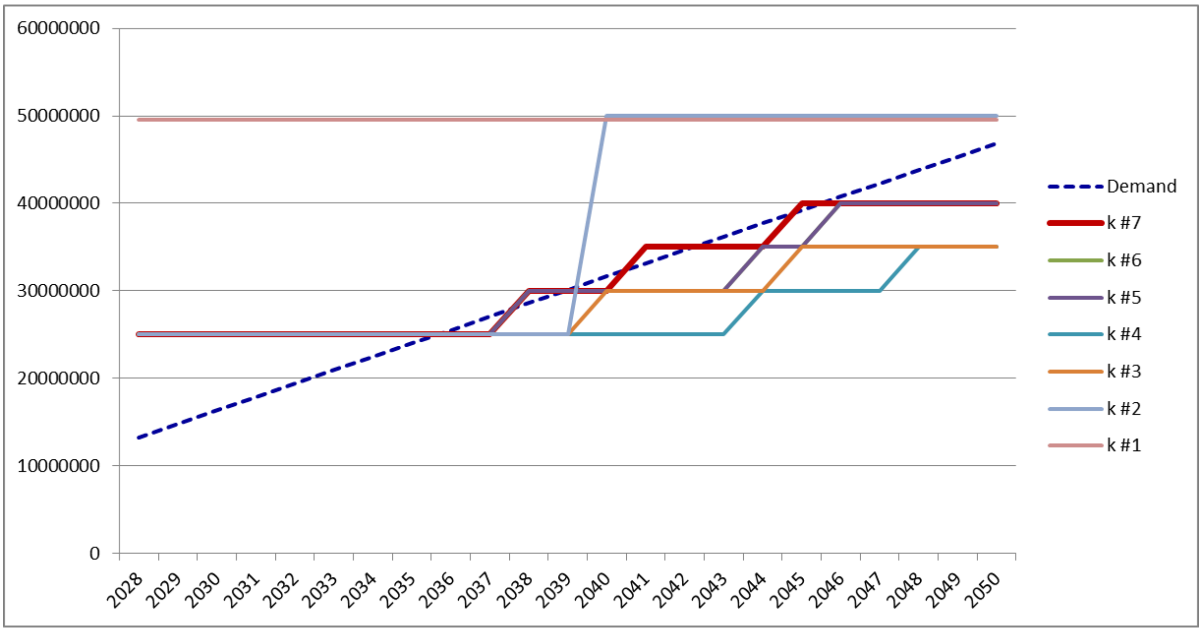
PICTURE 61 DIFFERENT OUTPUTS OF EVERY ITERATION

At the end of the test, the operative plan reported in Picture 6262 defined. In particular Picture 6262 shows that the “winner” combination of planning rules/variables levels assumes that: in years 5-8, 13-16, 20-22 no expansion will be allowed by the decision makers. Moreover, a good delay in taking the decision of expanding in presence of such demand scenario is 2 years, giving a good performance. That means that, in presence of a linear growth, the decision maker could afford not be so prudent and allow an investment of expansion even before just a few months that the traffic exceeds the terminal capacity. In the end, a good performance (always in terms of NPV) is given by an initial capacity of the terminal of 25 MPPY and of “small” expansion interventions in a sequence, of 5 MPPY each.

Component	Planning vectors				
	1	2	3	4	5
$y_{5\text{-}8}$	no				
$y_{13\text{-}16}$	no				
$y_{20\text{-}22}$	no				
dr	2				
k_t	5				
k_0	25				

PICTURE 62 PLANNING VECTOR PRODUCED

Errore. L'origine riferimento non è stata trovata.63 represents the comparison between the demand scenario adopted for the computation of this specific planning vector (the dashed line) and the capacities of the terminal obtained at each iteration. The “winner” iteration is number 7, in red, and it is the one that has the best performance in terms of NPV in the life cycle. It shows a clear progressive expansion with “small” works in a sequence, as the best solution to face a linear growth scenario. This chart describes the k_0 and k_t values of the vector represented in Picture 55.



PICTURE 63 DIFFERENT CAPACITY PERFORMANCE OBTAINED DURING THE 7 ITERATIONS OF THE AOFAT SEQUENCE, COMPARED WITH THE DEMAND TREND

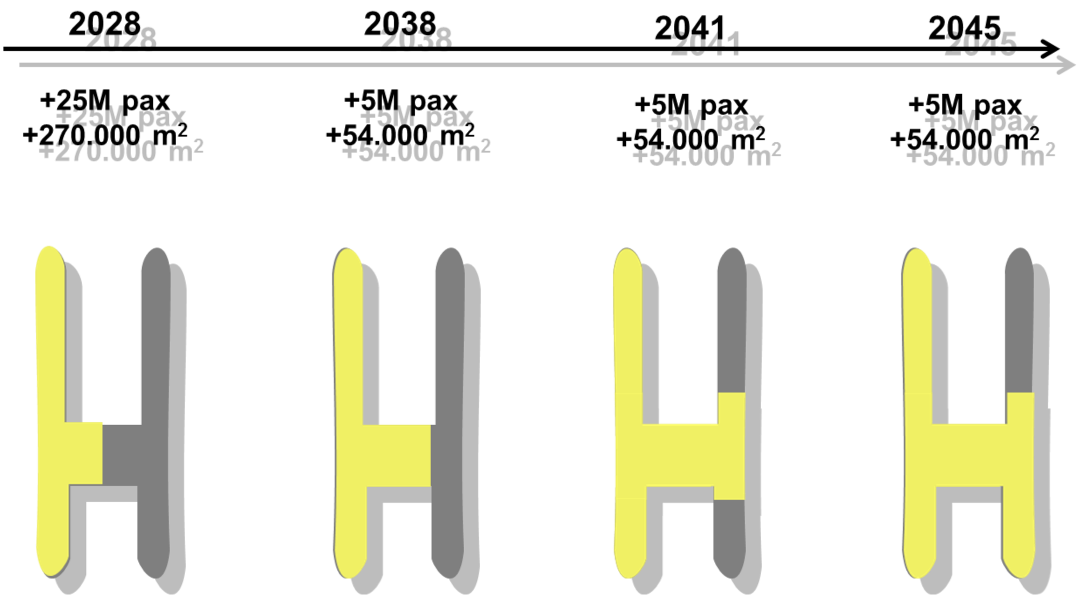
11.5 CONSIDERATIONS

What does this operative plan mean in the planning phase and to an airport planner?

The planning vector represented in Picture 6262, related to the capacity showed in **Errore. L'origine riferimento non è stata trovata.**63, states that, in case the passenger traffic followed the trend corresponding to demand scenario 1 (the only scenario considered in this test), the terminal should display this behaviour:

- ✓ It should be built to accommodate a traffic of 25M passengers per year
- ✓ The planner could wait about two years before expanding capacity; in this time frame, demand accommodation would be capped by an insufficient capacity. Demand would exceed capacity

- ✓ After said two years, the terminal could be expanded by airport planners for an additional capacity of 5M passenger per year, without losing the economic performance of the system
- ✓ Expansion is not considered in the initial and final years of the analysis period, as it does not bring any additional value to the whole performance



PICTURE 64 EXEMPLIFICATION OF THE "H" TERMINAL CAPACITY PROGRESSION IN RESPONSE TO THE DEMAND SCENARIO

<u>Why such an operative plan could be selected?</u>

The application has led to one operative plan, responding to a linear demand scenario. By defining more demand scenarios, more operative plans could be computed, using the very same computation process applied for this single operative plan.

