Streamer
European research on energy-efficient healthcare districts

D1.1

Taxonomy of healthcare districts focusing on EeB morphology and features

Deliverable Report: D2.1

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Taxonomy of healthcare districts focusing on EeB morphology and features

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Colophon

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Abstract

This report summarizes part of the work carried out in the Task 1.1 “Typology models of the healthcare districts” (Work Package 1) investigating on criteria and methodologies to implement a taxonomy of healthcare districts focused on energy-efficient buildings morphology and features.
The scope of the report is to analyze, compare and implement approaches and methodologies to define and develop a model-based classification of hospital buildings fit to Streamer.
The taxonomy of healthcare districts and the classification of hospital buildings and spaces developed in this report will become the basis for the development of semantic BIM ‘template’ for as-built models.
With this scope the main targets of the analysis have been related to: the identification of factors that the “EeB typology models” depend on, the definition of the “energy-related features” that allow to compare different typologies and arrangements; the implementation of a methodology for classifying and labeling functional areas and spaces, compatible with and suitable for the semantic model. Thus, the report presents some possible and compatible approaches and implements some criteria for a “STREAMER approach” to typology in relation to the energy related features.

A first achievement reached in Task1.1 and explained in this report is the implementation of an approach to the typology definition that interrelates: the typological, technical, distribution and functional characteristics of each building type; the functional aggregative configurations based on the proximity and the interdependencies between spaces and functions; the energy-related features and characteristics corresponding to the different building typologies.
The results achieved on this matter include:

– the definition of five levels to be considered to build up a healthcare district within Streamer;
– a breakdown method to be applied in the implementation of the semantic BIM model.

In particular, the breakdown system has been shaped in a flexible way so to be adaptable to different arrangements of existing HD and buildings and to be integrated into operating database and management tools. Moreover, the classification and labeling method implemented introduces a set of codes and references that allow to identify the spaces through the relations between spatial, functional and energy related features.

Results achieved in Task 1.1 until now (M1 > M12) and reported in this deliverable provide inputs and generate exchange of information with the following WPs.
An exchange of information and data will be carried on with WP3 to define criteria and select parameters (related to EeB KPIs established in T3.1) for the implementation of the semantic labels to be used in the BIM model.
The breakdown of the Healthcare Districts based on the five scale levels, the labeling system and the categories of labels will provide inputs for the development of semantic design models (WP1/T1.3) and their implementation with the ontological tools developed in WP5/T5.1, for the semantic design configurator in WP6 (in particular in T6.1) and for the description and analysis of the typology models of the demonstration projects in WP7 (in particular in T7.1/T7.2/T7.3/T7.4).

Publishable executive summary

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Before analyzing the different approaches to typology, a brief history of the development of healthcare has been recalled in order to understand the functional requirements of healthcare over time and to highlight the needs of the modern hospitals.
A comparison of the narrow plan vs the deep plan (Chapter 2) gives some indication about advantages and disadvantages offered by the two solutions. The narrow plan offers some advantages in terms of therapeutic environment, flexibility, energy reduction, clinical efficiency and staff motivation, etc.; but it has some disadvantages over the deeper plan regarding the single patient room solutions, staff travel distances, staff required for single patient accommodation.

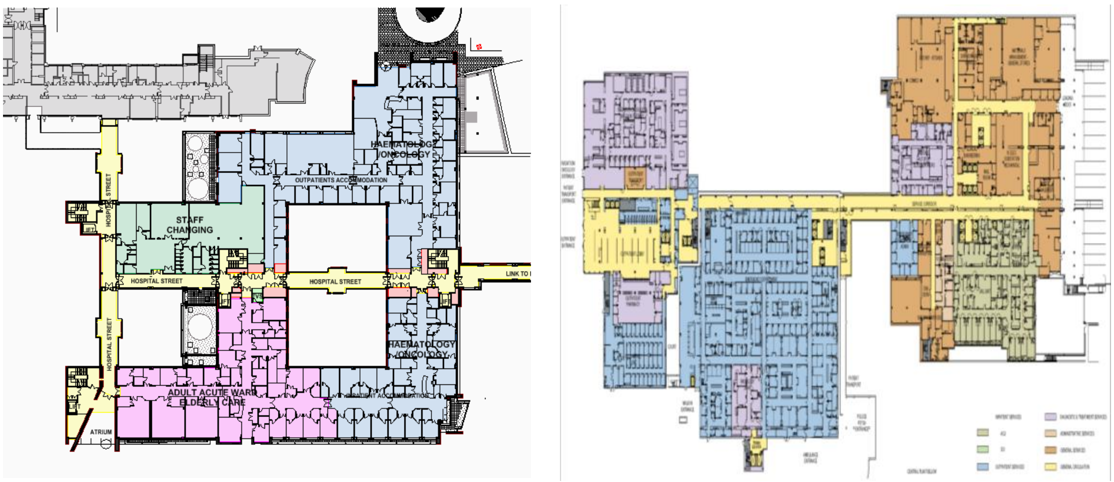


Fig. 1 Examples of narrow plan hospital (left) and deep plan hospital (right)

In short, the narrow plan concept and the provision of the single in-patient room will be a key driver in the clinical needs of patients of the future and will also support a reduction in energy which is a key requirement of the STREAMER project. Whatever the future holds it is imperative that we do all we can to address the typologies that are required to offer a high standard of affordable healthcare to all. A significant part of the affordability equation will be the reduction of the energy used.

For these reasons, the most common general arrangements, presented as theoretical archetypes considering the continuous evolution and changing demands in healthcare, are here analysed focusing on the relations between building typology and energy usage, according to the STREAMER scope. The general arrangements of building typologies identified are nine and are: Linked pavilion or finger plan (1), Low-rise multi-courtyard or checkerboard (2), Monoblock (3), Podium with one or more towers (4), Street (5), Atrium/Galleria (6), Unbundled (7), Campus (8), Layered (9).

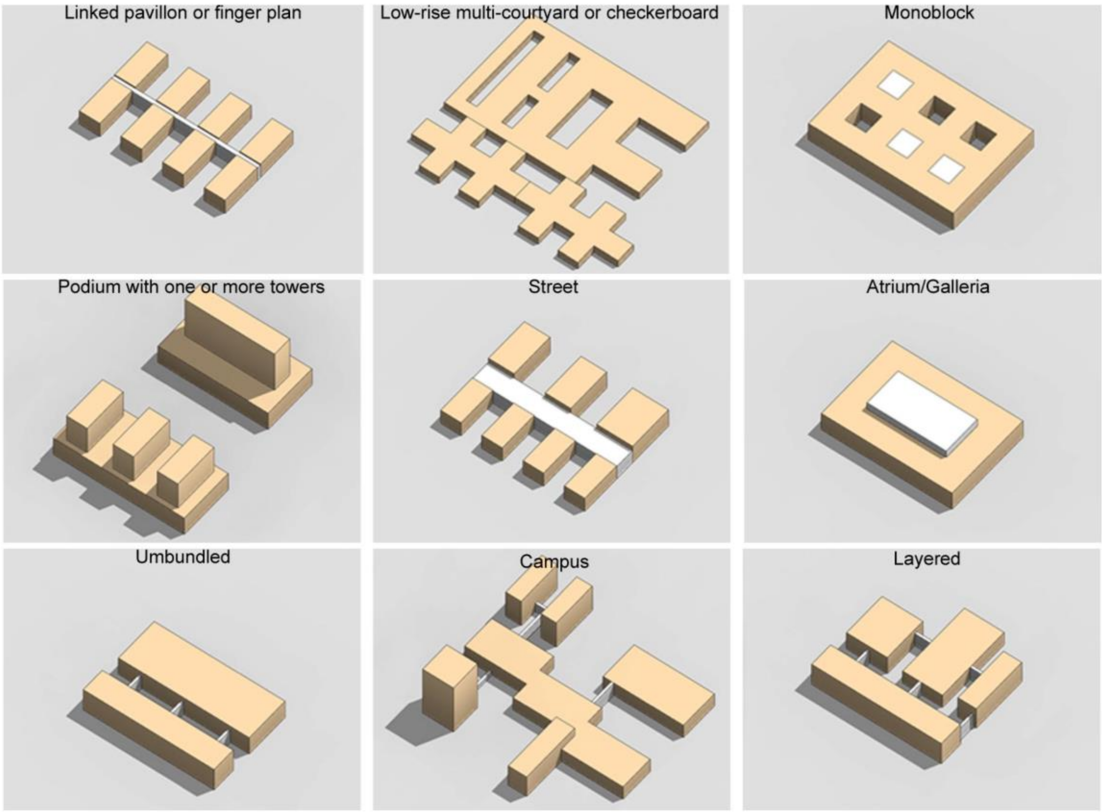


Fig.2 the nine general arrangements

Thus, each general arrangements is presented (Chapter 3) according to the relations that can be traced between its shape and the energy related features, the suitability of it according to the geographical location, and the HVAC systems characteristics required.

According to the research study pursued, two different existing approach to typology have been identified and deeply analyzed for their suitability to the STREAMER objectives: the Layers approach (chapter 4) and the Functional approach (chapter 5).

The **Layers approach** has been developed within a research study completed in 2007 by the Netherlands Board for Healthcare Institutions in the Netherlands. As a result of this new approach hospital managements are confronted with the task to develop strategies aimed at optimization of the accommodation. To be able properly to perform their strategic duties, hospital managements – and other parties involved – require practical tools supporting the perception and the decision-making process. One of those tools is the so-called Layers approach. This approach divides the function package of a hospital according to building typology into four layers: the **hot floor**, i.e. the capital intensive high-tech functions that are unique to the hospital; the **hotel,** which includes the larger part of the patient accommodations; the **office**, with the outpatient units, accounting, management and training functions; and **industry**, which accommodates those functions that are capital intensive, such as the laboratories and the production kitchen. Each of these layers has its own properties profile as regards specificity, investment costs, growth/downsizing requirements, and marketability of the property.

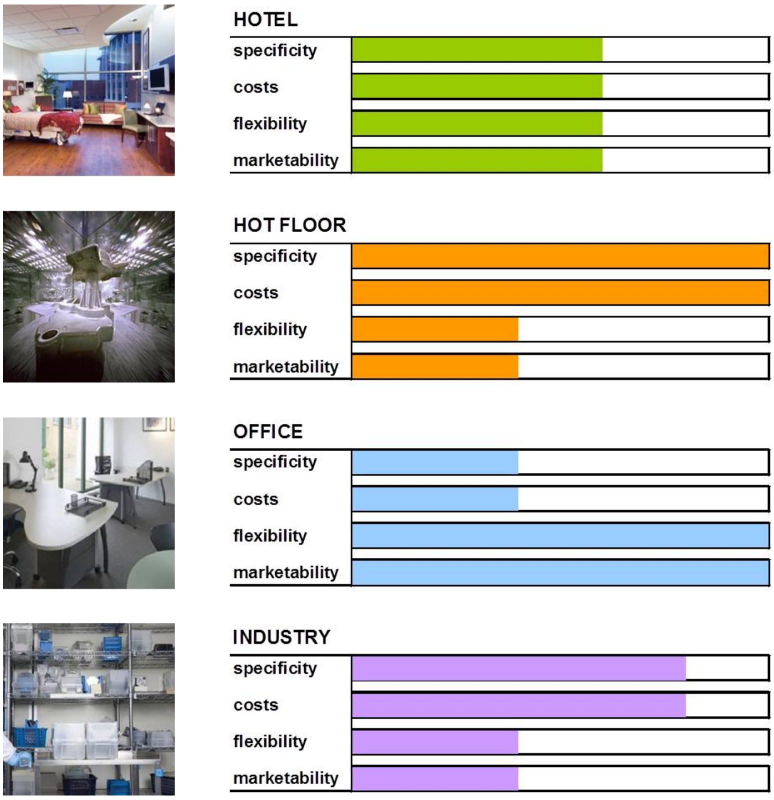


Fig. 3 Properties of a hospital's layers

The analysis of the main medical and organizational relations between function results essential for the elaboration of the proper accommodation model. Based on the preliminary inventory two categories of relations are distinguished: medical relations between departments that must be spatially available to provide sound healthcare, and organizational relations between departments that, although not strictly medically required, are so important to the proper course of the business processes in the primary process that, from a business operations perspective, it is highly preferable that they are situated in each other's (immediate) vicinity.

Originally intended as an analysis tool for considering investment decisions in hospitals (both in terms of investment cost and return of the investment) it is also usable for considering energy optimizations.

In the **Functional approach**, instead, single spaces, functional areas, departments, buildings and health care districts are analyzed and categorized considering proximity and interdependencies between spaces and functions. This approach operates on the *metadesign* level, entailing the definition of the spaces in terms of organization, layout, relationships and performances. The methodology resulting from this approach allows, on one hand, the definition of the functional layout of the areas within the whole healthcare district and, on the other hand, the definition of the performances of each space.

The definition of the functional model requires a complete breakdown of the healthcare district in different levels, entailing a hierarchic classification of all the spaces of an healthcare district. The main functional levels from which an healthcare district's functions can be analyzed are: functional macro-areas (FMA), functional areas (FA), sub-functional areas (SFA) and spatial units (SU).

The functional approach starts from the definition of the functional area to build up the functional model. A functional area is a group of spaces generally related to homogeneity of interdependencies between functions and spaces. The **functional areas are taken into prior analysis** as they could allow, on one hand, the definition of the sub-functional areas and spatial units in terms of spatial, technological and environmental requirements and, on the other hand, the definition of the upper level of macro-functional areas – thus building and healthcare district – in terms of functional, organizational and relational layouts.

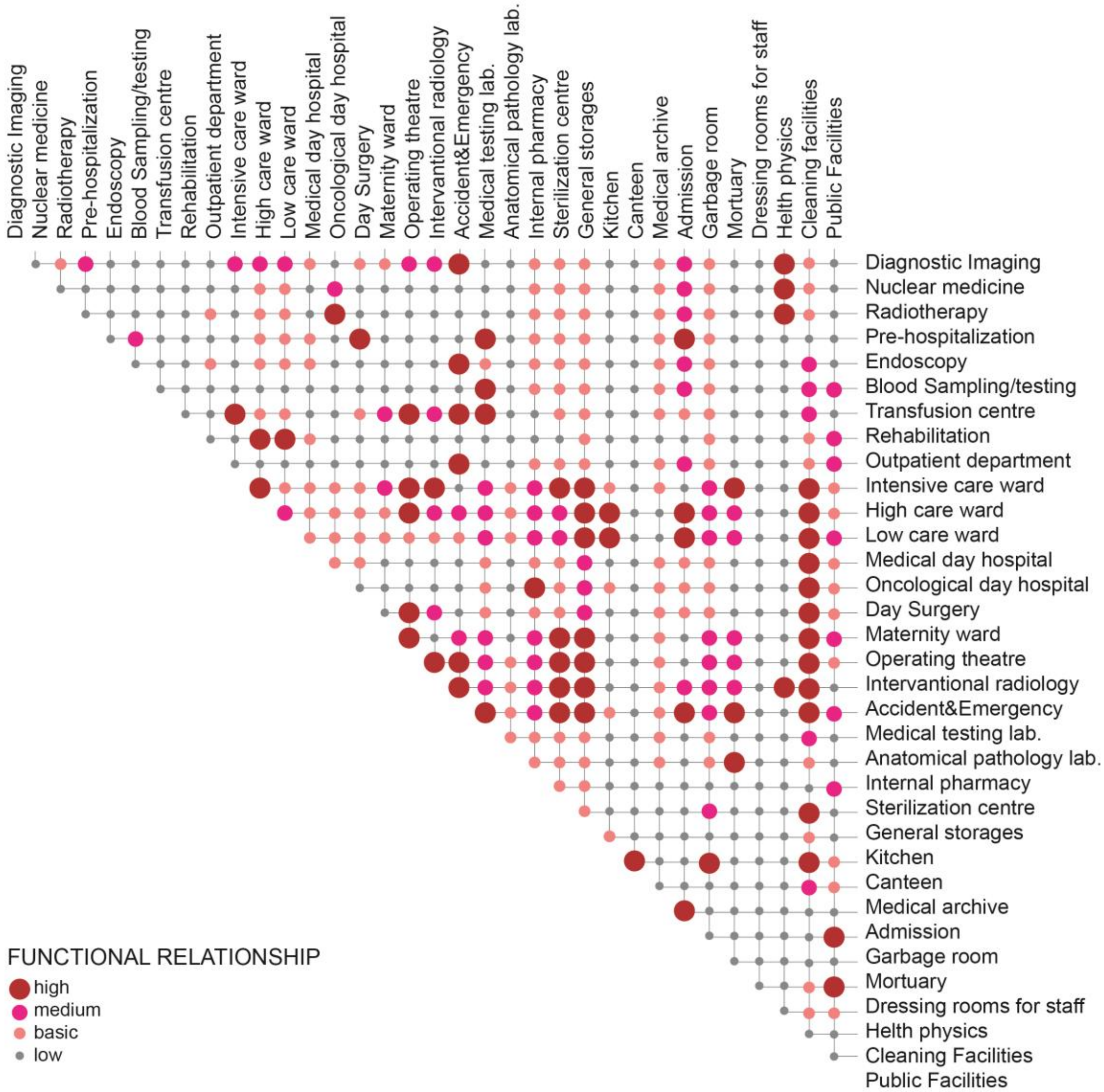


Fig. 4 Functional relationship between functional areas

This approach allows a high level of flexibility and applicability to the various contexts as it provides a not-contextualized model that could generate multiple typologies in terms of layout and building configuration, being the typology defined as the expression of the different functional, social, economic, spatial, environmental and technological organization.

Within STREAMER, the combination of **the layer approach and the functional approach** allows the definition of a universal system within which the typology could be approached from the more appropriate perspective for the specific hospital organization.
Being the focus of STREAMER taxonomy the definition of EeB morphology and features, it is necessary to establish which method is the most appropriate for the definition of the typology from the energy-related features perspective. Investigation and discussion on the typology models outlined two main approaches, apparently in opposition with each other, that generate two different process of the HD system breakdown and consequently different results in the classification and categorization of spaces: the **"Outside/In"** approach – so called "designer's view" – that defines of typology starting from a spatial classifications based on the layers approach and the **"Inside/Out"** approach – so called "engineer's view" – that defines the typology starting from a spatial classifications based on the technical properties and features of the single spaces.

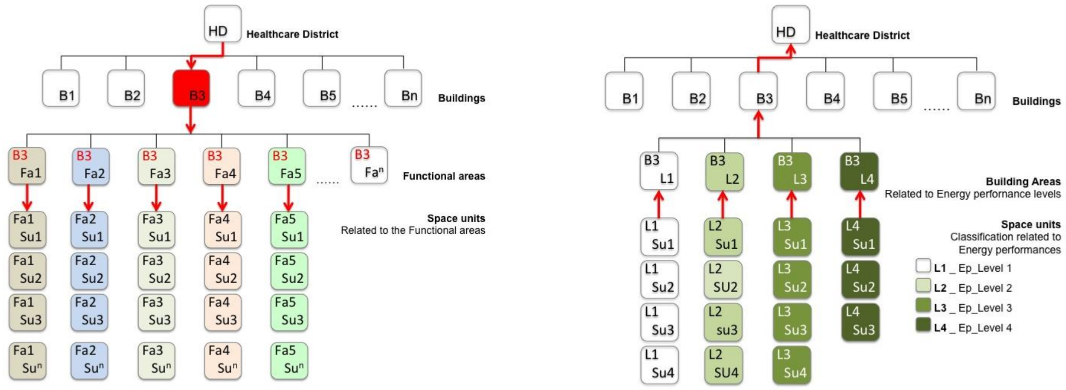


Fig. 5 Outside/in approach (left) and Inside/out approach (right)

The Streamer approach is a combination of the advantages offered by the two methodologies and it is based on criteria and models analyzed focused on the **layers and the functional approaches**. We use all approaches parallel to make best use of all information all these approaches give us. The method carried out aims to make compatible the two approaches crossing the different criteria of classification with the levels defined in a STREAMER breakdown of Healthcare Districts.
Looking at the spatial organization and the functional aggregative configurations of the existing typologies, five main different levels can be considered to build up a Healthcare District within STREAMER. These levels identified are: Component (level 1), space-unit (level 2), Functional area (level 3), Building (level 4), District (level 5).
A method for analyzing and classifying the Space units compatible with the two approaches can be implemented crossing different criteria of classification with the levels defined in the STREAMER breakdown of Healthcare Districts: (e.g. layers, energy related-features customized label according to the database or organization of the specific healthcare district, etc.) This happens assigning a set of labels to the space units.

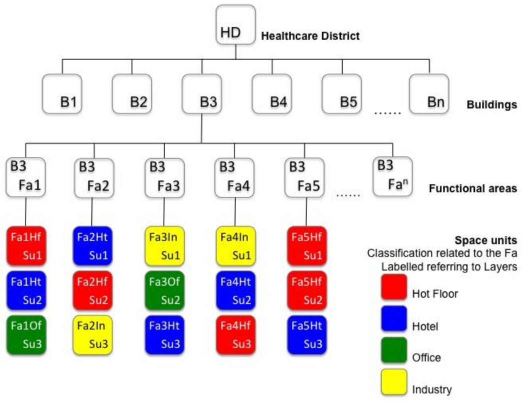


Fig.6 Crossing of Layers approach categories with functional breakdown of the HD system

A set of **parameters for labeling** the lowest level of space unit is here proposed. It makes it possible to attach properties and characteristics to the different spaces, which allows optimizations to be made, not only for energy performance, but also for activity levels, cleaning information or levels of access. Labels that carry implicitly a lot of semantic information and have a relation to the energy demand and other aspects of the design can be: Hygienic classes, Accessibility, Equipment, Construction, Flexibility of spaces, Emergency routes/rooms, Patient pathways for high volume patients, Connectivity / adjacency, etc.. With a combination of the building physics and the labels the energy demand of a room, and at a higher level the building block, can be calculated. The labels could be used to optimize the performance of buildings, but it is also helpful in understanding the implications of design choices (detecting conflicting / incompatible interest) in an early phase. In a wider and more practical view, the labeling system entails the identification of the parameters and information that will implement the semantic BIM model database.

The application of the labeling system in few exemplification has been pursued in order to validate the approach defined within STREAMER. For further details, see paragraph 6.5 and 6.6 where the application has been tested with two different methodology on the case study of **Bernhoven Hospital** in the Netherlands, and on **AOUC Careggi** in Italy (paragraph 6.5, 6.6)

The definition of five levels to be considered to build up a healthcare district and the breakdown method to be applied in the implementation of the semantic BIM model are two crucial results achieved in Task1.1 and explained in this report.

In particular, the breakdown system has been shaped in a flexible way so to be adaptable to different arrangements of existing HD and buildings and to be integrated into operating database and management tools. Moreover, the classification and labeling method implemented introduces a set of codes and references that allow to identify the spaces through the relations between spatial, functional and energy related features.

List of acronyms and abbreviations

- **A.d.a**: Area di Attività (Activity Area)
- **AOUC**: Azienda Ospedaliera Universitaria Careggi
- **B** : Building
- **BIM** : Building Information Modeling
- **BMD**: Bone Mineral Density
- **CAT**: Computer-aided Tomography
- **CSSD**: Central sterile services department
- **DAI**: Dipartimenti attività integrate (Integrated Activity Departments)
- **ECG**: Electrocardiography
- **EeB** : Energy efficient Buildings
- **FA** : Functional area
- **FMA** : Functional Macro-area
- **GIS** : Geographic Information System
- **HCU**: High Care Unit
- **HD** : Healthcare District
- **HVAC** : Heating, Ventilation, Air Conditioning
- **ICT** : Information and Communication Technology
- **ICU**: Intensive Care Unit
- **IRR**: Internal Rate of Return
- **KPI**: Key Performance Indicator
- **MEP** : Mechanical, Electrical ,Plumbing technologies
- **MRI**: Magnetic resonance imaging
- **NCV**: Net Cash Value OR. Operating room
- **PET**: Positron Emission Tomography
- **PoR** : Programme of Requirements
- **PV**: Photovoltaic
- **S.A.C.S**: Sistema di Analisi delle Consistenze Strutturali (System for the Analysis of Hopsital Equipment)
- **SFA** : Sub-functional area
- **SU** : Spatial Unit

Definitions

The layers approach – This approach (relevant for new hospitals or existing ones subject to significant renovation) divides the function package of an hospital into four layers (a layer = a building block).
Each of these layers (Hot floor, Hotel, Office, Industry) has its own properties profile as regards specificity, investment costs, growth/downsizing requirements, and marketability of the property.
Hot Floor refers to capital intensive high-tech functions that are unique to the hospital; *Hotel* refers to patient accommodations ; *Office* refers to outpatient units, accounting, management and training functions, *Industry* refers to laboratories, kitchen, etc.

Functional Macro-area (FMA) – FMA reflect the main medical activities conducted in hospitals. The main FMA are Diagnostic and Treatments, Wards, Operating blocks, Accident and Emergency (A&E), General Facilities, Public Facilities

Functional area (FA) – A FA is a group of spaces generally related to homogeneity of interdependencies between functions and spaces (see next slide)

Sub-functional area (SFA) – The sub-functional areas correspond to typologies of space, thus with homogenous characteristics, that can be generally found within each FA
Each of these layers has its own properties profile as regards specificity, investment costs, growth/downsizing requirements, and marketability of the property.

Spatial Unit – The single spaces or rooms are the lowest spatial entity that can be identified by specific functions and properties (operating rooms, patient rooms, nurse offices, etc.)

Outside-in approach – the "designer's view" by defining the typology based on the 4 Bouwcollege spatial classifications, as well as the campus-building taxonomy and organizational categories (e.g. local hospital, regional hospital, general hospital, academic hospital, etc.).

Inside-out approach – the "engineer's view" by defining the typology based on the technical properties of the rooms (e.g. the energy-related features of an operating room, a patient room, a nurse office, …) and building/MEP systems (e.g. the energy-related features of a sandwich-panel façade system, a certain type of ventilation system, etc.).

Contents

1. Introduction and scope

This report summarizes part of the work carried out in the Task 1.1 “Typology models of the healthcare districts” (Work Package 1) investigating on criteria and methodologies to implement a taxonomy of healthcare districts focused on energy-efficient buildings morphology and features.

The scope of the report is to analyze, compare and implement approaches and methodologies to define and develop a model-based classification of hospital buildings fit to Streamer. Outcomes of this work will contribute to the development of semantic BIM ‘template’.

The focus has been on organizational, distribution and functional aspects. The typological, technical, distribution and functional characteristics of building types have been related to the functional aggregative configurations based on the proximity and the interdependencies between spaces and functions.

Furthermore the study has been carried out analyzing the taxonomy of the most frequent typologies of existing health building in order to provide basis for comparison between typologies in terms of energy-related features and characteristics. Since the design of hospital involves many stake-holders the approach has been multidisciplinary, i.e. both the technical and non-technical aspects and parameters have been considered.

The report presents some possible and compatible approaches and implements some criteria for a “STREAMER approach” to typology in relation to the energy related features.

Data and parameters gathered from the analysis aim to be compatible with and suitable for the semantic typology models, as they provide the basis for the development of semantic BIM "template" for as-built models. These models contain the morphology of buildings/districts and the multi-dimensional representation of the existing objects in BIM and GIS, as well as the knowledge of the building operation, functional problems, and the optimization opportunities. The models will cover component, system, building, and district levels. During the design phases, these semantic models will be used as a baseline design, adapted and enriched with as-built information the actual performance data, and the building operators’ and occupants’ knowledge.

As stated, the analysis starts from the assessment of the different perspectives from which the typology models can be defined. Indeed, there are four different angles to look at the typology of a healthcare district. The typologies in all the angles impact in a variety of importance the actual layout of the buildings and the complex as a whole. Typology is a classification according to general type, so probably we will capture around 80% of generic solutions on all levels.

The first angle is the organization typology. The organization of the delivery of care in the district and in its surroundings can be based on patient groups (for instance neurology, oncology, sensory organs, et cetera) or it can be based on process features (acute, elective, complex, standardized, et cetera). It is the question how the organization scheme links with the building scheme.

From a building perspective in a 3-dimensional context there are vertical and horizontal arrangements possible to create an interrelationship between spaces. The way the spaces are grouped can be captured in typologies. There are different ways to determine typologies for a healthcare district. One

way is to use the angle of building typologies such as hotels, offices, industry, education, laboratories, etc. Each typology represents a standard way of construction and technical systems.
Another way to order typologies is to look at the way how the spaces are ordered and the circulation of the building complex is set up. It is about the form proportion of the complex as a whole. In a healthcare district there are form typologies known as Pavilion, Backbone, Podium and Tower, Central atrium and others.
From a user's perspective it is more relevant that the spaces can accommodate their activities and therefore it is a common way in hospitals to group spaces in function typologies such as nursing, outpatients' clinic, emergency, intensive care, operating complex, etc. Traditionally, these groups can be recognized as departments in a hospital.
The typologies in all the angles impact the actual layout of the buildings and the complex as a whole. To determine the level of impact the key performance indicators need to be addressed to get an insight on how to support decision-makers in the design stage.
Therefore, these different typology models should be investigated in order to get a good understanding of what the different typologies mean in terms of EeB features and to provide the background for the definition of the typology model to be identified in the STREAMER scope.
Within STREAMER, the methodology of the approaches to the typology models focuses on the comparison between the functional approach and the layer approach.
The combination of these two methodologies allows the definition of a universal system within which the typology could be approached from the more appropriate perspective for the specific hospital organization. In a more wider and practical view, the approach defined entails the identification of the parameters and information that will implement the semantic BIM model database.
The findings of this deliverable will provide the classification of elements, data and parameters inherent to healthcare districts to be used in further stage of the research according to the needs and the scopes of the different WPs.

After a brief history of the development of healthcare aimed to understand the functional requirements of healthcare over time and to highlight the needs of the modern hospitals (chapter 2), the reports focuses on an in-depth analysis on the relations between building typology and energy usage, comparing the different arrangements based on nine theoretical archetypes (chapter 3).
Analysis and comparison of the different approaches to the definition of the typology models with the aim to define the approach for Streamer is then implemented. After the description and the comparison between the classification of typology models based on the "Layers approach" (chapter 4) and the "Functional approach" (chapter 5), the report implements a proposal of a methodology based on the combination of a top-down and a bottom-up approaches to the typology definition(chapter 6). The method carried out aims to make compatible the two approaches crossing the different criteria of classification with the levels defined in a STREAMER breakdown of Healthcare Districts.

2. Typologies of Hospital and HD Districts: evolution and trends

2.1 Introduction

The purpose of this chapter is to consider the potential energy use, quality of space and flexibility for different building types to be found on an acute hospital district/campus. As an ever developing environment these sites often consist of a number of generations of buildings that will have different characteristics in terms of energy use, quality of space and flexibility. However, these characteristics were only seriously considered in the recent past with energy leading the way in the early 1970's due to the global oil crisis. Quality of space given prominence in the last 10 to 30 years depending on whether the healthcare system delivery was public or private and flexibility of facilities still not considered as significant enough to the development of a sustainable healthcare strategy to take a prominent position in the design process.

In order to consider the 3 characteristics mentioned above we should consider a brief history of the development of healthcare to try to understand the functional requirements of healthcare over time. This may then lead us to evaluate the building forms that were created.

2.2 The development of the hospital over time

Although there is some debate about the exact origins, it is generally accepted that the American Louis Sullivan (1856-1924) coined the phrase "form follows function" in his March 1896 *Lippincott's Magazine,* article "The Tall Office Building Artistically Considered". The actual wording is captured below:

"Whether it be the sweeping eagle in his flight, or the open apple-blossom, the toiling work-horse, the blithe swan, the branching oak, the winding stream at its base, the drifting clouds, over all the coursing sun, ***form ever follows function****, and this is the law. Where function does not change, form does not change. The granite rocks, the ever-brooding hills, remain for ages; the lightning lives, comes into shape, and dies, in a twinkling.*

It is the pervading law of all things organic and inorganic, of all things physical and metaphysical, of all things human and all things superhuman, of all true manifestations of the head, of the heart, of the soul, that the life is recognizable in its expression, ***that form ever follows function.*** *This is the law". (Sullivan, 1896)*

Nowhere better does this "law" apply than to the design of hospital environments. Where the function of many of the facilities have continued to change over time. The function in a healthcare environment is of course linked to the medical advances and it is worthwhile perhaps considering the various kinds of medicine, the associated units of analysis, the workplace and aims that healers may have had. William Bynum the Professor Emeritus of the History of Medicine at University College London (Bynum, 2008) has written a short introduction to the history of medicine, identifying five different kinds of Medicine that influenced the function of healthcare districts over time, which will help us reflect on the architectural and particularly energy related outcomes.

	Characteristics			
Kinds	Object of enquiry	Form and Site of Education	Goal	Example
Bedside	Whole patient	Apprenticeship	Therapy	Hippocrates (c.460-370)
Library	Text	Scholastic, Linguistic, University	Preservation, recovery, commentary	Constantine the African (d. before 1098)
Hospital	Patient, organ	Hospital	Diagnosis	R.T.H Laennec (1781-1826)
Social	Population, statistic	Community	Prevent	John Simon (1816-1904)
Laboratory	Animal model	Laboratory	Understand	Claude Bernard (1813-1878)

Table 2.1 The 5 kinds of Medicine (Bynum, 2008)

2.2.1 The bedside

The bedside was the focus for healthcare development in the Hippocratic era with a holistic approach being key considering mind, body and soul. The Hippocratic doctor needed to know everything about his patient including social, economic and personal circumstances. What they ate, drank, whether they travelled, whether they were free or slaves and what diseases they were prone to. At this time also there were healing temples dedicated to the Greek god of medicine, Asclepius. The temples were controlled by resident priests and hence had a religious bias to its delivery.

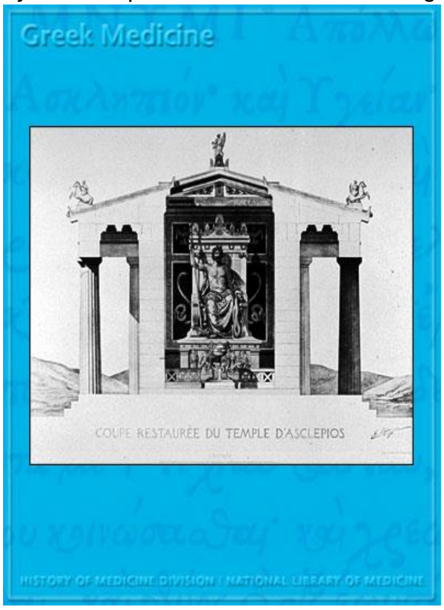


Figure 2.1 Greek healing temple (US National Library of Medicine)

2.2.2 The library

The Library was the era of transcribing medical practices. Examples include Hippocrates, Galen and other doctors who's writing formed the basis of medical practice into the 18th century. There we significant Islamic texts written around this time including the works of Rhazes (c.865-925/32), Avicenna (980-1037) The Canon of Medicine (Al-Qanum fi l-tibb) and Averroes (1126-98) English translated title "The Book of Universals", or Generalities of Medicine". They also took the Greek ideas and translated them into Middle East Languages which was in turn translated back into Latin by Constantine the African (d. before 1098) and many others. This was very much an era of sharing the knowledge that had been and was still being developed. Coincidentally at this time medical schools were set up and the qualified physician appeared.

Figure 2.2 Avicenna (980-1037) (Welcome Library London)

2.2.3 The hospital

The Hospital era began with the development of knowledge of anatomical structures through dissection, although it was a practice that was frowned upon as inappropriate with its links to grave robbers and murderers etc. The development of specialisms, the gulf between physicians and surgeons (with surgeons being of the lower order) and with the introduction of the movable printing press into Europe by Johannes Gutenberg (c1400-68) books could be massed produced and with the addition of woodcuts and engravings to the printed text, the human body could be explained with illustrations. Thomas Sydenham (1624-89) an English physician concerned himself with the classification of disease which produced scientifically based diagnosis and therapy. Following Sydenhams death there was a period of "enlightened medicine" where there was a mapping of disease aligned to a patient focus – a relationship between the feelings of the patient and knowledge of the physician. Two further scenarios were apparent, the first was that people for the first time were prepared to pay for their treatment and the second was that there began a period (c1700) of projects and institutions. Many hospitals were established throughout Europe mainly for the military and there was in the 19th century an era of great pessimism in the future of medicine.

Figure 2.3 The military hospital at Scutari 25th May 1862. Photographer Francis Bedford (1815-94). Royal Collection Trust/© Her Majesty Queen Elizabeth II 2014.

France appeared to lead the world at this time with the opening of medical schools and a teaching approach that was steeped in practice theater than theory. French hospital medicine became based on 3 founding principals, physical diagnosis, pathological-clinical correlation and the use of large numbers of cases to elucidate diagnostic categories and to evaluate therapy. These basic principals remain in place today as does the centrality of the hospital.

2.2.4 The community

The Community or social medicine era began in the 19th century and if hospitals were interventional then social medicine was preventive. Based originally on the need for public hygiene it developed to includes the practice of vaccination to prevent diseases such as smallpox etc. and the infrastructure requirements to support closed sewers and fresh water supply were key consideration. The Cholera pandemics spread from India in the 19th century and focused the minds of experts in Europe and North America. An unknown disease, there was uncertainty as to whether it was miasmatic or contagious. In miasma theory, diseases were caused by the presence in the air of a miasma, a poisonous vapor in which were suspended particles of decaying matter that was characterized by its foul smell. The theory originated in the Middle Ages and endured for several centuries. The contagious theory was based on a disease being spread from person to person and dealt with by protection through isolation. The development of germ theory proved this later theory to be an accurate theory but the focus on cleanliness in the community did no harm in the fight against the generation of bacteria.