Having such a set of possible and effective operating plans, responding each to a different demand scenario, means that the operation phase can be managed in a more guided way. In addition to the operating plan (planning vector) of this field test, more plans could be added to the catalogue in order to have a range of effective choices. As soon as demand occurs, the development of the terminal can be properly adjusted to the real necessity, with the support of the catalogue.

So the catalogue is a tool for aiding the entire development of the terminal, not only the initial phase of the very first construction and its design. The use of the catalogue would ensure that the whole terminal upheld a good performance during its lifecycle, from its construction, during its operation, until the end of the period of analysis.

In Picture 58 is represented the development expected for the terminal object of this field test, without the application of the catalogue: on the left the full terminal building is depicted, with its additional capacity of +50 million passenger per year. The catalogue, instead, proposes a different way of operating the construction: to identify an effective phasing of the construction process, ensuring a good performance of the whole terminal system, according to a probable traffic demand.

<u>And how would this operative plan and the whole Catalogue affect the design?</u>

During the planning process design brief is produced. In case of a complex project such as airport terminal several requirements by planner are included within this document. In particular, considering the evolutive nature of airport terminal, that is mainly due to the necessity to adapt to a continuous change (increase) in passengers flow, flexibility should be required from the designer as a feature of the final product.

Yet, flexibility must answer to changes that are not defined, and thus characterized as “unknown”. We understand that there will always be changes, but we cannot specify where the building will need them, or when the change will be needed, or what change will be needed. These changes will involve e.g.: the special planning; the number, location and typology of check-in counters; the number, location and typology of security checks; the total area and configuration of commercial areas; the number of gates, with their technological equipment and the configuration of remote gates or loading bridge gates; the total area dedicated to boarding; the waiting area after security checks; etc. We are asked to make designs flexible to meet future unspecified changes, gaining “sustainable” designs (Sher, 2013).

Here the Catalogue helps. In fact it suggests the planner - that has to specify every requirement to the designer - exactly what modification could occur in case of a specific change condition. The Catalogue **fills the gap between this need for future flexibility together with the ability to embrace change, and the inability to accurately predict this change, the certainty of uncertainty.**

Moreover, through the Catalogue uncertainty is identified and operative flexibility characterized. As a consequence, requirement for environmental and product flexibility can be addressed more effectively in the design brief, granting a more solid possibility to obtain a successful performance of the final building in its lifecycle.

How to approach flexibility?

Flexibility in planning and design is neither a number nor a vector; they just establish the base for further thinking. The Catalogue informs design. But a mere deterministic approach does not suffice to design flexibility.

The approach to flexibility must be practiced and optimized by the planning and design team. An interesting solution is the guided brainstorming exercise proposed by Cardin (2013), to create consciousness and confidence in thinking flexibly.

A deterministic approach has been confirmed as a valid approach for the specific application case. On the basis of this experience it is to be expected to be a useful tool for other applications, too. And it may also help to transfer the catalogue model to application practice. Indeed, the system lifecycle complexity is usually difficult to manage in the planning phase, whereas the catalogue methodology conveys a reasonable and measurable result. Furthermore, computations are the basis for all planning (and later design) actions into airport companies.

The translation of the Planning Catalogue outputs into design requirements is the main issue; starting from the model produced in this research and the tool provided, it should be carefully reviewed each time the planner approaches a new project, paying attention to the specific issues presented by the case. The attention of the user should be on checking that the main units used in the model and in the tool are the same (data collection can be homologous to the one conducted in this research?). Then the model should be carefully reviewed: are the cost and revenues considered as relevant to the life cycle performance valid also for the new application? Or they should be reviewed in accordance to the most heavy items in the Annual Report of the specific application? The more specific the flexibility requirements will be, the more the design team will answer with an effective design solution.

The design team has to answer the specific flexibility requirements, also by setting up its own flexibility design approach. Many efforts have been and are currently being done by design and research teams in order to address the issue of integrating requirements in design. The planning (and also the design) team should understand how to transpose Catalogue outputs into desirable solutions and systems necessary to gain flexibility, leading to the benefits of achieving adaptability. Then, beside the outcomes that might derive from the Catalogue, the team should address potential design solutions in terms of products, systems or tactics.

PART 3

THE WAY AHEAD

In short…

In Part 3 the reader will understand and learn:

- The keypoints of the critical discussion of the research developed, articulated into strengths and weaknesses
- The summary of the lessons learned during the doctoral thesis and the way ahead, towards new research opportunities

12. DISCUSSION

This chapter highlights all the limits and the starting points for future research identified during the research path.

Strengths	***Weaknesses***
A. Innovation in project design management: towards a smarter process B. Facing uncertainty through flexibility C. Validation on field with real data from the industry	A. Many facets of uncertainty B. Looking for more validation experiences C. Need for automatization and ease of use
Opportunities	***Threats***
A. Interest of the professionals in the proposal B. Team education and training possibilities C. Possible future upgrades of the research, according to the main open points of interest	A. Scarcity of data and lack of integration of efforts B. Lack of training of the team and sensitivity of the work environment C. Difficulties of application outside a business company

12.1 WEAKNESSES

A. MANY FACETS OF UNCERTAINTY

The model tailored to the specific airport terminal test was devised on the premises of the main requirement for this kind of infrastructure, that is passenger air transport demand. Traffic is the very first item affecting the life cycle of a terminal, being the main requirement that a terminal has to respond to; at the same time, flexibility could address other issues.

The methodology proposed produces a reasonable result in a reasonable time and through a reasonable effort. The further the timeline progresses, the more uncertainty becomes a threat. A more complex approach, though less manageable, could include other factors of uncertainty, such as discount rate and tariffs, which cannot ensure consistency over time.

B. LOOKING FOR MORE VALIDATION EXPERIENCES

This research work has as its foundation the ongoing research activity concerning the possibilities of application of a lifecycle approach to address uncertainty and gain flexibility. In particular, it makes reference to the Design Catalogue methodology, an interesting research product, still open to new applications for a large scale validation.

C. NEED FOR AUTOMATIZATION AND EASE OF USE

Airport companies, as any other contracting authority dealing with the planning of design requirements, are not interested into time consuming processes, even if they could add value to the company. Lack of a complete automatization of the methodology and ease of use could result in failure: this is said as a warning for any future research development.

A similar case is represented by the IATA (International Air Transport Association) capacity computations: they are not automatized, but are very simple and well explained to users through dedicated manuals. IATA computations are commonly employed in airport planning departments in order to address the main design requirements in terms of dimensioning the environmental units of a terminal.

12.2 Strengths

A. Innovation in project design management: towards a smarter process

The proposed process intends to implement a lifecycle perspective in planning activities, in order to make the contracting authority able to identify uncertainty and address proper flexibility requirements. The designer should respond to this need, achieving a final product characterized by a sustainable performance during its entire life cycle.

Moreover, the information concerning times and costs related to the performance of the product could serve as an input to an evolved asset management tool – e.g. 5D BIM -, in order to control the behaviour of the asset during its whole life cycle.

B. Facing uncertainty through flexibility

The proposed methodology addressed operation flexibility embracing change and uncertainty. In this way, the designer is also able to include a concrete reference to environmental and product flexibility.

Moreover, Flexibility in planning and design is neither a number nor a vector; the number establishes the base for further thinking. A mere deterministic approach does not suffice to design flexibility. Approach to flexibility has to be exercised and optimized in the planning and design team. An interesting solution is the guided brainstorming exercise (Cardin 2013), to create consciousness and confidence in thinking flexible.

C. Validation on field with real data from the industry

The research was conducted by making reference to real data and on account of a field experience, in addition to a desk research and a global deductive approach. This adds value to the work, as it addresses industry stakeholders and aims at a final application of the research proposal to the professional field.

12.3 Threats

A. Scarcity of data and lack of integration of efforts

The proposed process would fail to address all the flexibility requirements in case that the planning team could not obtain or have access to all the necessary data, and in case the co-workers failed to express support or receptivity in integrating their knowledge in the process.

B. Lack of training of the team and sensitivity of the work environment

Given the importance of integrating effort in the work environment, lack of proper training could be a source of failure for the effectiveness of the process.

C. Difficulties of application outside a business company

The effectiveness of the proposal depends on the integration of knowledge and information by the planner, during the definition of requirements. This means that a successful application is possible only in presence of an integrated working environment, appropriate to a business company.

12.4 Opportunities and way ahead

A. Interest of the professionals in the proposal

An opportunity for this research lies in the interest that the professional field and airport companies could show for the proposal, for concrete, on-field applications. This could translate into more tests, validation and improvement opportunities.

B. Teams education and training possibilities

Training opportunities for professionals could spread and attract the interest of the professional field to a process integrated with the concepts of life cycle approach and flexibility. In addition to that, education for students through academic seminars –yet ongoing- focusing on the main concepts of life cycle approach, life cycle costing and flexibility, could draw attention and interest of future professionals on the issue of integrating a life cycle perspective in architectural design.

C. *POSSIBLE FUTURE UPGRADES OF THE RESEARCH, ACCORDING TO THE MAIN OPEN POINTS OF INTEREST*

In consideration of the main weaknesses and threats, opportunities for this work lie in its possible future developments:

- **Portability to other terminal cases and Guidelines for application of the results to other cases**

  Generalization and **portability** of the results of this research to other cases is issue of further research, requiring a proper **scientific validation**. In particular the portability to other cases should start from the model and spreadsheet tool set up in this work. Further research should validate it comparing with parametric data and statistics. Useful sources of statistic data coming from airports worldwide are typically developed by Airport Council International (ACI). Access to these databases is not open nor free, but would help in reaching the validation or integration of the model developed.

  The model proposed in this research is tailored to an international hub, 1st in Italy and 7th in Europe for passenger traffic. Then the items involved in the computation are common costs and revenues for any Civil Aviation terminal. In any case before using it on other cases, without a scientific validation of its portability, as explained in Chapter 10 and 11, the user should: check the data available and then the units involved in the computation; check the main and heavier costs and revenues items to be considered, according to the Annual Report of the specific Airport Company.

  Proper **guidelines for application** of the results of this research to other cases should be a task for future research.

- **Guidelines for use of the tool**

The research set up a spreadsheet tool based on the algorithms proposed. It should be supported by a booklet reporting guidelines for use, together with any unlock code for its customization. Editing of the booklet is left to future research.

- **Tool upgrading**

As explained before, the opportunities for a methodology aiding planning processes are concrete in presence of a simple, automatized and ready-to-use tool, with a quick and effective application. Airport companies are not interested into time-consuming processes, even if they could bring an added value to the company.

An upgrading of the tool, that is one of the results of the present work, could be possible through further research activity.

This upgrading should start from the spreadsheet prepared during this research, based on the terminal computation model (Step 1 of the Catalogue methodology) and set of rules and variables (Step 3 of the Catalogue methodology). This tool has an acceptable level of automatization, concerning the complexity of the computation, but needs more work given the high number of iterations that the professionals have to make during the whole application of the methodology.

In particular, as highlighted in Chapter 11, sheet C1 should be upgraded since currently it requires the handy input of the user when expansion is required. This operation could be made automatic; otherwise it could be better pointed out to the user, both in the guidelines and in sheet C1.

- **Exploration of the full decision support level of the methodology**

The detailed study of the Catalogue as a decision support tool is left to future research.

In particular, this analysis should involve the transition from the Catalogue to Airport Company decision making, the translation of the Catalogue into proper flexibility qualitative requirements, the exercise and training of the planners and designers to flexible thinking and flexibility approach.

The further research should found on a complete application of the Catalogue approach. Then it should start from the results of this research to go beyond. Indeed it should take advantage of the terminal computation model studied and proposed in this thesis and of the first traffic scenario (linear traffic growth) used for the test. More "n" uncertainty (traffic) scenarios should be identified and the iteration of the computation process for each of the "n" scenarios should lead to "n" possible operating plans; a Montecarlo analysis would complete the process. Then research should explore how qualitative decisions concerning flexibility design requirements should be taken, according to the information given by the Catalogue vectors. Research should focus on "training" to flexibility of resources (both planners and designers).

- **Application to terminal UAT (Units of Airport Terminal, not limited to the terminal) and on the medium term**

Further research activity could be carried out in order to make the methodology suitable for application to medium term works, in the framework of renovations of existent airport terminals. Although the application to a terminal to be built *ex novo* is more interesting and more complex, renovation activities on current infrastructures are more frequent.

The application to the Units of Airport Terminal (UAT) should start from the terminal computation model set up and the tool itself. The model should be reviewed according to the income and cost issues of a smaller area (not so different from the general items considered in the research model) and then tested on a specific UAT case.

- **More tests**

The Catalogue approach is a quite new methodology, requiring more tests to be further validated and improved. Moreover, airport companies are interested in effective and efficient methodologies and their related tools, achieving results that are validated and demonstrated on an international scale.

This research marks another step forward in this direction. This research has taken the methodology from the application to a parking garage to a level of major complexity. In fact it produced the model for the lifecycle performance evaluation and the set of decision rules and planning variables, transposed it into a spreadsheet tool by making a test of a terminal with real data. It does not arrive to a full application of the methodology, given one iteration is functional to reach the tool set up.

More tests are needed, for the improvement and success of the Catalogue approach. And more test are needed to validate the model developed in this research.

These further tests should start from the terminal computation model and the tool set up in this research. The collection of the data operated on field, facing the specific airport company managing the test object (echoing the data collection of this test), should provide the input information to the Catalogue methodology. Application to European airports similar in size to the one of this research test (international hubs) should be operated; European hubs should be selected given the same regulatory framework in which they operate and these infrastructures are developed. Moreover, application to Italian smaller airport is desirable too. In this way a complete validation of the computation model and tool could be operated. This would also be a new step for the validation of the general methodology of the Catalogue.

13. CONCLUSIONS: RELEVANT ELEMENTS OF THE THESIS

The purposes of this work are:

- Main general purpose:
    - to include a life cycle approach aiming at flexibility in project design process and management of an airport terminal
    - to propose flexibility of airport terminals to face effectively uncertainty in changing of demand (traffic demand)
- Specific purposes:
    - To propose a new process concept, integrating the Catalogue approach as a tool located in a specific phase of the process.
    - To gain portability of the Catalogue to a test airport terminal,
    - Through the adaptation of the model for lifecycle performance and economic effectiveness evaluation and the adaptation of the set of decision rules and planning variables.
    - To transpose it into a spreadsheet tool,
    - Through a data collection on field
    - And through one iteration of the model, concerning one scenario.