Figure 2.4 A Glasgow street 1868 (Welcome Library London)

2.2.5 The laboratory

The laboratory era was a late intervention in the history of healthcare. The microscope being a symbol of the medical scientist in the 19th century in much the same way as the stethoscope was for the clinician (Laennec 1781-1826). The word biology dates from 1801, cell theory was accepted in the 1830's and the word "scientist" was created in 1833. There were major advances made by Louis Paseur (1822-95) and Robert Koch (1843-1910) and others in the areas of microbiology and bacteriology with laboratory facilities required for the necessary research activities. Germ theory was born and the implications were wide spread particularly in the areas of wound cleanliness.

Figure 2.5 Operating room of the Massachusetts General Hospital, Boston

That involved antiseptics (Joseph Lister 1827-1912) and aseptics. The first surgical demonstration of surgery under ether being held at Massachusetts General Hospital in October 1846 and Chloroform followed within a year. Hence the benefits of cleanliness coupled with pain relief, transformed the work of and the status of the surgeon. This period was considered as the arrival of the science of bacteriology and there were benefits for all. At this time a French physiologist Claude Bernard (1813-78) recognized that clinical domination could only go so far and that laboratory based medical science was an essential partner.

2.3 Summary

A simplistic view of the advancement of medicine and healthcare over the centuries can be derived from the previous pages. It appears that it was the 19th century when the hospital as we know it today with the departmental specialisms, medical teaching facilities and research had the potential to connect all the parts together for the first time in such a sophisticated way. It is therefore appropriate when looking at the developments in the hospital campus site to use this period as the starting point as it probably represented the first generation of modern hospital buildings. One area not considered but which needs to be highlighted is the in-patient accommodation. It was probably the development of military hospitals where large numbers of patients were expected to be housed and treated that focused the mind of governments on the quality of the environment. It was again in the 19th century that a greater level understanding of the environment for in-patient care was developed. Florence Nightingale's work with injured soldiers during the Crimea war and her subsequent evidence to the Royal Commission on the State of the Army in 1857 had a significant impact (Nightingale, 1857). She exposed the fragilities in infection control through statistical analysis, gave a clear indication of the spatial requirements for each bed space, instigated an efficient space planning arrangement for maximum numbers of beds and related observation and brought environmental conditions such as natural daylight, colour and air movement into the debate. Her strategy for ventilation was based on her belief in miasma, which was the theory that infection was delivered through corrupted air and that worse the smell the greater the danger. We are however better equipped with knowledge today and can integrate the Nightingale approach with improved knowledge.

2.4 The needs of the modern hospital including a comparison of the narrow plan vs the deep plan and the related single patient bedroom vs multi patient bedroom concepts

The approach that Florence Nightingale took was ventilation took priority over privacy and dignity, hence her planning model incorporating 24 beds in ward with double sided ventilation. What is important to consider is that in the mid 19th century the view by most healthcare stakeholders was that the spread of infection was by nature miasmic i.e. generated by filth that was carried on air streams. Hence the need for open spaces where in-patients' could benefit from high levels of natural ventilation which would "dilute" any infections generated in the space. Openings from both sides of the ward would introduced a cross flow of air from the windward side to the lee-ward side bringing fresh air in and removing the "infected" air. We now know that infection is driven more by person to person contact and vector to person contact. However, we had to wait until the mid 19th century for Robert Koch and germ theory to have a clear understanding of the real drivers of infection.

So in the 18th and early 19th century the generally accepted solution for reducing infection was cross flow ventilation and the narrow plan footprint was accepted as the form for the required ventilation effectiveness. Today however, there is an ongoing debate regarding the advantages of the narrow plan over the deeper plan facility (Figure 2.6 and 2.7). Below are some of the advantages of the narrow plan form including support for therapeutic environment, flexibility, energy reduction, clinical efficiency and staff motivation?

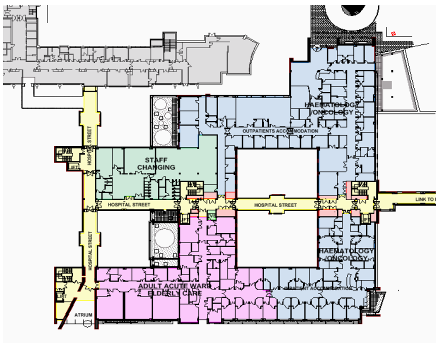


Figure 2.6 An example of a narrow plan hospital

The therapeutic environment for both staff and patients is created by being able to have a window in every room hence increasing the external views. The glazing allows for opening windows which reduces the need for mechanical ventilation and through lighting controls reduces the reliance of artificial lighting. Where a pavilion type arrangement is used the way-finding to specific blocks can be easier and greater adaptability with reduced disruption is assured. The flexibility of the narrow plan form allows single room accommodation to be created, particularly if external pods are used for en-suite facilities. This then provides the “next generation” of in-patient accommodation allowing for patient privacy and dignity, a digitally connected environment, less disturbance and a more restful hospital experience, a reduced potential for the spread of infection, more clinical activity around the bedside (an ever growing requirement), an environment that encourages visitors to stay with patients longer, an environment which supports the retention and recruitment of staff and creates a more domestic bedroom environment which is more familiar to the patient.

Figure 2.7 An example of a deep plan hospital

It is argued that a narrow plan single patient room solution does have some disadvantages over the deeper plan including staff travel distances can be greater and more staff are required for single patient accommodation (where this accommodation is provided). The former is related to an increase in façade length due to maximizing the glazing and the distances walked by staff in a normal working day. However, this analysis needs to be carried out with a model that takes into account local storage for supplies, perhaps robotic delivery technology and a fully embraced ITC strategy. The increase in the number of staff may be the case for cleaning staff if there are a significantly larger number of en-suites. Regarding nursing staff, an analysis needs to be carried out that again considers a fully embraced ITC strategy as well as an understanding of the potential for a reduced burden on the nurses if friends, family and carers are encouraged to spend more time with the patients in more comfortable private surroundings.

In short, the narrow plan concept and the provision of the single in-patient room will be a key driver in the clinical needs of patients of the future and will also support a reduction in energy which is a key requirement of the Streamer project.

2.5 The narrow plan form and the Layering approach

A further consideration is the ability to integrate the narrow plan form with the layering system explained in an earlier section. Two of the layers fit into the narrow plan concept easily and they are the in-patient accommodation (Hotel) and the out-patient/consulting and administration facilities (Admin). Both share the characteristic of being patient focused and hence the need for daylight, views and natural ventilation. The Hotel layer will of course be a 24/7 whilst the Admin layer will be more of a 10 hour day 5 days a week. The two layers that will not fit easily into the narrow plan format are diagnostic & treatment (Hot Floor) and CSSD, pharmacy, laboratories, catering, laundry, plant rooms (Industry). The Industry layer deserves a special mention because the pharmacy, laboratories and catering facilities associated with this layer may well lend themselves to the narrow plan concept. However, a bigger issue is that CSSD, laboratories, catering and the laundry facilities associated with this layer have over the past 20 years or so been outsourced to specialist suppliers and/or moved off site to a central services hub. The Hot Floor has specific clinical requirements including ventilation, air conditioning, air pressure gradients, artificial lighting and deep plan spatial requirement to house large imaging machines. The main question is whether scientific, clinical and technological advancements are taking the acute sector into larger machine driven processes or a more molecular direction?

2.6 Conclusion

We can assume that the provision of acute healthcare in the future will be subject to enormous change due to the scientific, clinical and technological advancements. It is interesting that the historical development of the hospital can be explained through the development of the model through "Bedside, Library, Hospital, Social, Community and Laboratory. We can visualize a move back through the historical models where molecular science will address the laboratory; the polyclinic and more local treatments will address the community; and the imperative of individuals to take responsibility for their own health given the increasing burden of non-communicable diseases will address the Social model. How we engage with the Hospital, Library and Bedside models remain to be seen. Whatever the future holds it is imperative that we do all we can to address the typologies that are required to offer a high standard of affordable healthcare to all. A significant part of the affordability equation will be the reduction of the energy used. The current clinical requirements of the Hot Floor layer and the complex variations to be found in the Industry layer suggest that energy reduction in these layers will be a challenge. However, the energy use in the Hotel and Admin layers, if appropriate plan forms are adopted, could reduce the energy significantly.

3. Building typologies and energy-related features

In this section the relation between building typology and energy usage is determinate.

In an early process of design stage, while the building typology is chosen, it's necessary to make a good decision within defined borders. And of course there's few information available. Have said that, the choice of the energy system is based on the total energy consumption and specific requirements like heating and/or cooling and/or electricity. And that's mostly based on room functions. Building shape do not have an big impact on the energy consumption.

The method to determinate energy related aspect is hospitals is made in D1.3. State of the art MEP techniques will be discussed in T2.2 and T2.3

3.1 The modern hospital – general arrangements

The arrangements as described in this deliverable are theoretical archetypes. In reality, due to evolution and changing demands in healthcare, hospitals are constantly evolving and rebuilding. As a result, the variation in hospital form is much bigger and hospitals can sometimes contain elements of more than one arrangement.

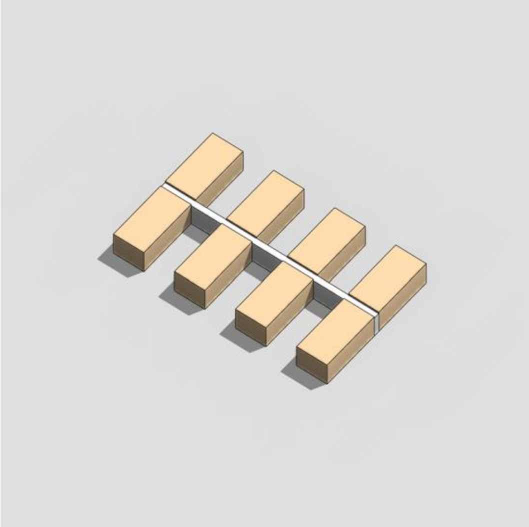
It is neither possible nor desirable to provide an example of every hospital form. The abstract level of this deliverable aims to provide a clear perspective of the relationships between building typologies and the choice of an energy strategy.

The typology diagrams and general descriptions mentioned in this chapter are based on: Prasad, Sunand (2008) Changing Hospital Architecture. London: RIBA enterprises.

The ninth typology (layered) has been added to classify hospitals that were designed using the bouwcollege approach.

The example projects of this chapter contain the four Streamer demonstration projects and, as much as possible, examples from the portfolio of Streamer participants in this deliverable.

3.1.1 **Linked pavillon or finger plan**



The oldest typology and still in common use. The pavillons would often have clinical spaces on lower levels with wards above.

Example:

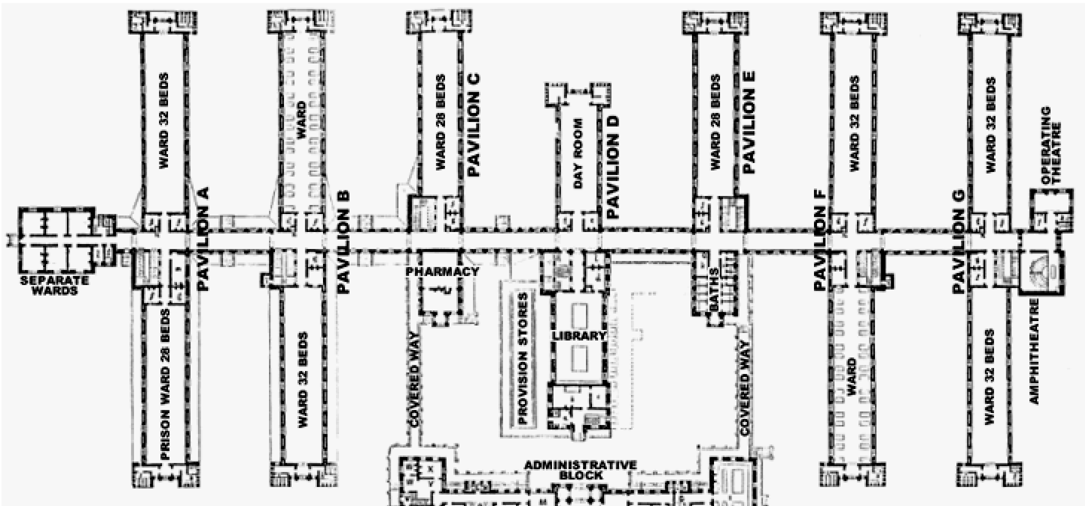
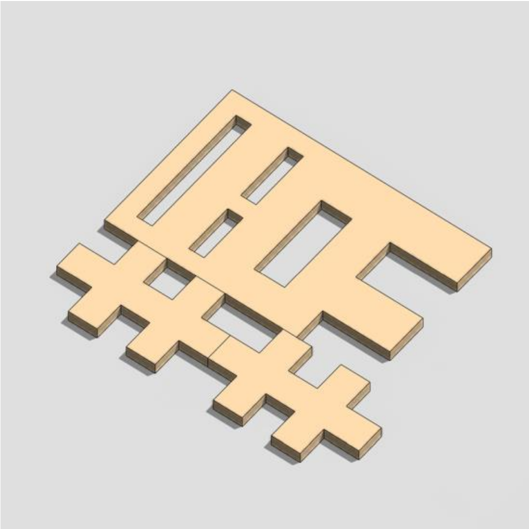


Fig. 3.1 Woolwich Hospital and St Thomas's Hospital, London, England (image found at http://www.royalherbert.co.uk/history.php)

3.1.2 Low-rise multi-courtyard or checkerboard

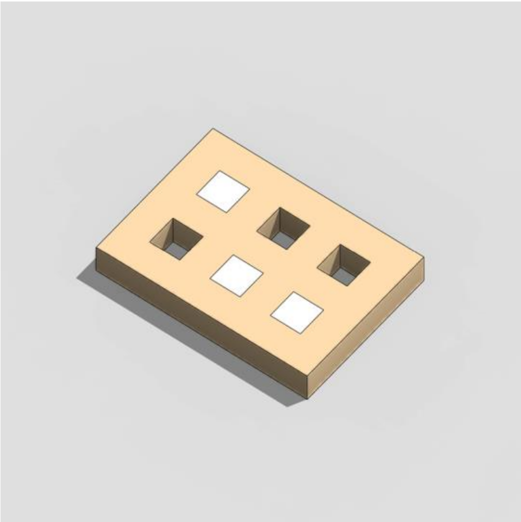


The typology can offer a human scale in contrast to the institutional character that tends to overwhelm most hospital design. However it will tend to apply to the larger, non-urban sites or smaller hospitals.

Example:

Fig. 3.2 Rotherham Hospital, Rotherham, UK - English Streamer demonstration project

3.1.3 **Monoblock**



The classic compact and circulation efficient type. The small atria/lightwells can take many forms and the lower floors may have fewer, with deep planning for non-patient areas or operating theatres. There is a need for artificial ventilation and the opportunity to incorporate Interstitial Service Floors.

Example:

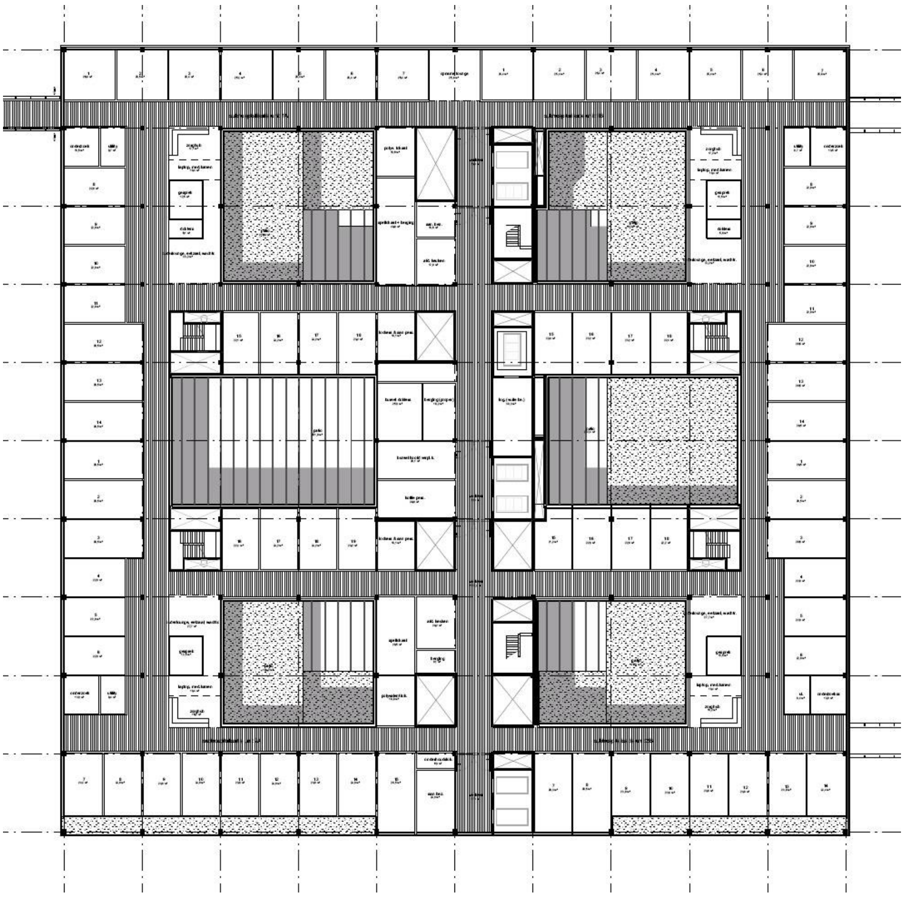
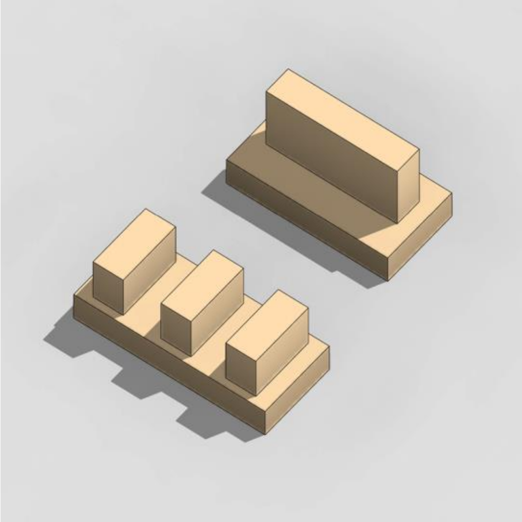


Fig. 3.3 UZ Leuven Phase 4B, Leuven, Belgium (image by DjGA)

3.1.4 Podium with one or more towers



4a. Podium and one slab/tower (also “Bundled” or “Stacked” in US)

The wards are generally in the tower with the clinical and technical areas in the slab. This typology can be effective on urban sites with small footprints but the upper floors can be problematic in term of travelling distance.