The results, pursued through a deductive desk research together with a field experience, are:

✓ The proposal of a model for process management that includes a life cycle perspective in order to gain flexibility

- ✓ The model for lifecycle performance and effectiveness evaluation and the set of rules and variables tailored to the case of an airport terminal
- ✓ A spreadsheet tool, based on the model tailored, set up through the collection of real data and one iteration of the model itself

While carrying out this work, the following negative and positive issues concerning the analysed topic have been verified:

- Strengths:
    - Innovation in project design management: towards a smarter process
    - Facing uncertainty through flexibility
    - Validation on field with real data from the industry
- Opportunities:
    - Interest of the professionals in the proposal
    - Team education and training possibilities
- Weaknesses:
    - Many facets of uncertainty
    - Looking for more validation experiences
    - Need for automatization and ease of use
- Threats:
    - Scarcity of data and lack of integration of efforts
    - Lack of training of the team and sensitivity of the work environment
    - Difficulties of application outside a business company

Given this, the possible future research developments of this work are:

- Portability to other terminal cases and Guidelines for application of the results to other cases
- Guidelines for use of the tool
- Tool upgrading
- Exploration of the full decision support level of the methodology
- Application to terminal UAT (Units of Airport Terminal, not limited to the terminal) and on the medium term
- More tests

In the end, the final recipients of this research are:

- Researchers and research organizations
- Specialists and architects working in airport companies and implementing airport terminal development, who could directly use the results of this work (both the methodology and the tool) for a professional purpose
- Consultants working for airport companies and aiding them in defining the requirement framework and the design brief of their terminal development projects.

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ACRONYMS

AIC	Airport Council International
ACRP	Airport Cooperative Research Program
aOFAT	One Factor At-a-Time
BHS	Baggage Handling System
CEN	European Committee for Standardization
CLCSA	Cost Life Cycle Assessment
DC	Design Catalogue
ELCA	Environmental Life Cycle Assessment
EU	European Union
FAA	Federal Aviation Administration
GPP	Green Public Procurement
HBS	Hold baggage screening
IATA	International Air Transport Association
ISO	International Organization for Standardization
IT	Information Technology
LCC	Life Cycle Costing
LCSA	Life Cycle Sustainability Assessment
MAPI	Modulo Abitativo di Pronto Intervento
NTR	Normativa Tecnica Regionale
NPV	Net Present Value
PV	Present Value
SAR	Stitchting Architecten Research
SLCA	Social Life Cycle Assessment
TC	Technical Committee
TEN-T	Trans-European Transport Network
TPHP	Typical Peak Hour Passenger
TRB	Transportation Research Board
UNI	Ente Nazionale Italiano di Unificazione
WLC	Whole Life Costing

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ACKNOWLEDGEMENTS

Thank you

The author would like to thank some special people that made possible the way towards the ambitious target of this research.

First of all, thanks to Prof. Maria Antonietta Esposito (Università degli Studi di Firenze), for her precious and continuous mentoring.

Thanks to Christiane Bohner that kindly and professionally gave me her deep experience in research projects evaluation, giving me rich comments in order to support and properly direct this work.

Special thanks go to Prof. Richard De Neufville (Massachussets Institute of Technology) for its support and its comments to this work, during the crucial turn at the second year of the PhD programme.

Special thanks also go to Prof. William Fawcett (Cambridge Architectural Research and Pembroke College, Cambridge) for its suggestions at the beginning of this work and for the opportunity of giving the author reserved access to CILECCTA software and its precious training modules, before they were published.

The author would like to thank all the professionals (and friends) working to the test terminal and in the airport planning and development field, that contributed with their deep knowledge, expertise and kind help in defining the necessary information for a concrete field application of this research.

APPENDIX

A. Teaching modules

LOGBOOK FOR AIRPORT DATA COLLECTION

Log-Book

Contents

- Airport Identity Card
- Sustainability Card
- References for drawings
- Attachments – Images

Name and surname

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Dipartimento di Architettura
Corso di Laurea Magistrale in Architettura
Laboratorio di Progettazione Ambientale
a.a. 2014/2015

Airport Identity Card

		Airport Name, Place (IATA code, ICAO code)	
1		General information:	
	A	Where: *(Place/City, Nation)*	
	B	Design dates: *(from– to)*	
	c	Construction dates: *(from – to)*	
2		Traffic information (ref. 2011, 2012, 2013):[1]	
	A	Movements: *(n. 2011, n. 2012, n. 2013)*	
	B	Passengers: *(n. 2011, n. 2012, n. 2013)*	
	C	Cargo: *(n. 2011, n. 2012, n. 2013)*	
3		Infrastructure information:	
	A	N. runways:	
	B	N. terminals:	
	C	Terminal typology:	

[1] Insert in brackets the years you are referring to, in case they are different from the default ones.
Insert the 3 numeric data in each row keeping them divided by a comma.

AIRPORT IDENTITY CARD

2

4		**Design team:**[2]	
	A	Project leader:*	
	B	Architectural design:*	
	C	Structural design:*	
	D	Mechanical systems design:	
	E	Air conditioning systems design:	
	F	Electrical systems design:	
	G	Signage design:	
	H	Lighting advice:	
	I	Acoustic advice:	
	L	Envelope design advice:	
5		**Additional information:**	
	A	Procurement process adopted:[3]	
	B	Short description of the building tipology: *(min. 50 words)*	

[2] Insert the names of the experts (with their qualifications; e.g.: eng., arch.) or the name of the societies, if you are able to know that. The starred fields are mandatory.
[3] Indicate the procedure of commitment that has been used (e.g.: reserved procedure).

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AIRPORT IDENTITY CARD

3

	C	Short description of the building structures and envelope: *(min. 50 words)*[4]	

[4] E.g.: construction system adopted, structural solutions, padding, etc.

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AIRPORT IDENTITY CARD

4

6			Images:[5]	
	A		Remote sensed photo/plan of the whole infrastructure, with functional analysis[6].	
		1	Credits:	
	B		Photos/Panning shots of the building from the outside, landise	
		1	Caption:	Terminal/s focused
			Credits:	
		2	Caption:	Terminal/s focused
			Credits:	
		N	Caption:	Terminal/s focused
			Credits:	
	C		Photos/Panning shots of the building from the outside, airside	
		1	Caption:	Terminal/s focused, Gate/s focused
			Credits:	
		2	Caption:	Terminal/s focused, Gate/s focused
			Credits:	
		N	Caption:	Terminal/s focused, Gate/s focused
			Credits:	
	D		Photos/Panning shots of the interior spaces of the building, public area (e.g.: hall check-in desks)	
		1	Caption:	Unità ambientale inquadrata, Terminal di riferimento
			Credits:	
		2	Caption:	Unità ambientale inquadrata, Terminal di riferimento
			Credits:	
		N	Caption:	Unità ambientale inquadrata, Terminal di riferimento
			Credits:	

[5] Each letter must refer to one or more images that have to be attached in the specific folder "6. Attachments – Images". Read carefully the fil .txt that you can find in that folder. Please, copy and paste the rows "Caption" and "Credits" for the number of images that you want to attach. Plase, be careful about giving the right name to each image: use the code of the correct row, do not get confused.

[6] Please, remember to insert the legend too. It can be a different jpg file (name it as 6A1legend) or it can be in the same jpg image of the plan.

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AIRPORT IDENTITY CARD

5

	E		Photos/Panning shots of the interior,sterile area (e.g.: departure lounge; commercial area)	
		1	Caption:	Terminal unit focused, Terminal which it belongs to
			Credits:	
		2	Caption:	Terminal unit focused, Terminal which it belongs to
			Credits:	
		N	Caption:	Terminal unit focused, Terminal which it belongs to
			Credits:	
	F		Images of one or more significant parts of the structures and/or envelope [7] (e.g.: structural joints, tree pillars, structural façade, envelope concept, etc.):	
		1	Caption:	Elements focused
			Credits:	
		2	Caption:	Elements focused
			Credits:	
		N	Caption:	Elements focused
			Credits:	

[7] Insert photos or pictures that focus on significant parts of the building structure/envelope. E.g.: shots of structural facades; photos or sketches of tree pillars or interesting spatial beams; significant structural joints; sketches of the envelope concept or of the structure concept; anything you think is necessary to complete the comprehension of the main features of the building.