Example:

Fig 3.4 Prinsess Elisabeth children's hospital, Gent, Belgium (image by DjGA)

Fig. 3.5 Honliv Hospital Cancer Centre (image by DjGA)

4b. Podium with two or more towers/blocks

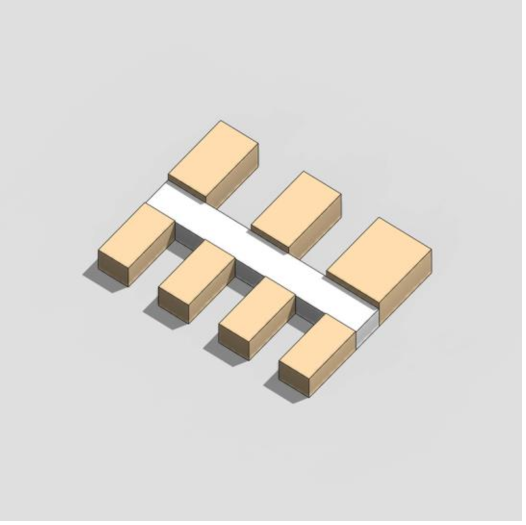
This typology avoids some of the potential travel distance and scale problems of the no. 4a but will require a larger site.

Example:

Fig. 3.6 Rijnstate hospital, Arnhem, The Netherlands - Dutch Streamer demonstration project (image by Rijnstate)

Rijnstate hospital also contains strong elements of the atrium typology. But because the wards are in the top buildings, the dominant typology is podium with two or more towers.

3.1.5 Street



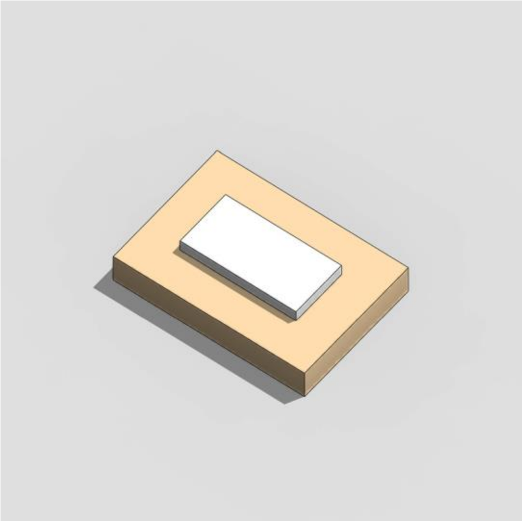
The attraction of this type has lain in its flexibility and extendibility as well as the legibility that the street itself offers to patients.

Example:

Fig. 3.7 St. Antonius hospital, Nieuwegein, the Netherlands (image by photographer Iemke Ruige)

The street in the St. Antonius hospital has been added as part of a masterplan containing multiple additions to the existing hospital.

3.1.6 Atrium/Galleria

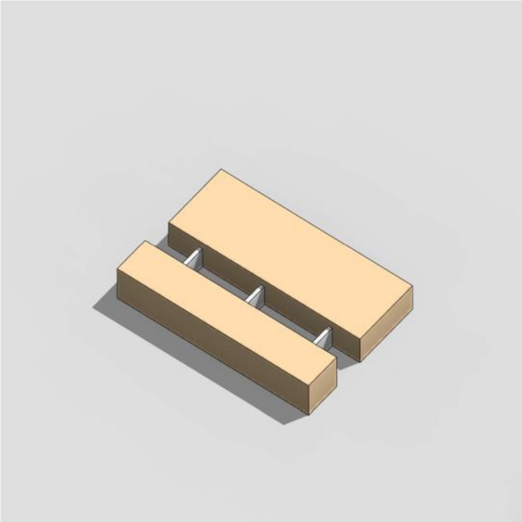


Atria have become extremely common in open plan office buildings where daylight can penetrate working floors from both sides. The cellular character of hospital buildings make atria a less obvious solution but there are a number of successful uses of this typology.

Example:

Fig 3.8 Jan Portaels hospital, Vilvoorde, Belgium (image by NU architectuuratelier)

3.1.7 Umbundled



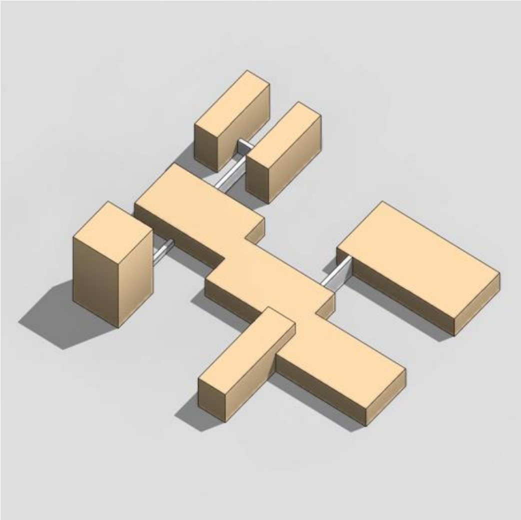
Unbundled is a pattern of segregation of the diagnostic and treatment functions on the one hand, and on the other the nursing functions along a shared circulation/support spine. “Unbundled” is a North American term and the typology is dominant in current design there; but it is also used worldwide.

Example:

Fig. 3.9 De Honte, Terneuzen, the Netherlands

De Honte also contains strong elements of the linked pavilion typology. But because the wards are coherent in the zigzag/shaped building, the dominant typology is unbundled.

3.1.8 **Campus**



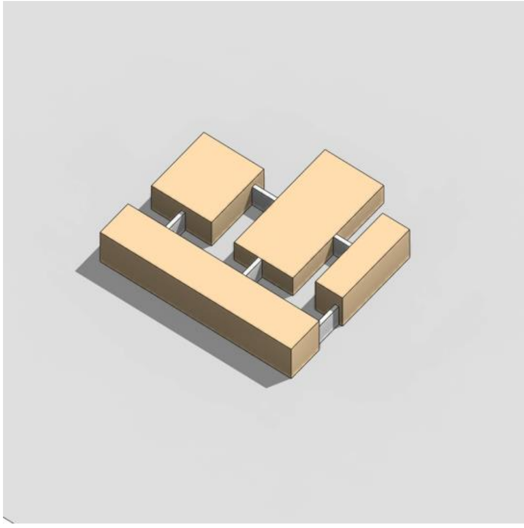
Individual buildings (that may belong to one or more of the typologies as described) disposed around the site with or without enclosed circulation network.

Example:

Fig. 3.10 Salpetriere – C. Foix University Hospital district in Paris (French Streamer demonstration project)

Fig. 3.11 AOU-Careggi Firenze (Italian Streamer demonstration project)

3.1.9 **Layered**



This type of hospital is the typical result of designing with the layer model in mind. It consists of separate but interconnected buildings with different layer properties.

Example:

Fig 3.12 Maas en Kempen Hospital, Maaseik, Belgium (image by DjGA)

Fig 3.13 Bernhoven, Uden, the Netherlands (image by Bernhoven hospital)

3.2 Relations

3.2.1 Energy

When looking at building energy consumption, an important distinction can be made between the energy consumed by the building and the energy consumed by the user equipment.

Although the energy consumed by the users plays a very important role, there is hardly any relation to building typology. For instance, longer opening times may reduce the energy consumption per treatment, but can be realized within any building typology or building form.

For these reasons, we are focusing only on energy consumption that is related to the building typologies. So energy usage related by function is not in the scope.

The impact of the building typology on the total energy consumption is mainly by energy loss outer surface and distance between generation and delivery system. But is not so big. The impact because of orientation, angle of obstruction and heat loss through the wall is more bigger.

The building shape is optimized by an improved compactness factor (= content / wall surface) or improved façade factor (= Facade Surface / gross floor area).

The indirect impact of the building shape is bigger. For example, a pavilion with a large facade surface, and as much natural light capability better comfort, but also a higher energy by plants to prevent overheating.

3.2.2 Geographical location

The geographical location is a crucial issue to be considered in the design of HD as the climatic variables related to the location affects the design decisions to be made especially in terms of energy use. Indeed, the temperature, wind, solar energy and moistures impact the performance of the buildings. For this reason, the identification of the climate zone of intervention is relevant for the definition of the parameters that could provide information for the design and operation of HD. The characterization of climate zones is based on seasonal climate characteristics ; among these: the heating degree days, the cooling degree days, the solar radiation, design dew-point temperatures and design wet-bulb temperatures.

It is not possible to show the proper design strategies to be adopted within each climate zone. Therefore, some crucial aspects to consider can be identified. As an example, the energy use for lighting depends on the available daylight, the use of renewable energy plants depends on the natural resources available, the selection of the HVAC system to be used depends on the efficiency necessity for each climate zone, etc.

Naturally, each building typology's performance is influenced by the climatic variables inherent to the geographical location, thus the climatic zone of reference. In particular, the design should consider the climatic issues with regards to the building shape, the building orientation, the number of stories, and the building floor plate configuration.

Four main climate zones can be identified in Europe:

Maritime Climate

It includes countries like Iceland, Great Britain, Ireland, Norway, southern Sweden, western France, northern Germany and northwestern Spain.

It shows intense temperature ranges, being very exposed to the Atlantic air masses. Thus, the weather is subject to many changes

Precipitations occur the most in autumn or early winter; they are generally acceptable.

Summers are hot or warm depending on the latitude and altitude.

Central Europe Climate

It involves the core of Europe, including countries like central Sweden, southern Finland, Oslo Basin of Norway, eastern France, southwestern Germany, and much of central and southeastern Europe.

The weather is considered transitional due to interaction of maritime and continental air masses.

Winters are characterized by coldness and substantial mountain snowfalls. Rainfall can overpass 80 inches (2,000 mm) in mountains and snow can often lay on high peaks permanently. Summers are instead warmer. Precipitations occurs from adequately to abundantly, generally heavier in summers.

Continental Climate

It involves a big part of Europe, including northern Urkraine, eastern Belarus, most of Finland, and northern Sweden. Winters are very cold and long, characterized by snow. Anyway, winters result coldest in the northeast and summers result hottest in the southeast. The range of temperatures in the first 6 months of the year is from 10 to 21°. Precipitations have their peak in summer, but less abundant than in the West of Europe. In parts of the south, being the precipitations unpredictable and inadequate, problems of aridity can seriously occur.

Mediterranean Climate

It includes the coastlands of southern Europe. Mild and wet winters, and hot and dry summers characterize this parts of Europe. The western part of this region is more affected by the influence of maritime air masses than the southeastern parts. Rainfalls in southern Europe depends highly on the distance to the rain-bearing westerlies (e.g. precipitations in Rome are much higher than in Athens).

3.2.3 HCAV system

The building typologies do have (obviously) specific characteristics that exclude or include HVAC systems, or add applicable. For example, a one floor pavilion allows for an individual HVAC system by department or by room. An building typology flat is more suitable for one big combined HVAC system. By the typology campus the distance between the buildings has big influence in choosing a collective or individual HVAC system. Or, let’s say: the more roof area the more PV panels could be applied. On the other hand, a larger roof gives more surface area for more energy loss. So, these possibilities and impossibilities for HVAC systems should be well known as well in the design stage.

So the building typology is the base for an energy system. Only the shape could be still be slightly modified.

3.2.4 Strategy

These are some (not complete listed) energy strategy’s

- Sustainability of the generation of energy and the ambition of sustainability, for example, energy neutral, or 20% energy reduction;
- Starting a specific existing or wanted generation like CHP and absorption chiller. See also WP 2.2 and WP 2.3.;

- Combined or not of heating/ cooling / production of (emergency) electricity / steam;
- Typology of delivery system (air, water of combination)
- Collectivity or individual HVAC plant, as it is now, or in the future.

Of course these are independent of the building typology. So in the next chapter, for each building typology, the energy related characteristics are showed.

3.3 Energy related characteristics

For each building typology, the energy related characteristics are showed.

3.3.1 Linked pavillon or finger plan

Characteristic	Description
Energy	
Compactness factor or building footprint	Because of the large surface area (façade and roof area), the compactness factor is very low. So there is more energy loss to the environment
Energy loss by length of piping	Because of the long distances within the building, there will be more distribution related energy losses.
Energy usage for vertical transport systems (lifts)	Depending of the number of floors, but mostly there are many lifts needed to reduce walking distance.
Available roof area for PV(T)-panels	Because of the huge roof area, there is plenty space available for PV(T)-panels
Energy usage for lighting	Due to the large façade area a lot of day light can enter the building. Therefore energy use for lighting will be low.
Suggested building orientation	N.A.
Preferred Climatic zone	Central Europe and Continental climate
Indoor quality	
Natural daylight	Because of the large façade area, there is a large possibility of natural daylight through windows.
View out	View out to the opposite building is a relevant part of the design configuration.
External lighting control	Required in almost every room.
Natural ventilation possible	Yes, but not everywhere. In the tower, it needs to be designed very carefully
HVAC system	
Recommended plant configuration	Especially for the bigger hospitals, more HVAC plants are recommended, so a decentralized system is suggested.
Flexibility for future changes	In the infrastructure, there is not much flexibility. Only flexibility in the HVAC plant.

3.3.2 Low-rise multi-courtyard or checkerboard

Characteristic	Description
Energy	
Compactness factor or building footprint	Because of the low rise building the external wall and roof surface area is large. The energy losses to the surroundings are relatively high, but less than the linked pavilion or fingerplant configuration.
Energy loss by length piping	Because of the long distances within the building, there will be more distribution related energy losses.
Energy usage for vertical transport systems (lifts)	Depending of the number of floors, but mostly there are many lifts needed to reduce walking distance.
Available roof area for PV(T)-panels	Because of the large roof area, there is plenty space available for PV(T)-panels
Energy usage for lighting	The inner rooms do not receive day light, so it needs more energy for lighting.
Suggested building orientation	N.A.
Preferred Climatic Zone	Central Europe and Continental climate
Indoor quality	
Natural daylight	Because of the large façade area, there is a possibility of natural daylight through windows, except for the inner rooms.
View out	View out to the opposite building is relevant part of the design configuration.
External lighting control	Required in almost every outside room.
Natural ventilation possible	Only in the outside rooms.
HVAC system	
Recommended plant configuration	Especially for the bigger hospitals, more HVAC plants are recommended, so a decentralized system is suggested.
Flexibility for future changes	In the infrastructure, there is not much flexibility. Only flexibility in the HVAC plant.

3.3.3 Monoblock

Characteristic	Description
Energy	
Compactness factor or building footprint	The compactness factor is average, but the outside wall surface area is relatively high. The energy loss to the surroundings is moderate. Energy loss through windy air infiltration is moderate
Energy loss by length piping	Moderate
Energy usage for vertical transport systems (lifts)	Because of the large number of floors, there are many lifts required to reduce the walking distance.
Available roof area for PV(T)-panels	Because of the small roof area, there is not so much space available for PV(T)-panels
Energy usage for lighting	The inner rooms and the rooms with the outside walls at the inside of the building, especially on the lower floors require more energy for lighting.
Suggested building orientation	North South
Preferred Climatic zone	Mediterranean climate
Indoor quality	
Natural daylight	Because of the relatively large façade surface area there is a possibility of natural daylight through windows, but it is limited at the inner side of the building.
View out	View out to the opposite building is relevant part of the design configuration.
External lighting control	Required in almost every outside room, not in the inside rooms.
Natural ventilation possible	Moderate, only at outside of the building.
HVAC system	
Recommended plant configuration	More HVAC plants are recommended.
Flexibility for future changes	In the infrastructure, there is not much flexibility. Only flexibility in the HVAC plant.

3.3.4 Podium with one or more towers

4a. Podium and one slab/tower (also “Bundled” or “Stacked” in US)

Characteristic	Description
Energy	
Compactness factor or building footprint	Compactness factor is good.
Energy loss by length piping	Because of the long distances within the building, the energy losses caused by distribution are large.
Energy usage for vertical transport systems (lifts)	It depends on the number of floors, but mostly there are many lifts required to reduce walking distance.
Available roof area for PV(T)-panels	Because of the relatively large roof area, there is plenty space available for PV(T)-panels
Energy usage for lighting	The inner rooms (present especially on the lower floors) require more energy for lighting,
Suggested building orientation	North South
Preferred Climatic zone	Central Europe and Continental climate
Indoor quality	
Natural daylight	In the towers the façade surface area is high, so it has a good possibility for natural daylight. The (large number of) inner rooms in the podium do not receive daylight.
View out	View out everywhere in the tower
External lighting control	Required in almost every room in the towers, but only in the outside rooms of the podium.
Natural ventilation possible	In the outside rooms well possible. In the tower it needs to be designed very carefully
HVAC system	
Recommended plant configuration	At least one HVAC plant in the tower and one in the podium is recommended.
Flexibility for future changes	In the infrastructure, there is not much flexibility. Only flexibility in the HVAC plant.

4b. Podium with two or more towers/blocks

Characteristic	Description
Energy	
Compactness factor or building footprint	Compactness factor is good, but less good than 4a.
Energy loss by length piping	Because of the long distances within the building, the energy losses caused by distribution are large.
Energy usage for vertical transport systems (lifts)	It depends on the number of floors, but mostly there are many lifts required to reduce walking distance.
Available roof area for PV(T)-panels	Because of the relatively large roof area, there is plenty space available for PV(T)-panels
Energy usage for lighting	The inner rooms (present especially on the lower floors) require more energy for lighting,
Suggested building orientation	North South
Preferred Climatic zone	Central Europe and Continental climate
Indoor quality	
Natural daylight	In the towers the façade surface area is high, so it has a good possibility for natural daylight. The (large number of) inner rooms in the podium do not receive daylight.
View out	View out everywhere in the tower
External lighting control	Required in almost every room in the towers, but only in the outside rooms of the podium.
Natural ventilation possible	In the outside rooms well possible. In the tower it needs to be designed very carefully
HVAC system	
Recommended plant configuration	At least one HVAC plant in each tower and one in the podium is recommended.
Flexibility for future changes	In the infrastructure, there is not much flexibility. Only flexibility in the HVAC plant.

3.3.5 Street

Characteristic	Description
Energy	
Compactness factor or building footprint	Because of the low rise building the external wall and roof surface area is large. The energy losses to the surroundings are relatively high, but less than the linked pavilion or fingerplant configuration.
Energy loss by length piping	Because of the long distances within the building, there will be more distribution related energy losses.
Energy usage for vertical transport systems (lifts)	Depending of the number of floors, but mostly there are many lifts needed to reduce walking distance.
Available roof area for PV(T)-panels	Because of the large roof area, there is plenty space available for PV(T)-panels
Energy usage for lighting	Due to the large façade area a lot of day light can enter the building. Therefore energy use for lighting will be low.
Suggested building orientation	N.A.
Preferred Climatic zone	N.A.
Indoor quality	
Natural daylight	Because of the large façade area, there is a large possibility of natural daylight through windows.
View out	View out is every where
External lighting control	Required in almost every room.
Natural ventilation possible	Yes, almost everywhere.
HVAC system	
Recommended plant configuration	One HVAC plant per building is recommended.
Flexibility for future changes	In the infrastructure, there is not much flexibility. Only flexibility in the HVAC plant.

3.3.6 Atrium/Galleria

Characteristic	Description
Energy	
Compactness factor or building footprint	Because of the rectangular shape, the compactness factor is moderate.
Energy loss by length piping	Because of the long distances within the building, the distribution related energy losses will be high.
Energy usage for vertical transport systems (lifts)	Depending of the number of floors, but in most cases not so many.
Available roof area for PV(T)-panels	Because of the large roof area, there is plenty space available for PV(T)-panels
Energy usage for lighting	Because of the large façade area with windows and transparent roofs not so high.
Suggested building orientation	North South
Preferred Climatic zone	Maritime climate
Indoor quality	
Natural daylight	Because of the large façade area and transparent roof, there is a good possibility to have daylight through windows.
View out	View out everywhere
External lighting control	Required in the outside rooms
Natural ventilation possible	Yes, but only in the outside rooms.
HVAC system	
Recommended plant configuration	Depending on the dimensions of the hospital
Flexibility for future changes	In the infrastructure, there is not much flexibility. Only flexibility in the HVAC plant.

3.3.7 Umbundled

Characteristic	Description
Energy	
Compactness factor or building footprint	The compactness factor is low and because of the large surface area (façade and roof area) the energy loss to the environment is significant.
Energy loss by length piping	Because of the long distances within the building, there will be more distribution related energy losses.
Energy usage for vertical transport systems (lifts)	Depending of the number of floors, but in most cases a few in each building.
Available roof area for PV(T)-panels	Because of the huge roof area, there is plenty space available for PV(T)-panels
Energy usage for lighting	Due to the large façade area a lot of day light can enter the building. Therefore energy use for lighting will be low.
Suggested building orientation	North South
Preferred Climatic zone	Maritime Climate
Indoor quality	
Natural daylight	Because of the large façade area, there is a large possibility of natural daylight through windows.
View out	View out almost everywhere in each building, but possible to the opposite building
External lighting control	Required in almost every room.
Natural ventilation possible	Yes
HVAC system	
Recommended plant configuration	At least one HVAC pant in each building is recommended
Flexibility for future changes	In the infrastructure, there is not much flexibility. Only flexibility in the HVAC plant.

3.3.8 Campus

Characteristic	Description
Energy	
Compactness factor or building footprint	The compactness factor is low and because of the large surface area (façade and roof area) the energy loss to the environment is significant.
Energy loss by length piping	Because of the long distances within the building, there will be more distribution related energy losses.
Energy usage for vertical transport systems (lifts)	Depending of the number of floors, but in most cases a few in each building.
Available roof area for PV(T)-panels	Because of the huge roof area, there is plenty space available for PV(T)-panels.
Energy usage for lighting	Due to the large façade area a lot of day light can enter the building. Therefore energy use for lighting will be low.
Suggested building orientation	N.A.
Preferred Climatic zone	N.A.
Indoor quality	
Natural daylight	Because of the large façade area, there is a large possibility of natural daylight through windows.
View out	View out almost everywhere in each building, but possible to the opposite building
External lighting control	Required in almost every room.
Natural ventilation possible	Yes, almost everywhere.
HVAC system	
Recommended plant configuration	At least one HVAC pant in each building is recommended
Flexibility for future changes	In the infrastructure, there is not much flexibility. Only flexibility in the HVAC plant.

3.3.9 Layered

Characteristic	Description
Energy	
Compactness factor or building footprint	The compactness factor is low and because of the large surface area (façade and roof area) the energy loss to the environment is significant.
Energy loss by length piping	Because of the short distances within the building, there will be less distribution related energy losses.
Energy usage for vertical transport systems (lifts)	Depending of the number of floors, but in most cases a few in each building.
Available roof area for PV(T)-panels	Because of the huge roof area, there is plenty space available for PV(T)-panels.
Energy usage for lighting	Due to the large façade area a lot of day light can enter the building. Therefore energy use for lighting will be low.
Suggested building orientation	N.A.
Preferred Climatic zone	N.A.
Indoor quality	
Natural daylight	Because of the large façade area, there is a large possibility of natural daylight through windows.
View out	View out almost everywhere in each building, but possible to the opposite building
External lighting control	Required in almost every room.
Natural ventilation possible	Yes, almost everywhere.
HVAC system	
Recommended plant configuration	At least one HVAC pant in each building is recommended
Flexibility for future changes	In the infrastructure, there is not much flexibility. Only flexibility in the HVAC plant.

4. Analysis of typologies: the Layers approach

The perception of the use of buildings in healthcare is changing: buildings are increasingly considered a means of production contributing to efficient business operations. In this chapter the so-called “Layers approach” is introduced. Originally intended as an analysis tool for considering investment decisions in hospitals it is also usable for considering energy optimizations. The approach is developed by the Netherlands Board for Healthcare Institutions in the Netherlands. In the research study completed in 2007 the Layers approach divides the hospital into four buildings, referred to as the layers.

4.1 Introduction

The changing demands in healthcare and the overall economic situation has necessitated a different perception of accommodation of healthcare organizations. In this new, business-like, setting property has become a regular means of production that is to contribute to efficient business operations of a hospital to the maximum extent. The accommodation is to provide optimum support for the business processes, its price should be keen to secure the competitive position vis-à-vis other healthcare providers, and it should be able to cover changes to the nature and scope of the business activities. In addition, to maintain the profitability of the institution in the long run it is also more than desirable that the accommodation is sufficiently marketable and modular to facilitate disposal of all or part of the building by lease or sale. As a result of this new approach hospital managements are confronted with the task to develop strategies aimed at optimization of the accommodation.

This is far from easy, as there is no unambiguous answer to the question as to when a hospital’s accommodation is optimum. If the accommodation fits the organization like a glove, the available floor area is fully used and the functional structure is fully tailored to efficient operation of the current business processes. However, relatively minor extensions or shrinking of such a glove, or limited adjustments to the operations, will easily disrupt the primary process and lead to expensive and often difficult constructional adjustments. On the other hand, an accommodation model based on spatial over-sizing and standardized modular construction provides maximum change-resistance. However, such over-sizing and standardization lead to often unacceptably high operating costs.

As often, the optimum route will be somewhere in the middle, but in order to determine where exactly, hospital managements are challenged clearly to project the desired lay-out and the expected future development of the primary (and supporting) processes to be accommodated, as well as to translate such organizational analysis into suitable property solutions.

To be able properly to perform their strategic duties, hospital managements – and other parties involved – require practical tools supporting the perception and the decision-making process. One of those tools is the so-called Layers approach. This approach divides the function package of a hospital according to building typology into four layers: the hot floor, i.e. the capital intensive high-tech functions that are unique to the hospital; the hotel, which includes the larger part of the patient accommodations; the office, with the outpatient units, accounting, management and training functions; and industry, which accommodates those functions that are capital intensive, such as the laboratories and the production kitchen.

Each of these layers has its own properties profile as regards specificity, investment costs, growth/downsizing requirements, and marketability of the property. Figure 4.1 gives an impression of those. With the present study we intend to answer the question as to how the layers approach can be used to develop accommodation models that can provide optimum support to the hospital's performance of its functions and to its operations.

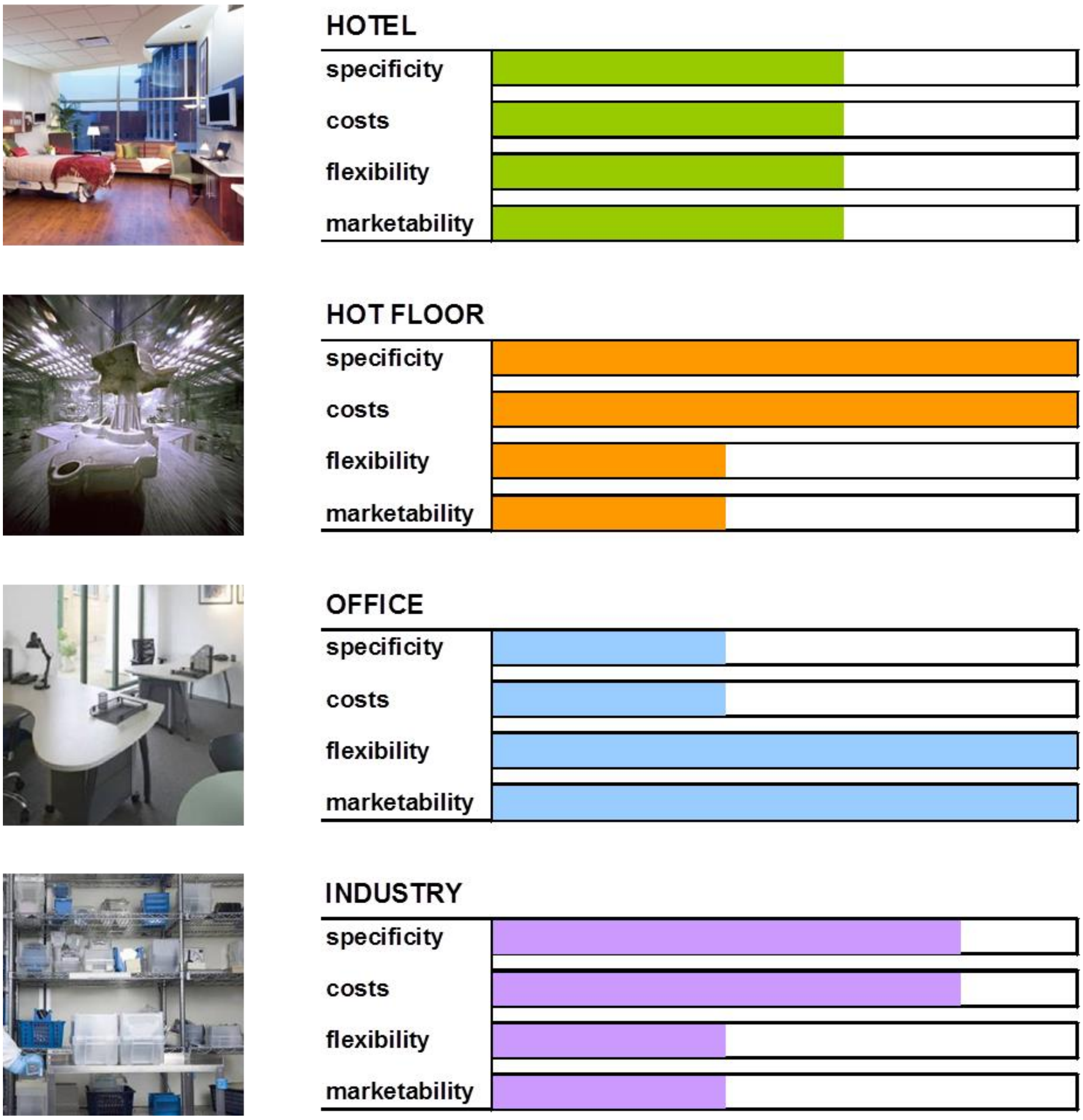


Figure 4.1 Properties of a hospital's layers

4.2 Results

This paragraph presents the results of the research study in which an explanation of all aspects of the three accommodation models developed based on the layers approach and explains which choices and design principles played a role in each of them. The layers approach does not prescribe one type of accommodation as being optimum, but is a dissection of the hospital's function package based on building typology, which can be used as a tool for (strategic) accommodation issues. This means that, in actual practice, given the diverse function profiles, case mixes, market conditions, and ambitions of individual hospitals, a broad and non-transparent range of accommodation solutions can be generated using the layers approach. To make the research question manageable and clear, as well as to structure and clarify the report, it has been deemed useful to select three accommodation models from this range with clearly distinguished positions within the range of possibilities, illustrating three different design principles.

Model A is best characterized as a monolith. In this model all functions are accommodated in one building with no or hardly any constructional differentiation. It should, in principle, be possible to accommodate each function in any location within the building. The leading design principle is INTERNAL FLEXIBILITY.

Model B is a hybrid model, in which a layer consists of heterogeneous elements. Functions are usually separated based on constructional typology, but this distinction is not implemented as a dogma. A number of functions are (partially) accommodated in a building-typological foreign environment if that seems to be preferred on process grounds. The leading design principle in this model is BALANCED OPTIMIZATION.

Model C is the most far-reaching as regards differentiation and, thus, the extreme model. This model uses a strict function separation based on building typology: functions with different constructional profiles are accommodated in different parts of the building. The leading design principle is CONSTRUCTIONAL OPTIMIZATION.

The next part focuses on the main medical and organizational relations and will give a graphic representation of the division of functions over the various building types. A hospital is a labyrinth of relations between function groups. This many-branched interrelationship largely determines the complexity of the design assignment characterizing a hospital. On further review it turns out that most of these interrelations can be sufficiently secured if the relevant functions are separated, provided that the necessary conditions as regards operations – e.g. organization of staffing, ICT support, etc. – are available. A limited number of functional relations is, however, so important to proper and sound performance of the processes at the hospital that these medical and organizational relations must be taken into account. A relation means that functions are situated in each other’s immediate vicinity or connected by a fast unhindered route.

Based on the preliminary inventory two categories are distinguished:

- Medical relations between departments that must be spatially available to provide sound healthcare. These medical relations are crucial because the necessary time it takes to walk the distance is vital. It is important that the following combinations of functions are situated in each other’s immediate vicinity or are connected by a fast unhindered route:

– emergency and operating theatres
– emergency and diagnostic imaging
– emergency and coronary care
– emergency and intensive care
– operating theatres and intensive care

– operating theatres and delivery

- Organizational relations between departments that, although not strictly medically required, are so important to the proper course of the business processes in the primary process that, from a business operations perspective, it is highly preferable that they are situated in each other's (immediate) vicinity. These are organizational relations between:
  – pediatric nursing (neonatology) and operating theatres
  – pediatric nursing and maternity
  – maternity and delivery
  – (surgical) day nursing and operating theatres
  – laboratory clinical chemistry and emergency
  – laboratory clinical chemistry and intensive care

An important condition for uninterrupted performance of the primary process at a hospital is adequate situation of the departments with a medical relation. The basic principle in model shaping is for these departments to be accommodated in one layer, the hot floor. The second principle is that it is possible for departments with an organizational relation to be accommodated in different layers. The relations are leading for the division of the functions over the layers. The next step is to prepare an overview of the functions and the interrelations for the three models. First of all, model A, the monolith.

In model A, the monolith, all functions are accommodated in one undifferentiated building complex. This approach makes it simple properly to accommodate all medical and organizational relations from a constructional perspective (Figure 4.2). As, from a functional and technical point of view, nearly all functions can be accommodated in virtually any place within the building complex, this model is also well able spatially to cover any changes in the organization of the healthcare. The key disadvantage is the fact that the developments in the market are not used, because the building complex does not link up with existing building types. Disposal of parts cannot easily be realized. Moreover, in the event of changes other functions are often unnecessarily moved because they are no longer in the right location. An example is that, as a result of an increase in the department of diagnostic imaging an outpatient unit located behind it would be so far from the route that it has to be moved as well.

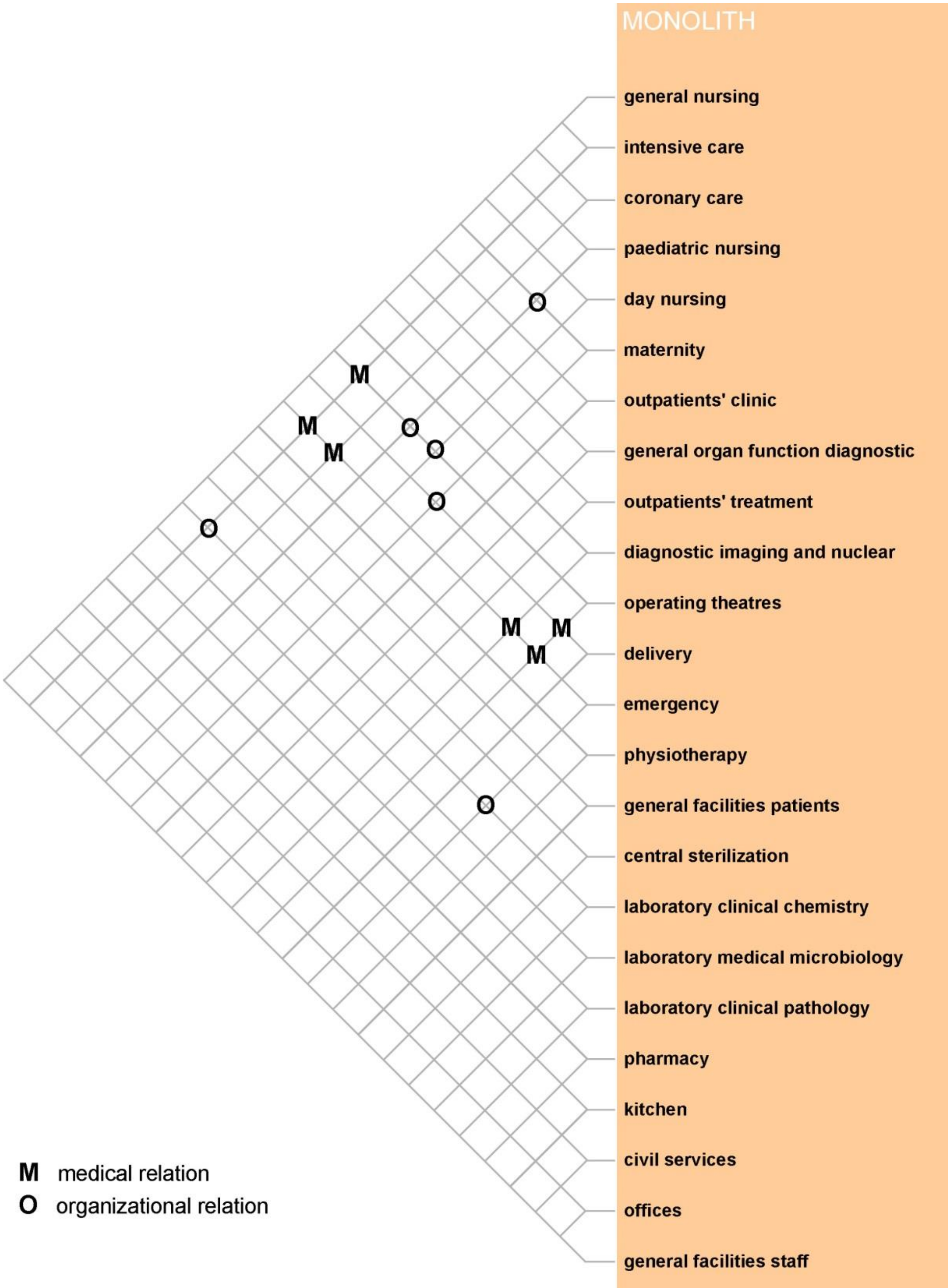


Figure 4.2 Relations Diagram in Model A, the Monolith

The hybrid model B is subject to constructional differentiation, which results in four layers (see Figure 4.3). A number of functions, however, are accommodated in a constructional "foreign" environment for organizational reasons. The effect thereof can especially be noted in the size of the hot floor. In addition to the functions that belong here from a constructional perspective, a somewhat broader than strictly necessary buffer bed capacity for standards care/medium care in the hot floor has been taken into account. The women's/mother's/child's centre is also located in the hot floor, based primarily on the medical relation between delivery and the operating theatres. The bed capacity for surgical day nursing is accommodated in the hot floor, because of the organizational relation with the operating theatres. Furthermore, the hot floor includes part of the diagnostic offices destined for medical disciplines and research processes making intensive use of the diagnostic functions available in the hot floor. The hot floor also accommodates the entire laboratory clinical chemistry, the organizational relations for urgent diagnostics with the operating theatres and the emergency unit being decisive.