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7 Bibliography:

Author (Surname, Name Initial)	Year	Title	Publisher	City	ISBN	ISSN

8 Webliography:

Author	Year	Title	Link

ACADEMIC TOOL FOR LCC/WLC INTRODUCTION AND APPLICATION TO DESIGN

While the research progressed, educational tools have been set up. The tools have been prepared for an academic use.

The first aim was to produce a first output of the PhD research, to be combined with a teaching module concerning Life Cycle Costing and airport design. The second aim was to transfer the main concepts about LCC to students of Airport Construction Systems Module within the Environmental Design Laboratory at the Architectiure Degree Programme by the Università degli studi di FIrenze, in order to make their preparation more complete and up to date according to the latest research achievements on architectural design management. The academic tools have been proposed to students in academic year 2015-2016 beside two front classes of 2 hours each, introducing:

Lesson A, Terminal Life Cycle:

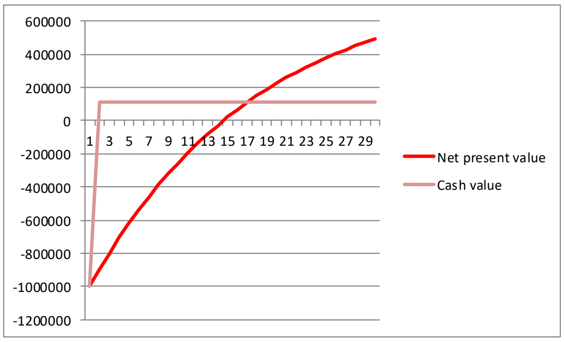
- Life Cycle: service life, life cycle, 3 pillars of LCA
- Life cycle management: integrated decision making; ISO 15686
- Life cycle costing: Definitions; when and what LCC informs; case study

Lesson B, Net Present Value – evaluating investment options:

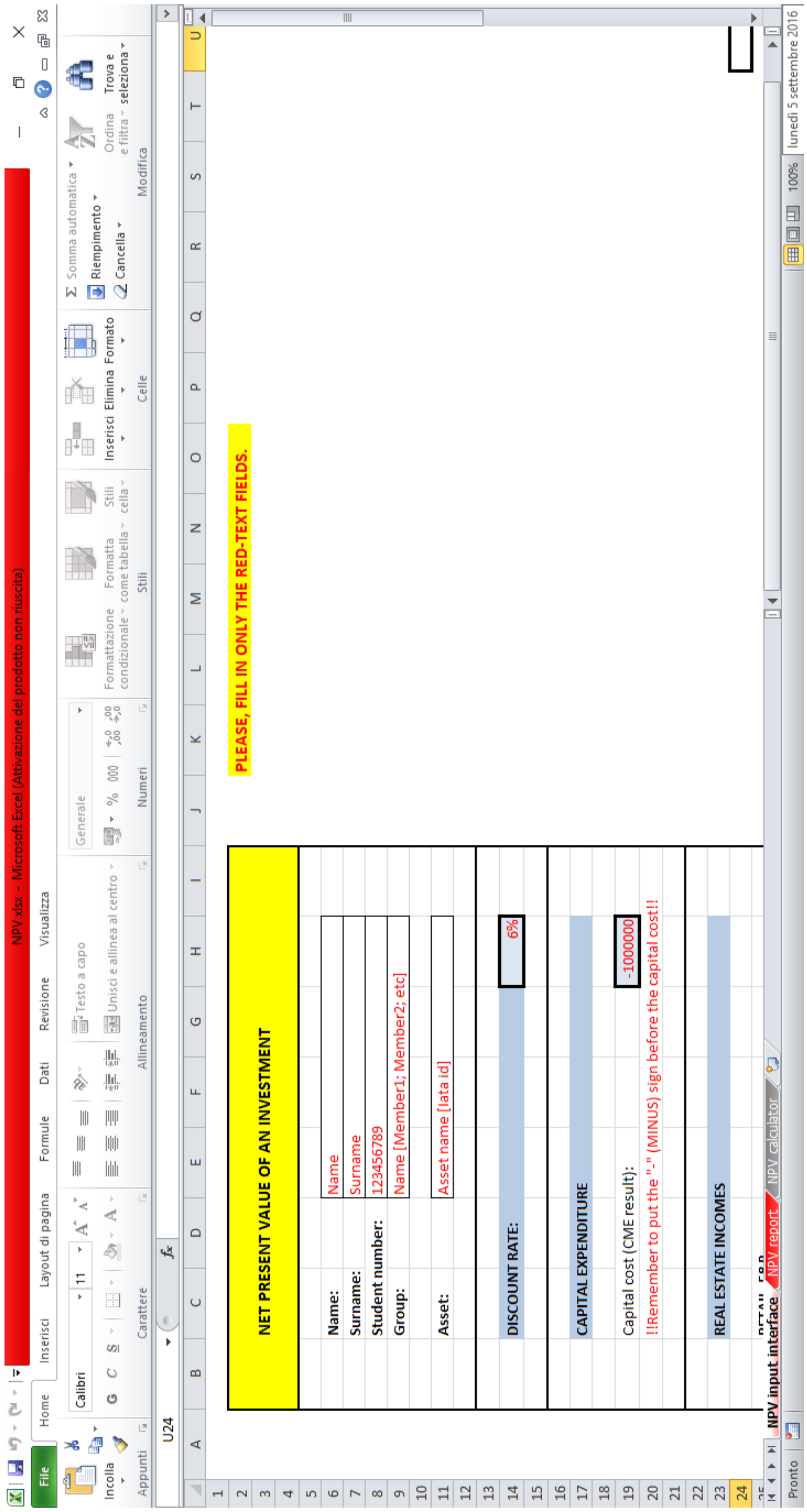
- Definition of NPV
- Computation of NPV
- Relation between NPV and LCC
- Evaluation of investment options

PLEASE, FILL IN ONLY THE RED-TEXT FIELDS.