The facilities for the other laboratories and the pharmacy in the hot floor are limited to front office facilities and room for urgent diagnostics or, alternatively, for preparing medications for administration. Finally, also the civil and technical services that perform specifically for the core functions in the hot floor are accommodated in the hot floor. This extensive hot floor comprises all medical and organizational relations. The general rooms for patient accommodation and staff facilities are allocated to the building environments (excluding industry) based on relevant rough allocation formula. In addition to the rooms for patient accommodation the hotel accommodates front office facilities of the pharmacy (decentralized storage and provision of medications) and rooms for the kitchen for distribution of meals.

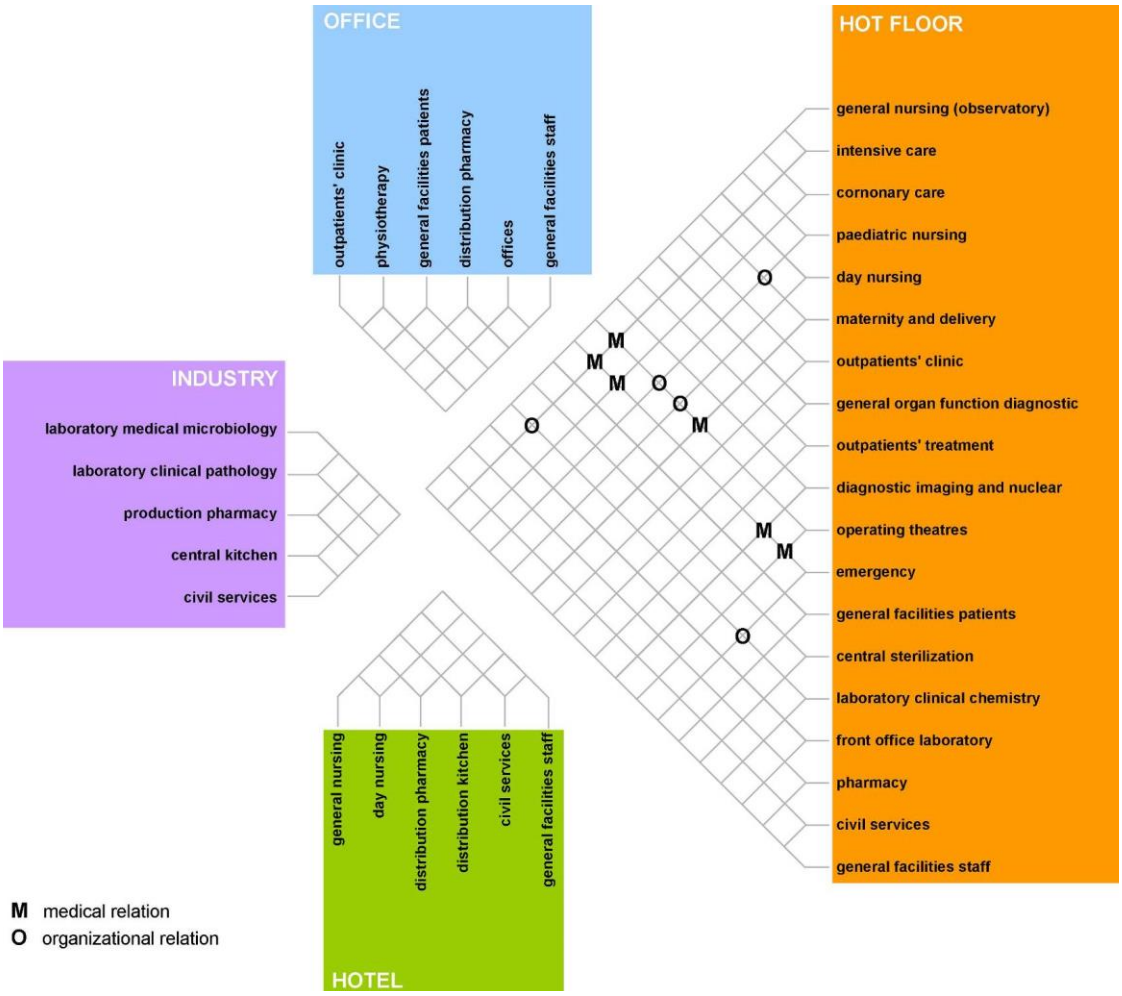


Figure 4.3 Relations Diagram in Model B, the Hybrid Model

The meals are produced in the central kitchen and are heated up only. These rooms, too, can be allocated to the hotel from a typology perspective. In addition, the hotel accommodates those civil and technical services that perform specifically for the hotel.

The extreme model C has the most far-reaching constructional differentiation (see Figure 4.4). A number of particulars and conditions should, however, be observed in this extreme model. The situation of paediatric nursing in the hotel assumes that this hospital does not offer ICU or HCU neonatal healthcare; both from a typology and a functional perspective, these units should be accommodated in the hot floor. The outpatients facilities are accommodated in the office environment, which is possible only if no surgical treatment is performed that requires a fully equipped OR environment.

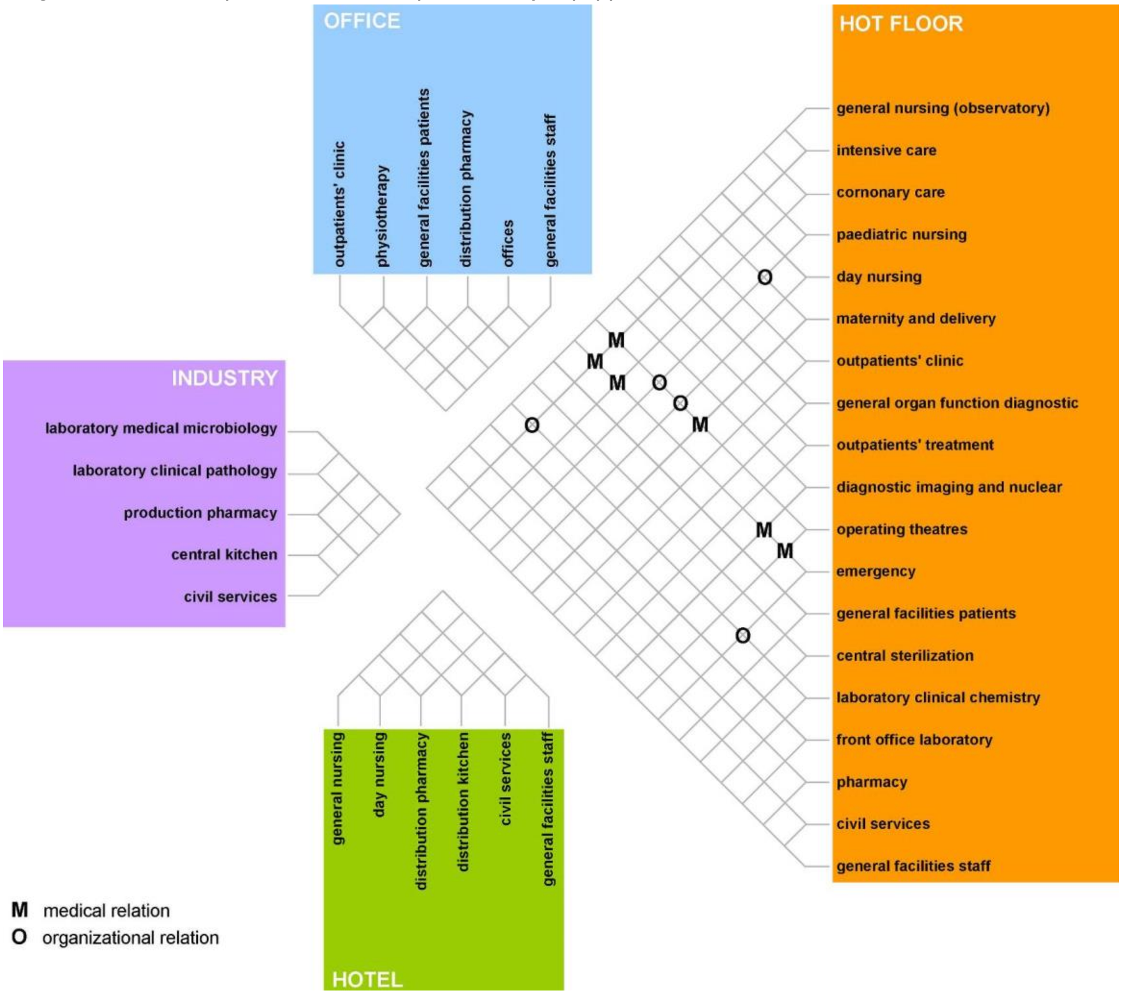


Figure 4.4 Relations Diagram in Model C, the Extreme Model

The office layer includes a laboratory for taking blood samples for the large flow of patients needing it. Just as in model B medications and meals are produced in a central location (the industry) and room is reserved only for distribution.

As may, however, be clear from the overview of organizational relations, too strict an implementation of differentiation of buildings will result in serious organizational bottlenecks. A connection from the hot floor to the hotel and the office will be desirable to cover such bottlenecks. This requires additional constructional facilities and, hence, costs.

The figures included in the following part are a spatial translation of the hybrid and extreme models. After division of the functions over the layers the next step is to organize the functions in the various floors, based on the following three principles. Firstly, the relations diagram discussed in the foregoing paragraph will be leading for this exercise. Functions with a medical relation are accommodated either on the same floor or directly over each other, provided that a lift may be used only once. The organizational relations are subject to the same condition, but the distance between the various functions with a relation may be larger than for the functions with a medical relation. A second principle in the spatial translation is to create an equal division of floor area over the floors, so that the outer wall does not stand out, either externally or internally. Finally, the choice of a maximum building height of five floors allows for the model to be conceivable in both urban and rural environments. Moreover, this way the model can be well compared with a substantial number of existing hospital buildings.

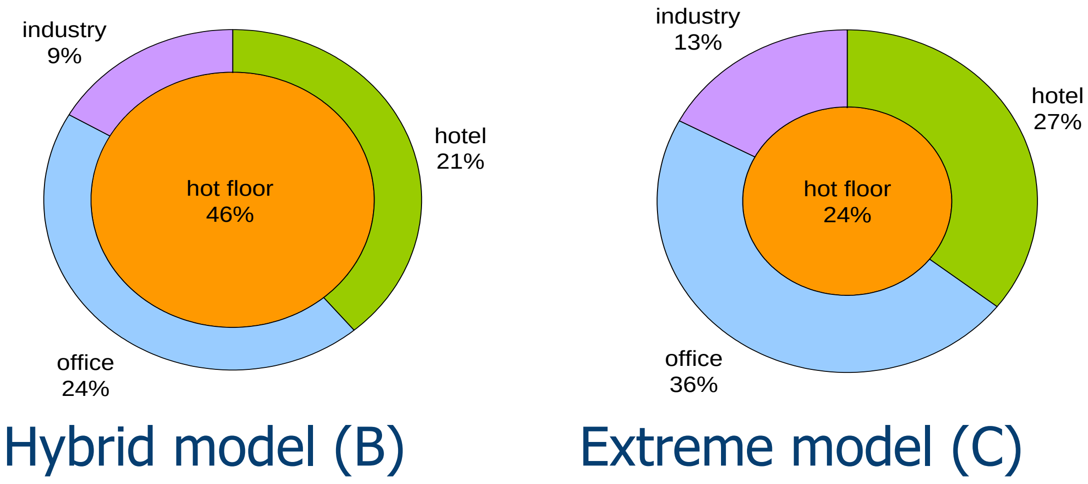


Figure 4.5 Proportional Division of the Floor Area over the Layers

The second factor for reduction of the construction costs can be found in the level of equipment of the hotel and office layers. The basic principle in this study is that the construction costs of the functions in the other two layers – hot floor and industry – are the same for all models. This assumption is realistic as these functions with capital intensive activities set such specific requirements for the built environment that it does not make much difference whether they are accommodated in one overall building complex or separately. The specific requirements claim a substantial part of the construction costs, so that differentiation has no or hardly any impact on the total construction costs.

For the hotel and office layers elements have been weighed that are deemed common for hospitals, but are not found in a hotel or office not destined for healthcare. This means that, e.g., a hospital's bed centre contains elements that are not found in a hotel, such as the equipment for medical gases with which usually every patient room is equipped. A large group of patients do, however, not use any medical gases in their rooms. The construction costs can be reduced by leaving out the equipment for medical gases in a number of rooms, the only condition being that the patients are categorized on various care levels (standard care, medium care, high care and intensive care). Note that in Germany this principle has already been successfully used by Rhön-Klinikum, a group of privatized hospitals.

Even more important than saving initial investment costs is the increase of the return on the property if the layers approach is used. In determining the return on the property, in addition to the initial investment costs also capital charges, building-related operating costs and the costs of subsequent adjustments, on the one hand, and the revenues from the property on the other, are taken into account.

An international unit expressing returns on property is the Internal Rate of Return (IRR). Determining the IRR requires net cash value (NCV) computations. The computations of the return (IRR) puts all future expenses and income in relation to the initial investment. To simplify matters, the computations compare the monolith with the extreme model. Any reference in the following paragraphs to the extreme model may also be deemed to refer to the hybrid model. The gross floor area of the extreme model has been used as a basis. The computations are based on the assumption that the construction costs of the monolith exceed those of the extreme model by 7%. Within the band width of the construction cost reduction this is a moderate assumption. This choice has been consciously made so that not only the extremes will be made transparent.

The computation shows that the extreme model scores better than the monolith on all points. According to Figure 4.6, the differences, i.e. the increases in return, between the monolith and the extreme model vary from approximately 15% for the hot floor, 22% for the industry, to even approximately 25% for the hotel and the office.

	Monolith *	Extreme	Hotel	Hot floor	Office	Industry
gross floor area (m²)	**46.075**	**46.075**	**12.923**	**11.372**	**16.270**	**5.510**
building costs (mln.)	**68,0**	**63,4**	**17,5**	**19,0**	**17,7**	**9,3**
investment costs (mln.)	**99,1**	**92,4**	**25,4**	**27,7**	**25,7**	**13,6**
life span (yrs.)	**40**		**50**	**20**	**50**	**20**
Internal Rate of Return (IRR)	**6,00%**		**7,49%**	**6,92%**	**7,47%**	**7,33%**
increase return			**25%**	**15%**	**25%**	**22%**

**** = for comparison the gross floor areas are equal and the monolith costs 7% more***

Figure 4.6 Comparison of Return in the Monolith and the Extreme Model (Model C)

The most important causes of the differences in the hot floor and the industry are the exclusion of mid-life renovations, lower investment costs, lower vacancy, and the absence of loss of income during renovations. These factors more than outweigh the short life-cycle of 20 years. In the office and the hotel the lower costs of the mid-life renovation, lower investment costs, and limited loss of income during renovations mainly determine the increase in return. The increase in the return is, therefore, the result of the said spatial and financial strategy. This strategy development takes place during the feasibility phase of the design process. At that stage the banking risk and banking profit can be controlled, so that it would be obvious to involve the financial property expertise of capital providers in the feasibility of property. Particularly investors and financiers are increasingly interested in healthcare property, more or less forced by the enormous capital stocks profitably to be invested.

4.3 Conclusions

What is next? Existing structures can still definitely be used and need not be disregarded right away. The layers approach shows that in developing property strategies it is good to link up with established building types on the market. The aspects of the layers approach referred to in the report can also be used for existing structures, even on a smaller scale, if the project is not entirely new but partially relates to renovation. The key is to look across the borders and question all the known concepts in developing accommodation models. When selecting a scenario for the future healthcare will absolutely need a clear vision of property.

5. Analysis of typologies: the functional models

This section will implement a classification of typology models based on the functional approach.
Single spaces, functional areas, departments, buildings and health care districts will be analyzed and categorized considering proximity and interdependencies between spaces and functions.
The aim is to address a design methodology that takes the definition of functional areas as the basis for the identification of the design criteria to be applied in order to provide a theoretical model of high quality and efficiency healthcare district. The model provided should configure an integrated complex of harmonized and synergic activities and services. Therefore, the functional integration requires constructive integration, as the layout of spaces is considered a decisive factor for the development of the synergies among the different activities and services present within the healthcare district (Del Nord, 2011).
The methodology resulting from the functional approach generates sets of methodological, operative and functional prescriptions to be applied in the design phase in order to define the architectural, functional, constructive and installation systems aspects of the building organism starting from the identification of the functional areas and the spaces included.
The application of a design methodology based on the definition of the functional model allows the identification of the quantitative and qualitative parameters that will become the basis for the development of the semantic BIM model, on which the EeB features and values of the typology can be defined, objective which STREAMER research project aims to.

5.1 Definition of the functional model

The definition of the functional model requires a complete breakdown of the healthcare district in homogeneous functional areas and the definition for each of them of the environmental, technological, dimensional, functional and relational characteristics, always taking into consideration the main and general aim of the model (Assr, 2003).
The functional areas are then analyzed in terms of spatial units included in each area (elementary spaces). Each spatial unit is put in relationship with another belonging to the same functional areas in terms of spatial and functional dependency required for the development of either a solo complex activity or the sum of many elementary activities. (Giofrè and Terranova, 2004).

This approach operates on the *metadesign* level, entailing the definition of the spaces in terms of organization, layout, relationships and performances.
The methodology resulting from this approach allows, on one hand, the definition of the functional layout of the areas within the whole healthcare district and, on the other hand, the definition of the performances of each space, meaning that it provides for the elaboration of an appropriate “program of intervention” defined in its main parts and boosted with the most significant layouts on which the evaluation of the objective can be optimized.
Therefore, the definition of functional areas according to their inherent features allows the control of the space from multidisciplinary perspective: economy, management, performance, construction, relations,

entailing the identification of the main parameters of evaluation of the healthcare district from the usage and operation point of view. (Assr, 2003).
In exploring the STREAMER scope, the definition of the functional approach could provide and optimized model on which the EeB issues could be analyzed and the related values could be set at each level of the healthcare district.