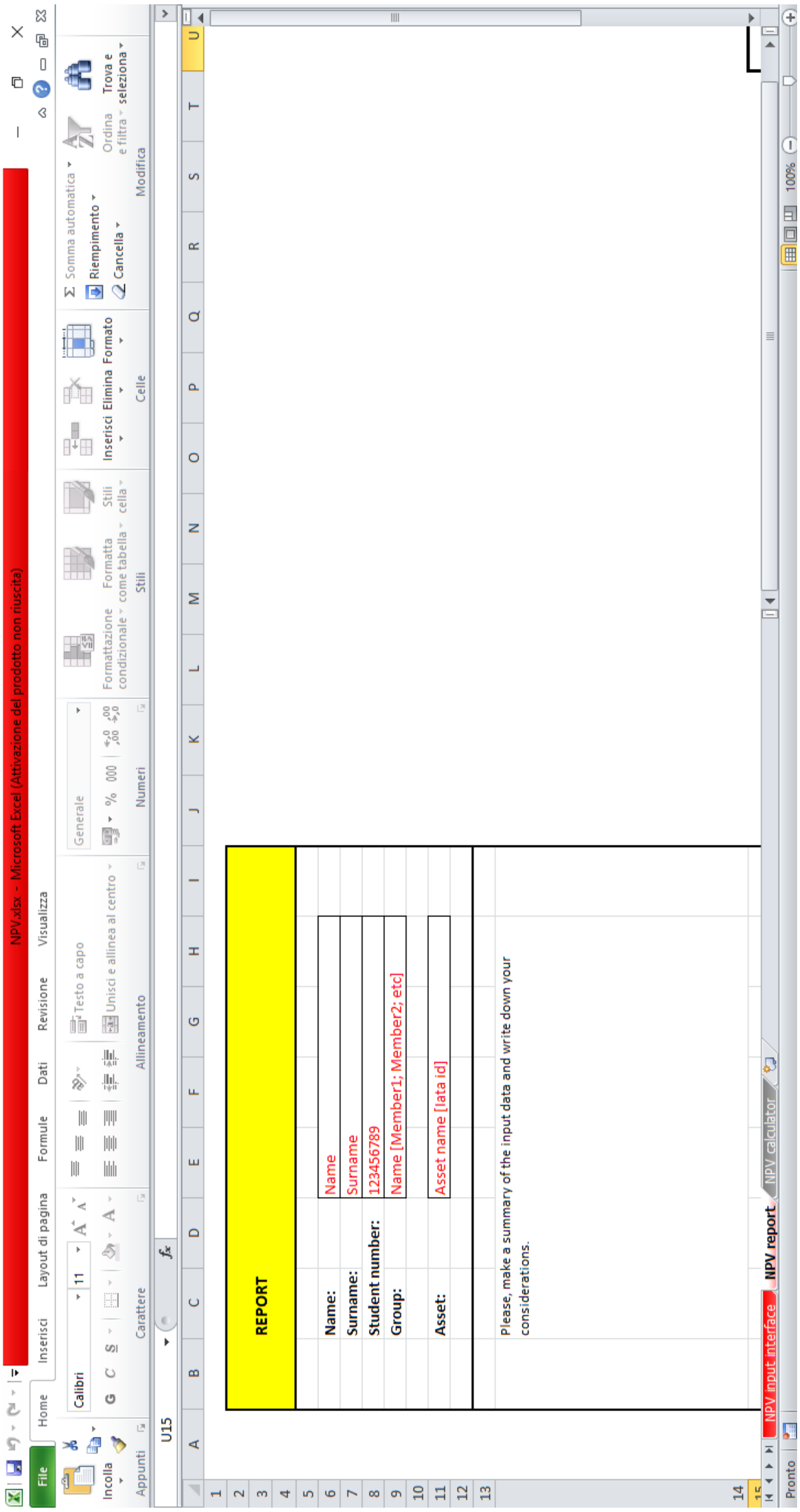
NET PRESENT VALUE OF AN INVESTMENT	
Name:	Name
Surname:	Surname
Student number:	123456789
Group:	Name [Member1; Member2; etc]
Asset:	Asset name [Iata id]
DISCOUNT RATE:	6%
CAPITAL EXPENDITURE	
Capital cost (CME result):	-1000000
!!Remember to put the "-" (MINUS) sign before the capital cost!!	
REAL ESTATE INCOMES	
RETAIL, F&B	
m^2	100
€/m^2/month	45
€/year	54000
VIP LOUNGES	
m^2	50
€/m^2/month	55
€/year	33000
OFFICES	
m^2	100
€/m^2/month	19
€/year	22800
TOTAL ANNUAL INCOME	
€/year	109800
NET PRESENT VALUE: (29TH YEAR)	492261,2



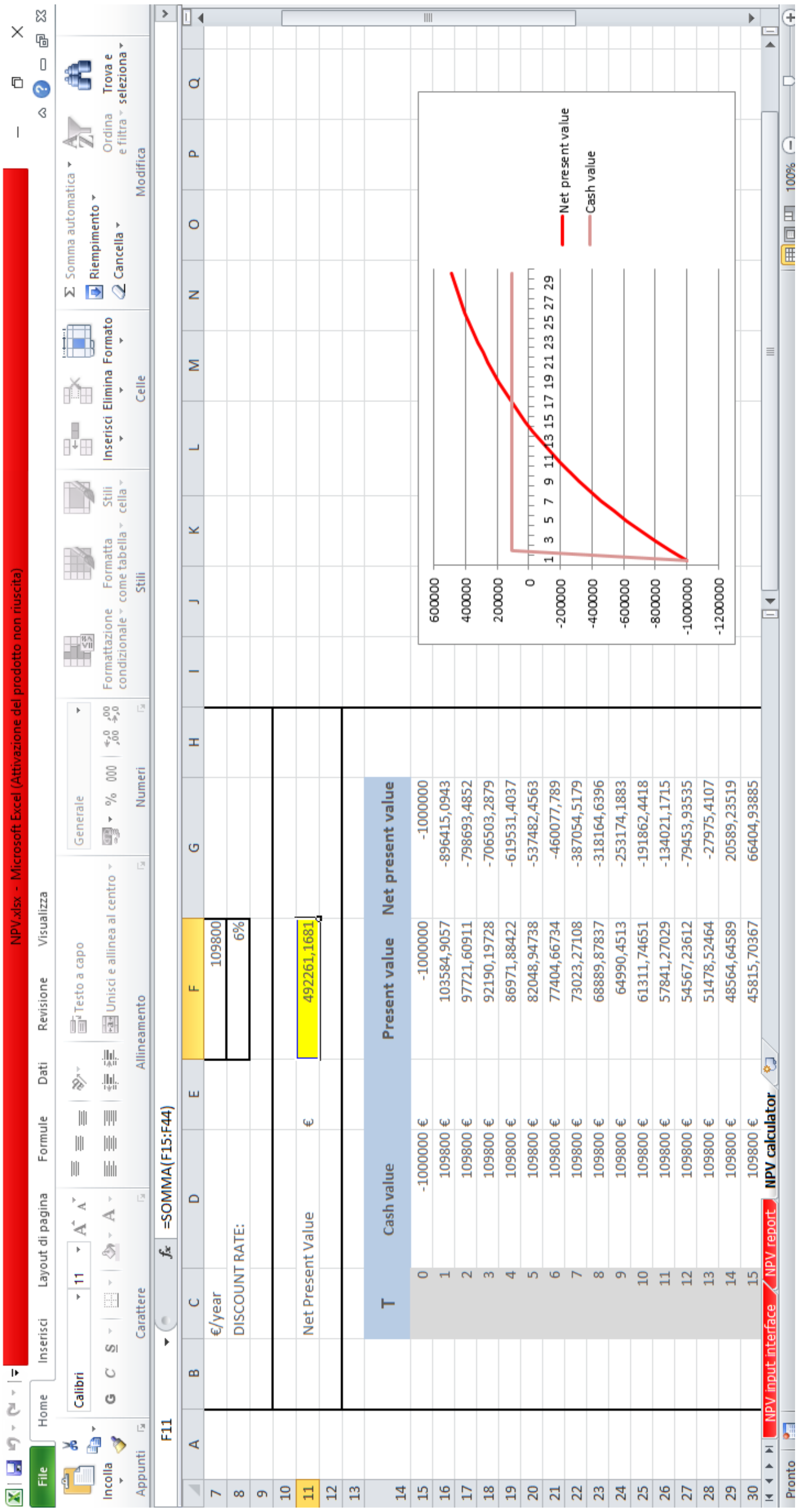
PICTURE 65 ACADEMIC TOOL, FOCUS ON THE STUDENT INPUT TABLE



PICTURE 66 ACADEMIC TOOL, INPUT SHEET



PICTURE 67 ACADEMIC TOOL, REPORT SHEET



T	Cash value	Present value	Net present value
0	-1000000 €	-1000000	-1000000
1	109800 €	103584,9057	-896415,0943
2	109800 €	97721,60911	-798693,4852
3	109800 €	92190,19728	-706503,2879
4	109800 €	86971,88422	-619531,4037
5	109800 €	82048,94738	-537482,4563
6	109800 €	77404,66734	-460077,789
7	109800 €	73023,27108	-387054,5179
8	109800 €	68889,87837	-318164,6396
9	109800 €	64990,4513	-253174,1883
10	109800 €	61311,74651	-191862,4418
11	109800 €	57841,27029	-134021,1715
12	109800 €	54567,23612	-79453,93535
13	109800 €	51478,52464	-27975,4107
14	109800 €	48564,64589	20589,23519
15	109800 €	45815,70367	66404,93885

PICTURE 68 ACADEMIC SHEET, CALCULATION SHEET

B. Summary of the research – Italian

DOTTORANDO: Arch. Elisabetta Fossi

TUTOR: prof. PhD Arch. Maria Antonietta Esposito, Università degli Studi di Firenze

XXIX ciclo / 2013-2016

Settore disciplinare prevalente: ICAR 12

FAR – Flexibility in Airport ARchitectural Design

Flexibility in Airport ARchitectural Design (FAR) propone una soluzione per integrare una vision di ciclo di vita nel processo progettuale di un terminal aeroportuale, con il fine di includere la flessibilità come nuova classe di requisiti del progetto. Tale esigenza di ricerca appare necessaria alla luce della natura evolutiva di una tipologia architettonica come il terminal, che in primo luogo deve rispondere ai requisiti spaziali e funzionali che consentono di processare il traffico passeggeri, un aspetto in continua evoluzione. L'inclusione della flessibilità avviene mediante una accettazione del cambiamento continuo e soprattutto dell'incertezza nella definizione delle esigenze alla base del progetto. Gli ultimi sviluppi della ricerca sul tema dell'approccio life cycle ed in particolare della metodologia Life Cycle Costing propongono una soluzione in questo senso.

Posizionamento della ricerca dottorale

La ricerca si colloca nella macro area concorsuale 08/C1 – DESIGN E PROGETTAZIONE TECNOLOGICA DELL'ARCHITETTURA, che coinvolge settori di ricerca connessi non solo all' oggetto architettonico in sé ed ai suoi componenti, ma anche ai processi e ai metodi che determinano la creazione del prodotto di architettura. In particolare, la ricerca afferisce al settore scientifico disciplinare ICAR/12 – TECNOLOGIA DELL'ARCHITETTURA.

KEYWORDS

Gestione della Progettazione; Progettazione Aeroportuale; Progettazione degli Edifici su base Prestazionale; Innovazione del Processo di formulazione dei requisiti di progetto; Pianificazione e Pre-progettazione; Flessibilità; Flessibilità operativa; Incertezza; Life Cycle Costing; Whole Life Costing.

BACKGROUND

La ricerca dottorale si inserisce nel contesto internazionale ed europeo in particolare, oggi definito dal così detto Cielo Unico. Il trasporto aereo è riconosciuto come un settore fondamentale, non solo per l'Europa, per incrementare la crescita economica delle nazioni, la loro connettività e mobilità sostenibile. La Commissione Europea nella sua Comunicazione al Parlamento Europeo del 2011 ha fissato i nuovi obiettivi per le politiche dell' Unione Europea su capacità, qualità e ambiente, che dovranno essere raggiunti entro il 2030. Secondo le previsioni, l'Europa, in relazione al trend globale, dovrà fronteggiare una crescita nella richiesta di trasporto aereo che rimarrà in parte non soddisfatta; la domanda non soddisfatta sarà di 1.9 milioni di voli entro il 2035. Ottimizzare ed incrementare la capacità degli aeroporti in una rete di trasporto così congestionata è uno dei principali obiettivi e sfide definite dall'Europa (Eurocontrol "Challenges of Growth", 2013).

In tale contesto delineato dalla Commissione Europea e riguardante l'intero tema del trasporto aereo, si inserisce anche la singola infrastruttura di terminal. Il traffico aereo converge verso il terminal aeroportuale. E gli utenti finali – i passeggeri- fruiscono dello stesso e all'interno di esso vengono processati. Il terminal è infatti una fabbrica di imbarchi (Bosi, 2015), nato per rispondere a questa esigenza. Pertanto, la prestazione principale del terminal aeroportuale è misurata dalla domanda di traffico, prima di qualsiasi altro requisito caratterizzante un qualunque altro progetto complesso. Il terminal risponde a tale requisito attraverso una adeguata capacità.

Ma il traffico passeggeri e quindi la domanda cambia continuamente. Cambia nell'arco della giornata, nell'arco della settimana, dell'anno. E soprattutto è in continua evoluzione da un anno all'altro. Quindi il terminal deve essere in grado di ospitare la domanda quando e nelle modalità in cui questa si presenta. In definitiva, il terminal deve evolvere adeguatamente, in risposta alla domanda.

OBIETTIVI DELLA RICERCA

Il principale obiettivo della ricerca dottorale è di includere un approccio life cycle nella gestione del progetto e del processo di sviluppo di un terminal aeroportuale, finalizzato all'identificazione del requisito di flessibilità. Contemporaneamente, altro obiettivo generico della ricerca è proporre la flessibilità di un terminal aeroportuale come la risposta per fronteggiare in modo efficace l'incertezza nel mutamento delle esigenze (ed in particolare dell'esigenza primaria che è la domanda di traffico passeggeri).

Il terminal aeroportuale è un edificio caratterizzato dalla tipica natura evolutiva di una infrastruttura. Ciò significa che il primario requisito di un terminal è quello di soddisfare la domanda di trasporto aereo. E la domanda di trasporto aereo è in continuo cambiamento negli anni. Per tanto, un terminal aeroportuale ha la necessità di essere adattabile al mutamento di tale esigenza; ed il progetto deve considerare necessariamente il continuo cambiamento che caratterizzerà il ciclo di vita del terminal stesso.

Gli obiettivi specifici sono:

- Proporre un nuovo concept di processo per il design del terminal aeroportuale, integrando il Catalogue approach (Cardin, 2013) come uno strumento collocato in una specifica fase del processo.
- Raggiungere l'adattamento del catalogo a un test terminal,
- Attraverso l'adattamento del modello per la valutazione della performance e dell'efficacia economica nel ciclo di vita e l'adattamento del set di regole decisionali e variabili pianificatorie.
- Trasporre tale modello in un strumento di calcolo,
- Grazie a una data collection effettuata on field
- E attraverso una iterazione del modello, sulla base di uno scenario di traffico.

- Tra gli obiettivi, anche la diffusione scientifica dei risultati parziali e finali della ricerca

METODOLOGIE, METODI E STRUMENTI DELLA RICERCA

La ricerca è stata sviluppata principalmente seguendo un approccio di induttivo. La metodologia del Design Catalogue, inquadrata in una prospettiva di ciclo di vita, è stata identificata nello stato dell'arte come un interessante elemento di applicazione al caso del terminal per contribuire alla risposta alla domanda di ricerca. Quindi l'osservazione della realtà è stata possibile attraverso desk research, interviste, accesso a documenti e dati specifici del test terminal. Ed infine la ricerca ha portato alla formulazione di una proposta di modello adattato al caso specifico e di un concept di processo.

Per colmare una limitazione relativa alla difficoltà di reperire dati ed informazioni sul processo dal mondo professionale, è stato anche adottato un approccio di Field Research.

Pertanto la ricerca è stata svolta sul campo, colmando quindi -nella fase di indagine sullo stato dell'arte -le lacune in letteratura concernenti il processo di sviluppo di un terminal; ed al contempo effettuando per la fase propositiva della ricerca una attività di raccolta dati per l'applicazione e l'adattamento della metodologia ad uno specifico test terminal.

Questa combinazione di metodi, in aggiunta, ha contribuito alla formazione del profilo di ricercatore dal punto di vista personale e professionale, con lo sviluppo di skill e know-how specifico dell'ambito di indagine e nel settore di applicazione della ricerca.