5.2 Structure and levels of the functional model

The functional approach requires a breakdown of hospital functions in first place, as stated. The decomposition can be operated on different levels, entailing a hierarchic classification of all the spaces of an healthcare district. The main functional levels from which an healthcare district's functions can be analyzed are: functional macro-areas (FMA), functional areas (FA), sub-functional areas (SFA) and spatial units (SU).
Looking at a healthcare complex as the sum of levels provides a complete understanding of all its parts and allows an optimization of the performances assessment at each level.
Within the STREAMER scope, this structure allows an optimized definition of the design issues, in particular the EeB related issues, as each of them can be addressed at the most appropriate level. On the operative side, it allows a more effective and clear elaboration of the semantic model, as each level is informed by different sets of factors and parameters (e.g. functional features, performances, relationship, objectives).

A description of the levels of the functional model here follows:
Functional macro-areas (FMA): the functional macro-areas identified reflect the main medical activities conducted in hospitals. The main functional macro-areas are Diagnostic and Treatments, Wards, Operating blocks, Accident and Emergency (A&E), General Facilities, Public Facilities.

Functional areas (FA): a functional area is a group of spaces generally related to homogeneity of interdependencies between functions and spaces. The functional area can be classified considering both their functional and technical properties and characteristics, including their energy-related features.
The functional areas (FA) can be clustered according to the functional macro-areas (FMA) they belong to, as these are the result of a breakdown of the main functions (FMA) into homogeneous functional areas. The main homogeneous functional areas that can be found in healthcare district are here listed clustered according to the functional macro-area they belong to. Paragraph 5.4 presents a brief description of each functional area of this list.
Diagnostic imaging

- Nuclear medicine
- Radiotherapy
- Pre-hospitalization
- Endoscopy
- Blood sampling/testing
- Transfusion centre (blood bank)
- Rehabilitation
- Outpatient department

Ward (FMA):

- Intensive care ward
- High care ward
- Low care ward
- Medical day hospital
- Oncological day hospital
- Day surgery
- Maternity ward

Operating block (FMA):

- Operating theatres
- Interventional radiology

Accident and Emergency (FMA):

- Accident and Emergency (A&E)

General facilities (FMA)

- Medical testing laboratory
- Anatomical pathology laboratory
- Internal pharmacy
- Sterilization centre
- General storages
- Kitchen
- Canteen
- Medical archive
- Admission (reception, information, reservation)
- Garbage room and special materials disposal
- Mortuary
- Dressing rooms for staff
- Health physics
- Cleaning spaces

Public facilities (FMA)

Sub-functional areas (SFA): Within each functional areas some sub-functional areas (SFA) can be identified. The sub-functional areas correspond to typologies of space, thus with homogenous characteristic, that can be generally found within each functional area. Depending on the functional area, not all sub-functional areas are present. They represent categories of areas in which the main activities of each function can be developed. The sub-functional areas are:

- admission/reception/orientation area
- technical/administrative area
- diagnostic/treatment area
- intervention/operating area
- staff area
- ancillary facilities area

- hotel facilities area
- working area

The categorization of sub-functional areas, within which all the spatial units could be classified, allows the optimization of analysis of spatial units as they can be considered sub-sets with homogeneous characteristics from the functional, environmental and technological perspective.

Spatial Units (SU): the single spaces or rooms are the lowest spatial entity that can be identified by specific functions and properties (operating rooms, patient rooms, nurse offices, etc.).
Spaces can be classified considering both their functional and their technical properties and characteristics, including their energy-related features.

As stated, the functional approach starts from the definition of the functional area to build up the functional model. The **functional areas are taken into prior analysis** as they could allow, on one hand, the definition of the sub-functional areas and spatial units in terms of spatial, technological and environmental requirements and, on the other hand, the definition of the upper level of macro-functional areas- thus building and healthcare district- in terms of functional, organizational and relational layouts.

5.3 Methodological approach: analysis of functional areas

The analysis of each functional area should be pursued according to the factors that intervene in the definition of each function. The factors identified should provide the basis for the development of the semantic model, which would operate for the assessment of the EeB related issues of Healthcare District, as foreseen in the STREAMER aim.
Considering these premises, all functional areas are subject to a double analysis which approach them from two opposite perspectives: an endogenous analysis (1) that approaches the functional area from an internal perspective, and an exogenous one that instead approaches the functional area from and external perspective (Assr, 2003).
The endogenous analysis(1) aims at the comprehension and optimization of the internal mechanism of functional areas in terms of spatial layout, definition of single unit spaces and performances and their relationship within the functional area. The exogenous analysis(2) instead aims to highlight the system and the degree of relationship among functional activities, in order to optimize the location of functional areas according to patients, staff and goods flows, and organizational and medical relationship between functional areas required.
Therefore, each functional area could be analyzed according to these factors: activities developed, performance to be guaranteed, spaces, EeB features, accesses and flows required, relationships.

Activities and performances

It is essential to define the activities to be developed within each functional areas. The gathering of the activities could provide the basis for the programming of the spaces required for the regular development of those activities. Thus, the aim to be fulfilled according to be fulfilled according to the volume of activities is worth to be analyzed (Terranova, 2005).

The performances of each functional areas should foresee the respect of the minimum standards required by the law in first place. Technological, spatial and environmental parameters should be set to guarantee the fulfillment of the performance required.
Therefore, it is crucial to describe the pattern usage of a functional area in terms of activities and performances as it provides the information necessary to determine its energy use.

Spaces

The spaces required in each functional area entails the proper definition of the program of intervention.
The listing of the spatial units allows an analysis of the internal mechanism of each functional area, thus the functional layout. The spatial units foreseen in each functional area should be compatible with the activities and performances characterizing the function.
Therefore, each spatial unit could be described according to the minimum spatial, technological and environmental performance requirements (Terranova, 2005) such as flat area required, necessary equipment, installation system foreseen.
Introducing the level of the sub-functional area could provide a simplification in the definition of the spaces required, both in terms of performance and relationships.
Of course, the correct definition of the performance requirements could be conducted according to the specific law requirements of each context (Assr, 2003).
The definition of the internal mechanism includes, on one side, an audit list of the spatial units strictly necessary to respond to the needs of the model and, on the other side, the additional spatial units, optional, that rather guarantee an optimized level of performance in terms of cost control, maintenance, operation, etc. (Assr, 2003).

EeB features

The EeB features requires an attentive analysis, as the energy efficiency requirements acquire a relevant role in the STREAMER scope. An appropriate approach to define the EeB requirements might be to adopt the Layers Approach developed in the Bowcollege research project, consisting in labeling each functional area with a layer depending on the quality of the space necessary for the development of the activities in the functional area. The layers identified are Hot Floor, Hotel, Industry, Office. Each layer consist in different peculiar characteristics that could theoretically provide inputs and basis for the definition of the supposed energy consume of the function. The layer approach could possibly be extended to the most appropriate level of the building according to the typology of performance being analyzed.

Accesses and patients, staff and goods flow

Each functional area provides for connections, which weight with different percentage on the total flat area (Terranova 2005).
Understanding the hierarchy of accesses and circulation routes is essential to provide suitable connections within the functional area and between functional areas. Thus, a correct analysis of the different use of space by patients, staff and goods would provide and optimized connection system, limiting its weight inside the functional areas in terms of space and energy consume.

The analysis of accesses and patients, staff and goods flow directly influence the relationships analysis, being the last one the result of the first one.

Relationships

Both relationships among spatial units within functional area and among functional area within buildings should be analyzed. The analysis of relationship among spatial units aims to the development of an optimized functional layout of the functional areas, establishing the link between activities that requires connections in terms of space or medical organization.

The relationships among functional areas instead are analyzed on two different level: spatial relationship, which establishes the spatial relation taking into consideration the flow of patients, staff and goods, materials, samples, etc.; and functional relationship that analyzes the link between different function within the same building, thus the virtual connection required for the correct development of the hospital operation (Assr, 2003). Of course, the actual relationship among functional areas highly depends also on the organizational and form typology of the specific healthcare district; although some constants in the system of relationship always occur. There are different ways define the criteria to be used for the identification of the relationships. One way is to define the parameter of relationship instead is to use the degree of dependency required: high, medium, basic, low (Assr, 2003). Tarek El-Khatib, from Zeidler Partnership Architects of Toronto, identifies instead three key concepts to be adopted for the analysis of relationship among functional areas: Integration, Interaction and Collision.

5.3.1 Advantages

First of all, this approach allows a high level of flexibility and applicability to the various contexts as it provides a not-contextualized model operating as a reference for the realization of design development in specific context and with distinguishing medical characteristics.

At the same time, the functional model approaches the design from a multidisciplinary perspective, entailing the integration with the territory, the technological innovation capabilities, the management efficiency of the buildings and the systems/plants (Assr, 2003).

Moreover, the functional approach defines the criteria that could operate on the metadesign level, generating multiple typologies in terms of layout and building configuration, being the typology defined as the expression of the different functional, social, economic, spatial, environmental and technological organization.

The breakdown of the hospital functions in different levels involves a more appropriate assessment of the requirements inherent to each level, allowing a better control and fulfillment of the performances, which becomes essential regarding the EeB related issues.

Moreover, starting from the definition of the functional areas layout allows a better definition of the different functions lifespan and maintenance and economic requirements, entailing - as stated by Kagioglou and Tzortzopoulos - a more attentive life-cycle analysis in terms of single spatial units.

In addition, the functional approach, especially if combined with the layers approach, entails the possibility to group functions according to their technical requirements, offering thus more cost-effective and energy-efficient layouts.

Last but not least, the functional model provides for the possibility of defining the factors and parameters that would develop and inform the semantic BIM model, entailing the integration of programming, controlling, designing and evaluation issues.

5.4 Description of functional areas

The main functional areas are here described, according to the literature findings and current practices, through the activities conducted and the spaces, the accesses and the relationships required.

5.4.1 Diagnostic and treatment functional macro-area (FMA)

Diagnostic imaging: this functional area gathers all the diagnostic functions including both the ones related to the traditional radiology, breast medicine, CAT, MRI, BMD, ultrasound, etc.; and the ones inherent to nuclear medicine and endoscopy. The spaces are organized according to the patients flow, providing for waiting areas, toilet, bypassing dressing rooms for patients, and diagnostic areas. The observatory and control area for the staff and the equipment should be positioned outside the diagnostic rooms and should be in direct link with the back-of-facilities (e.g. medical offices, medical reporting areas, staff facilities, printing development areas). Diagnostic imaging requires three accesses: one for outpatients, one for in-patients, and a third one for goods and staff.

Nuclear medicine: this functional area involves diagnostic activities but not therapeutic ones. It is split in two areas: a cold one including the reception and admission, contingent to the examination rooms and back-of facilities; and a warm one including staff working space and laboratory, feeding rooms, gamma camera and PET, etc., conveniently filtered, controlled and isolated from the other parts of the structure. The observatory and control area for the staff and the equipment should be positioned outside the diagnostic rooms. This area requires two separated accesses, one for patients and another one for the staff and the goods, designed in order to avoid contamination between the two and to provide a system of filters and decontamination space in case of accident.

Radiotherapy: the radiation therapy involves diagnostic, therapeutic and follow-up activities. It involves a clear distinction of areas dedicated to diagnostic activities and the ones dedicated to therapeutic activities. It requires different accesses for outpatients, inpatients and goods and staff.

Pre-hospitalization: it allows the examination of outpatients and inpatients and the execution of the preparatory procedures before a surgery. The diagnostic activity is generally composed of chest X-ray, specialist medical examination, ECG, blood sampling and anesthesiology examination. The pre-hospitalization activities are generally executed in adjoining rooms, equipped with dressing rooms, in order to allow the patients to optimize the time and the transfers from the examination, the sampling and the chest X-ray. It should accessible directly from the public area.

Endoscopy: it includes the doctor office, the diagnostic room and the area dedicated to the preparation, according to the typology of diagnostic procedure to be executed. The diagnostic rooms are connected through a back-of corridor on which the ancillary and technical spaces overlook. A protected area for the observation, control and rest of the patient after the examination is suitable. It requires two separated accesses for outpatients and inpatients. An additional access in needed for the staff and goods.

Blood sampling/testing: this function is dedicated to the outpatients only. It provides for boxes for sampling, all generally connected to each other. An emergency room is foreseen in case of accident. Separated accesses, one for patients and one for staff, goods and sampling, are required. A waiting area for admission and payment is needed at the patients' access. It is essential to separate the central waiting area from boxes. It should be directly connected with the analysis laboratories.

Transfusion centre (blood bank): the transfusion centre includes an area dedicated to the blood donation and an area dedicated to the laboratories. The laboratories involve a control area, a registration area, the manipulation, the re-elaboration and the stock of blood and blood products. The sampling spaces are generally separated by curtains. An emergency area is foreseen in case of accident.

Rehabilitation: this functions operates both for pre-operation and rehabilitation of patients affected by orthopedic, cardiac, neurological, chest medicine, urologic, gynecological, gastroenterology. The rehabilitation function is structured in two main equipped areas : one dedicated to group activities involving static and dynamic gym, one for individual therapy, both served by filters and dressing rooms for patients. The function requires separated accesses for inpatients and outpatients.

Outpatient department: its aim is to operate as a filter to avoid inadequate and indiscriminate hospitalization. The outpatient department involves specific medical offices of the different medical specialization, characterized by an high level of flexibility as they should be suitable for different medical discipline. The outpatients and inpatients requiring examination flow should be separated, thus two access are required. The admission and connection space is crucial to sort the patients and address them to the specific medical office. Being mostly dedicated to outpatients, the function does not have to be in direct link with the hospitalization areas.

5.4.2 Ward functional macro-area (FMA)

Intensive care ward: this function is dedicated to the patients in critic conditions requiring a continuous monitoring and it is composed of three main macro areas. The first one, enclosed in a protected area, includes the patients-units and the monitoring spaces. The second area provides for back-of-spaces for the staff (e.g. dressing rooms, emergency care, space for rest, storages). The third area is dedicated to visitors and relatives (e.g. waiting area, meeting room). All the accesses, for patients, visitors, staff and goods are appropriately preceded by a filter. The visitors could have access to the patients area upon a filter and being subjected to a dressing action. It should be strictly linked with the A&E, the operating theatres, the interventional radiology and also with diagnostic services.

High care ward: the function includes patients-units, comforts and facilities for patients and spaces and services for visitors. High care ward are generally subject to a limit of patients-units. The function requires an area where ancillary spaces, facilities and workspace for staff are allocated (e.g. nurse station, offices, workspaces, storages).

Low care ward: the function includes patients-units, comforts and facilities for patients and spaces and services for visitors. The function requires an area where ancillary spaces, facilities and workspace for staff are allocated (e.g. nurse station, offices, workspaces, storages).

Medical day hospital: this function is aimed to specific patients treatments and diagnostic examinations. It involves clinic space for examination and conference with patients; and beds area for the diagnostic performances and care. It requires two accesses, one for the patients and one for staff and goods.

Oncological day hospital: this function is aimed to specific patients treatments and diagnostic examinations. It involves clinic space for examination and conference with patients; beds area for the diagnostic performances and care, and spaces dedicated to the preparation of antiblastic medicines. It requires two accesses, one for the patients and one for staff and goods.

Day surgery: this functional area is dedicated to patients subject to surgery entailing a daily-stay at the hospital. It involves patients-units provided with beds, dressing rooms for patients, a pre-surgery area, in addition to staff facilities. It requires accesses, one for the patients and one for the staff and goods, endowed with a filter. It should be connected with operating theatres when not included in the department, and with intensive care and high care hospitalization in case of accident or emergency.

Maternity ward: it should be a place where the whole concept of childhood and maternity department is fully realized and satisfied. It has be treated differently from the other hospital departments as it does not involve diseases. It is composed of the maternity ward and the kindergarten. Social spaces for visitors and waiting areas should be included. Only one access, for both patients and visitors is required. It should be connected with the operating theatres when the labour room is not present in the department.

5.4.3 Operating block functional macro-area (FMA)

Operating theatres: operating theatres are generally grouped within operating blocks.

They overlook on soiled and clean area upbringing to the sterilization centre. The storage for sterilized materials, instruments and medications, the sub-sterilization room and the emergency laboratory are allocated in the clean area. The area for the staff is connected to the operating theatres, including an area for the surgeon washing, dressing rooms and toilets, relax area for the staff, medical offices, interview room and meeting room, adequately filtered. Two area for the preparation and the recovery of the patients precede the operating theatres. It must be enclosed in a protected area but should at the same time be adjacent to intensive care, ER, sterilization centre, day hospital departments. It should also be spatially related to the Maternity Ward when the labour room is not foreseen inside the functional area.

Interventional radiology: this functional area is dedicated to hemodynamics, arteriography, etc. The interventional radiology rooms overlook on soiled and clean areas upbringing to the sterilization centre. The storage for sterilized materials, instruments and medications are allocated in the clean area. The area for the staff is connected to the interventional radiology rooms, including an area for the surgeon washing, dressing rooms and toilets, relax area for the staff, medical offices, interview room and meeting room, adequately filtered. The interventional radiology rooms, adequately filtered as well, are preceded by the preparation and recovery areas for patients. It must be enclosed in a protected area but should at the same time be adjacent to intensive care, ER, sterilization centre, day hospital departments.

5.4.4 A&E functional macro-area (FMA)

Accident and Emergency (A&E): considering the role of this functional area, the analysis of the spaces, the accesses and the relation with other departments is crucial. This department involves areas for the stabilization and areas for the emergency intervention, with boxes equipped with technical beds for the treatments. A waiting room for the observation of patients is required, in addition to a hospitalization area for longer staying in, a walk-in clinic, diagnostic facilities, a plastering room and other ancillary spaces. The access to the A&E is equipped with an external hot floor/stationery. The layout should allow at the triage to operate a proper and immediate sorting of the patients according to the level of emergency. The emergency flow must be clearly defined and controlled in order to avoid interferences with the minor emergence flow. It should easily be connected to the departments of intensive care, operating theatres and other diagnostic facilities.

5.4.5 General facilities functional macro-area (FMA)

Medical testing laboratory: it involves the clinical chemistry, haematology, microbiology, histology, cytology and other analytical methods on biological samples. The layout of spaces should aim to flexibility and possible configurations. The laboratories are split in emergency ones-operating 24/7 and special laboratories. It requires an adequate relation with the blood sampling, transfusion centre, the hospitalization, the operating theatres, etc.

Anatomical pathology laboratory: laboratories require to be adjacent to the medical testing laboratories, considering a possible expansion and a sharing of facilities. The aim is to optimize flexibility and professional synergies. This functional area involves also archives, medical offices, and supportive facilities. It require a relationship with the operating theatres, mortuary facilities, endoscopy, outpatient department.

Internal pharmacy (including storage): it is divided in two main sectors: one dedicated to the deposit and handling of the requests for the drugs distribution; and another one for the preparation of the medicines, the laboratories and the administrative area. The deposit contains a drugs storage with safety closets and fridges for conservation of special drugs.

Sterilization centre: this functional area is aimed to the sterilization of all the instruments/tools. It is structured in three main sectors: cleaning/washing area where the soiled materials is brought to, a packing area and a sterile storage. The sterilization devices are allocated in between the packing area and the storage. The function includes spaces for the staff. Each area is preceded by a filter. It should be strictly connected to operating theatres.