RISULTATI, RILEVANZA, INNOVAZIONE ED UTILITÀ DELLA RICERCA

I risultati del lavoro di ricerca sono riassumibili in:

- Proposta di un concept innovativo di processo per il caso di sviluppo del terminal aeroportuale, con particolare riguardo per la fase di formulazione dei requisiti di progetto, che includa una prospettiva di ciclo di vita per identificare il requisito di flessibilità.
- Il modello per la valutazione della performance e dell'efficacia nel ciclo di vita e il set di regole decisionali e variabili adattati al caso specifico del test terminal.

- Uno strumento di calcolo, basato sulla trasposizione del modello adattato, grazie a una data collection effettuata su dati reali e una iterazione del modello stesso.
- Disseminazione scientifica dei risultati parziali della ricerca attraverso pubblicazioni scientifiche, moduli didattici e seminari accademici specialistici.

La ricerca propone quindi una innovazione nel processo di sviluppo di un nuovo terminal aeroportuale, identificando una metodologia e proponendone un adattamento al caso specifico di un nuovo terminal, proponendo una collocazione in un concept di processo innovativo, il modello di valutazione del ciclo di vita e il relativo strumento di calcolo. Il lavoro è a supporto della definizione dei nuovi requisiti di progetto introdotti, e fornisce un indirizzo per identificare il requisito di flessibilità e includere al tempo stesso la prospettiva del ciclo di vita nel progetto, facendo riferimento a uno specifico test terminal.

Inoltre l'attività di ricerca ha trovato il superamento del principale limite, e cioè la scarsa disponibilità di informazioni e dati circa il processo di sviluppo di un nuovo terminal aeroportuale, dovuto alla scarsità delle pubblicazioni in merito. Il superamento è stato possibile mediante l'attivazione di una fase di ricerca sul campo.

Un terminal aeroportuale è un prodotto che ha la principale funzione di rispondere all'esigenza di trasporto aereo ma anche appartiene alla categoria dell'architettura complessa; tale categoria è in continua evoluzione nel tempo ed il terminal in particolare deve necessariamente adattarsi alla domanda che, tipicamente, è in costante crescita da decenni a livello mondiale. Tuttavia la crescita ha un trend che non è noto, è solo prevedibile con una certa approssimazione. Per cui la progettazione dovrebbe tener conto dell'esigenza di flessibilità. Al contrario ad oggi questa esigenza non è identificata né trova risposta. Il lavoro di ricerca intende collocarsi in discontinuità con tale contesto, fornendo una proposta concreta per affrontare l'incertezza della futura domanda, finalizzata all'identificazione del requisito di flessibilità ed assicurare al prodotto finale del progetto una prestazione adeguata considerata nel ciclo di vita come schema che consenta di correlare tale problema con la sostenibilità.

DESTINATARI, APPLICABILITÀ E SPENDIBILITÀ DELLA RICERCA

I destinatari diretti della ricerca ed i possibili finanziatori sono:

- Ricercatori ed organismi di ricerca, che potranno utilizzare i risultati raggiunti da questa ricerca, per andare oltre e progredire con riferimento al proprio ambito scientifico;

- Specialisti, professionisti ed architetti che lavorino in aziende di gestione aeroportuale, italiane ed internazionali, in quanto potranno fare uso ed applicazione dei risultati di questo lavoro (sia per quanto riguarda la teoria della metodologia, la teoria del processo, lo strumento di calcolo) per scopi professionali; in merito alla generalizzabilità della proposta, si rimanda in particolare agli sviluppi futuri della ricerca, oggetto di discussione nella Parte 3.

- Le parti che lavorino in collaborazione con compagnie di gestione aeroportuale, supportando esternamente il gestore nella definizione dei requisiti di progetto alla base di una gara di affidamento per i servizi di progettazione di nuove infrastrutture di terminal in relazione alle esigenze complessive di sviluppo dell'infrastruttura.

I professionisti coinvolti nello sviluppo dei terminal aeroportuali e nel loro progetto sono i principali beneficiari della presente ricerca, insieme ai ricercatori. I destinatari indiretti invece sono: l'ente di controllo (Ente Nazionale Aviazione Civile); il cliente (linee aeree, altre compagnie operanti nel terminal); il fruitore del terminal (i passeggeri); il progettista.

La ricerca si volge principalmente all'ambito dell'aviazione civile, con particolare riguardo per il tema dello sviluppo delle infrastrutture aeroportuali e tra queste il terminal aeroportuale. La proposta originale della ricerca è contestualizzata all'interno dell'iter e del processo di sviluppo del terminal, inserita nella fase finale della pianificazione, che porta alla formulazione dei requisiti di progetto. Per tanto i principali fruitori del lavoro dottorale sono le parti coinvolte nel processo di sviluppo infrastrutturale: l'azienda di gestione aeroportuale, il progettista, parti interessate correlati.

La proposta di ricerca parte da una metodologia che si colloca nell'ambito del lavoro della comunità scientifica sul tema dell'inclusione dell'incertezza e quindi della flessibilità nel progetto di architettura, grazie ad un approccio life cycle e all'ausilio del Life Cycle Costing. La metodologia, nata e studiata sul caso di un parcheggio multipiano, è stata cucita in modo sartoriale su un terminal aeroportuale. Il principale limite della ricerca è consistito nella difficoltà di reperire informazioni circa l'effettivo iter e processo di sviluppo infrastrutturale, per mancanza di letteratura inerente. Questo gap è stato colmato grazie all'attività di field research che contraddistingue questo lavoro.

SVILUPPI FUTURI

Collocandosi in tale ambito di riferimento ed essendo la ricerca sul tema LCC come strumento per l'ottenimento di flessibilità in risposta all'incertezza ad oggi aperta, la tesi dottorale si propone come una ulteriore applicazione di una metodologia innovativa, della quale per tanto costituisce nuovo spunto di critica e di riflessione.

Il lavoro di ricerca, dunque, apporta un ulteriore contributo alla validazione della teoria del Design Catalogue. E, più nello specifico, il lavoro di tesi potrà essere punto di partenza per un'attività di ricerca approfondita e mirata al settore industriale dell'airport design.

In sintesi, i possibili futuri sviluppi della ricerca sono:

- La generalizzabilità del modello, per l'applicazione ad altri terminal, insieme alla formulazione di linee guida per l'applicazione dei risultati stessi di questa ricerca anche ad altri casi
- La formulazione di linee guida per l'utilizzo dello strumento di calcolo
- L'ottimizzazione dello strumento di calcolo
- L'esplorazione completa del supporto della metodologia al livello decisionale
- L'applicazione alle UAT (Units of Airport Terminal), non solo al terminal, e sul medio termine
- Consolidamento del modello e della metodologia mediante altri test.

FAR proposes a solution for integration of a life cycle approach in the planning and design process of an airport terminal, in order to introduce flexibility requirement in design. This need for flexibility becomes necessary in accordance to the evolutionary nature of such a building typology. It has to answer indeed to the need for passenger traffic processing, which is a continuous change. The latest research developments about life cycle approach and in particular Life Cycle Cost methodology propose a solution to these issues. Then flexibility is sought by accepting within the process continuous change and uncertainty of the needs that are the basis of the terminal design.

Elisabetta Fossi, architect, graduated with honours in Architecture, with a thesis in Architectural Technology and Project Design Management entitled "Basic-Benchmark of Architectural Solutions for the Italian Core Network", is a member of Txp Research Unit since 2012. Enrolled in the Architecture Technology & Design PhD at the School of Architecture of the University of Florence, from 2013 is teaching fellow for Project Design Management course and Environmental Design Lab at Dipartimento di Architettura (Università degli Studi di Firenze). Airport planner at Aeroporti di Roma SpA.

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