General storages: the storages are classified and sized according to the goods they contain and the supply expectation/prevision. Otherwise the goods could be stored at the suppliers'.

Kitchen: in the kitchen, the food for both the patients and the staff is prepared. The kitchen is organized in three main areas dedicated to the preparation, the cooking and the packing activities. An access for the meals and another one for the other goods are foreseen. The exit ways for carts distributing meals is connected to the clean area of the kitchen, while the entrance of carts is connected to the soiled and washing area. It should include support and ancillary spaces for the staff (e.g. dressing rooms, WCs).

Canteen: when present, it provides meals on predefined time schedule, which are cooked in the internal kitchen. it is generally managed by external firms.

Medical archive: It includes both archives for paper materials and archives for electronic materials. It is generally composed of different areas dedicated to control, data entry, preparation of the medical folders to be delivered and archiving storage. The dimension of these spaces changes according to the usage of digital documentation of each specific hospital.

Admission (reception, information, reservation): this functional area has the role first interface between the hospital and the patient, address them and optimize the admission timing. it involves front office activities such as examination reservation and hospital admission, in addition to the collection of medical reports. The admission for outpatients is separated from the admission for inpatients.

Garbage room and special materials disposal: this function should be positioned separated from the hospital for ecologic reason, and connected to the hospital through an indoor safeguarded way. Generally, the radioactive rubbish is directly collected within the department of nuclear medicine by qualified staff.

Mortuary: it includes rooms for observation, conservation and preparation of the bodies, mortuaries, space for burial services, rooms for autopsy; in addition to Facilities and services dedicated to the grieving people. The function provides for an access from an external area for upcoming grieving people and the movement of the bodies. This function spatially relates itself with Anatomical pathology laboratory and possibly to the A&E through a reserved itinerary.

Dressing rooms for staff: Both centralized and adjacent to specific facilities dressing rooms for staff should be foreseen. The centralized dressing rooms should be allocated next to the staff access in order to ensure the control, ease the provision, simplify the flow mechanism, to fulfill the health and sanitation conditions.

Health physics: It is composed of medical offices, conference rooms, laboratory areas. It should preferably be allocated next to Radiology.

Cleaning facilities: this function includes all the spaces that operate for the achievement and satisfaction of the clinical and hygienic condition of the hospital. It includes laundries, storages for the tools and materials used for the cleaning of spaces, spaces for the car cleanings, etc.

It should be related to all the functions that requires a more attentive cleaning and hygienic policy.

5.4.6 Public facilities functional macro-area (FMA)

The public facilities include several kind of functional area, whose presence in a Healthcare District varies according to the specific complex. The macro-area includes ancillary facilities such as hall, cafeteria, restaurants, stores, baby park, bank, post office, association offices and connections, according to the requirements of the specific intervention.

5.5 Spatial and Functional relationships between functional areas (FA)

The relationship among functional areas can be expressed in two diagrams/matrixes; the first one defining the spatial relationship and the second one the functional relationship. The spatial relationship matrix takes the flow of patients, staff and goods and proximity of spaces as the main factor for the analysis. Instead, the functional relationship matrix analyses the virtual connection required between different functions. The criteria to analyze the relationship used is the level of relationship required: high relationship required, medium relationship required, basic relationship required, low relationship required.

Fig 5.1 Functional relationship between functional areas

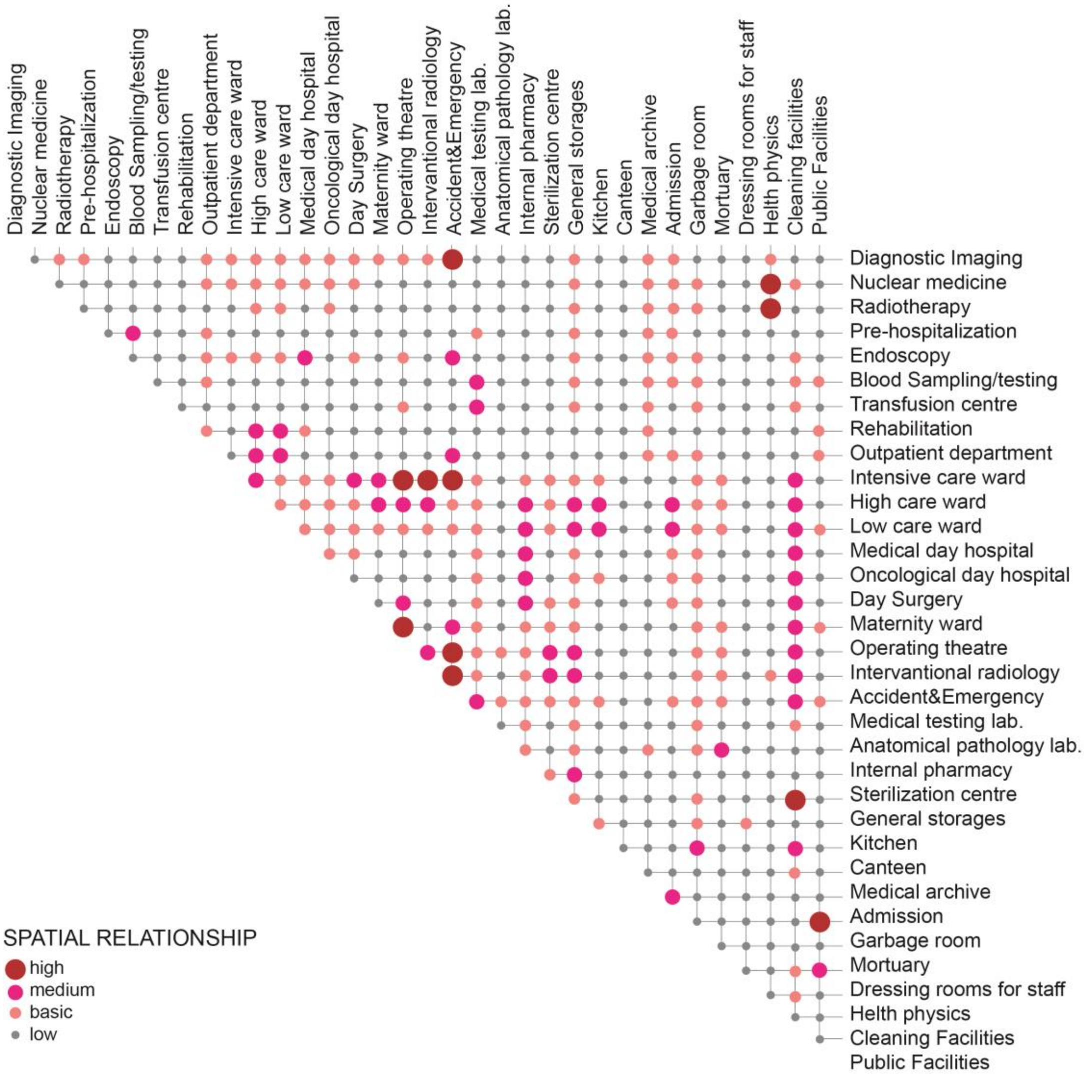


Fig 5.2 Spatial relationship between functional areas

5.6 Example sheet: Operating theatre FA

Activities and performances:

Activities:

- Patients: arrival from the ward or A&E area, preparation, anesthesia, entrance to the o.t., surgery, waiting and waking up, transfer to wards
- Staff: access, preparation, anesthesia, surgery, patients monitoring, materials and instruments management, rooms cleaning and disinfection,
- Goods: arrival and sorting, gathering, instruments delivery to sub-sterilization, garbage disposal

Performances to be guaranteed for complex surgery treatment and intervention: pre-surgery preparation, environmental condition for patients waking up, staff cleaning condition, disinfection guaranteed, instruments and goods sterilization.

Spatial Units:

Admission, Reception, Orientation area:

- Visitors waiting area and Wc
- Visitors interview room
- Intervention, Operating area:
- Patients preparation
- Patients recovery room
- Nurse station and work
- Surgeon preparation and scrubbing
- Operating theatre (general medicine, high specialty, traumatology, etc.)

Staff area:

- Control area
- Staff dressing room and Wc
- Staff relax area
- Medical office
- Medical reports area
- Conference room

Ancillary Facilities area:

- Sub sterilization
- Soiled materials storage
- Clean materials storage
- Sterilized materials storage
- Medical and surgical products and devices storage
- Medicine/anaesthetic storage
- Equipment storage
- Cleaning area

Accesses and flow

Patient access with filter, staff access with filter, visitors access, materials access.

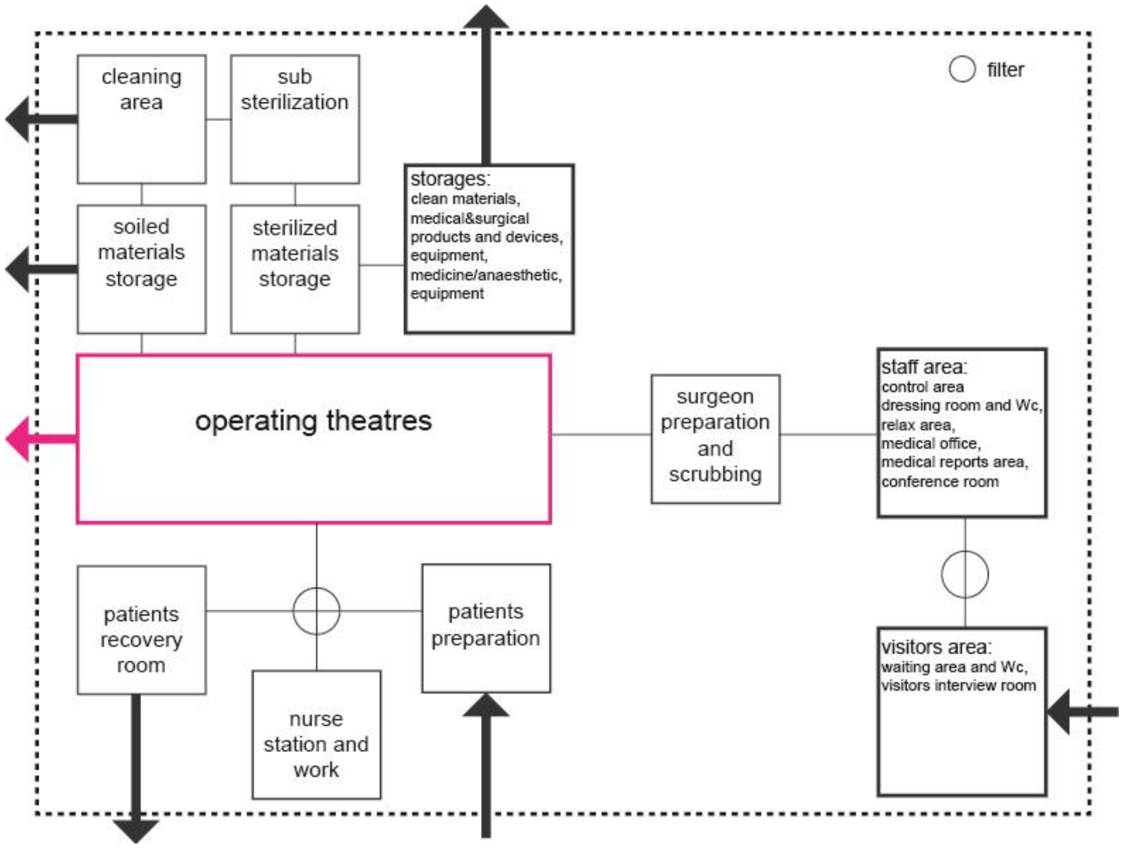
Patient internal flow (preparation, operating theatre, recovery, etc.), and from/to other FA (A&E, ward, mortuary, etc.).

Visitors flow (access, waiting, doctor's interview).

Materials internal flow (cleaned, soiled, sterilized, etc.), materials flow from/to other FA (sterilization, etc.)

Staff internal flow (dressing-up, scrubbing, etc.)

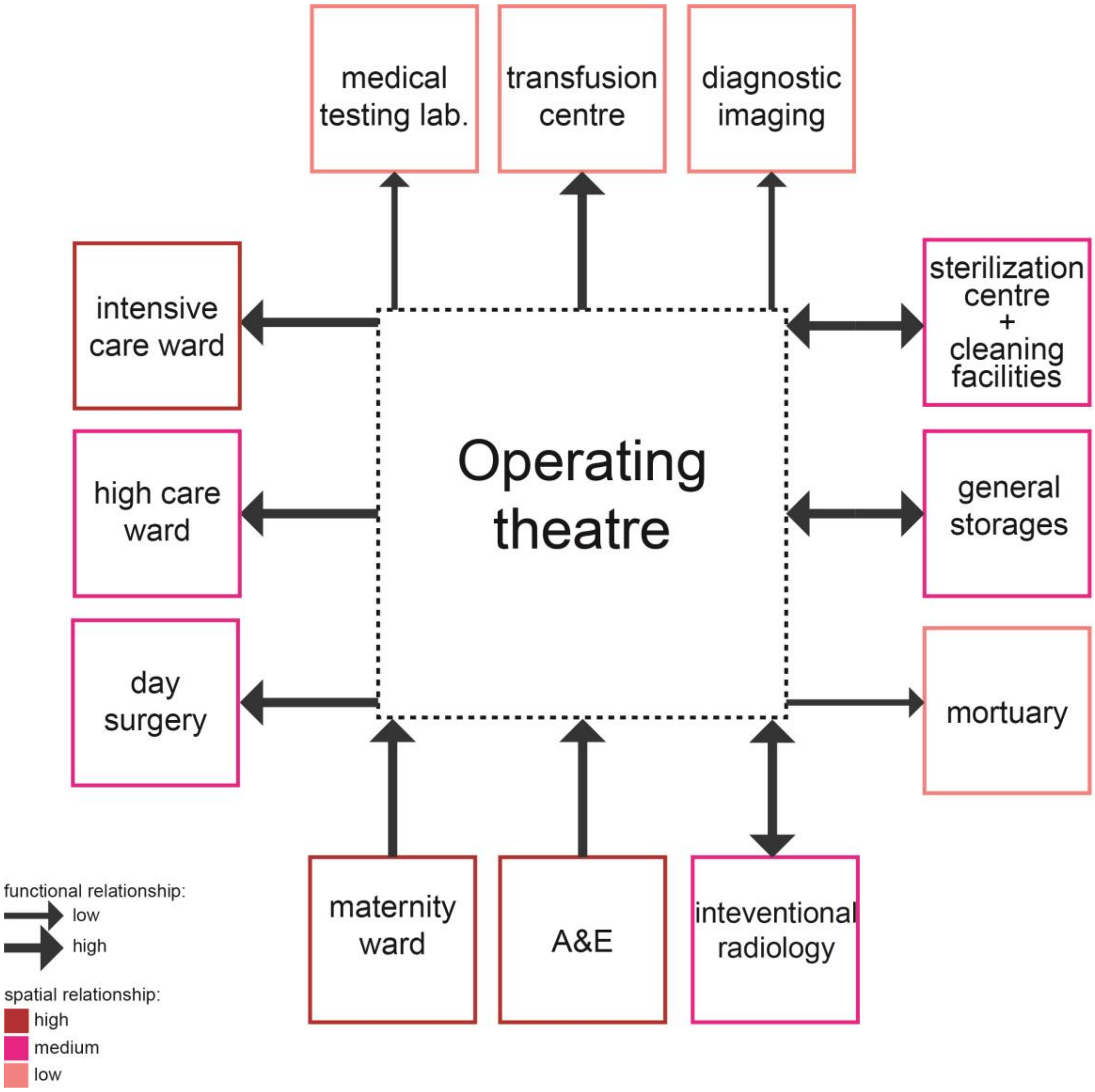
Functional aggregative layout/configuration:



Energy-related characteristics:

This functional area has generally to be operative 24/7 in case of urgent unscheduled surgeries and has to ensure specific hygrometric characteristics in terms of internal temperature (e.g. 20-24 °C), relative humidity (e.g. 40-60%), air exchange per hours (e.g. 15 times per hour), etc., entailing a high level of energy consume. Moreover, the energy use depends also on the supply required for the adequate operation of equipment and instruments for surgical intervention (e.g. monitoring, lighting system, medicine conservation fridge, etc.). The performances to be guaranteed highly depend on the national building regulations and guidelines, and on the demand from the organization.

Main relationships with other functional areas:



6. Definition of the typology models: the Streamer approach

6.1 Introduction

This chapter focuses on the analysis and comparison of the different approaches to the definition of the typology models with the aim to define the approach for Streamer.

We use the following analysis and taxonomy of typologies to define criteria and methods for:

- the breakdown of the Healthcare District organization
- the identification of typological, technical, distribution and functional & organizational characteristics of the different building types
- the functional aggregative configurations based on the proximity and the interdependencies between spaces and functions

The following issues have been considered as well:

- analysis and taxonomy of typologies should generate common "EeB typology models", thus the "energy-related features" must be the main issue and analysis on and comparison between typologies has to be focused on energy-related features and characteristics;
- for Streamer scopes the "scale" of the typology models is restricted to the Healthcare Districts (HD);meaning the focus is on building with a healthcare function;
- data must be compatible with and suitable for the semantic model;
- since the design of hospital involves many stake-holders the approach should be multidisciplinary, i.e. both the technical and non-technical aspects and parameters have to be considered.

Investigation and discussion on the typology models outlined two main approaches, apparently in opposition with each other: the **"Outside/In"** approach – so called "designer's view" – that defines of typology starting from a spatial classifications based on the layers approach and the **"Inside/Out"** approach – so called "engineer's view" – that defines the typology starting from a spatial classifications based on the technical properties and features of the single spaces.

These approaches – the first one corresponding to a **top-down** methodology and the latter to **bottom-up** one - generates two different process of the HD system breakdown and consequently different results in the classification and categorization of spaces.

The Streamer approach is a combination of the advantages offered by the two methodologies and it is based on criteria and models analyzed in the previous sections focused on the layers and the functional approaches. We use all approaches parallel to make best use of all information all these approaches give us.

6.2 Considerations on typology model and classification of spaces

The breakdown of HD functions in different levels allows to approach the typology from the different perspectives defined in the previous chapters. Being the focus of STREAMER taxonomy the definition of EeB morphology and features, it is essential to get a good understanding of what the different perspectives mean for the energy-related features. **Thus, it is necessary to establish which method is the most appropriate for the definition of the typology from the energy-related features perspective.** To reach this goal, the study has been conducted starting from the description of the hospital activities, as the development of an activity defines the use of the space and, thus, the energy consumption required. This will give an answer to the energy demand based on activity levels.

The fulfillment of the users' demand is crucial to meet the goal of the project, which is the optimization of the energy performance. After all, a building exists because there is a use for it. In the healthcare districts many different users are there: patients and their beloved ones, the working staff such as medical specialists, nursing staff, supporting staff, management, etc. To get a good understanding of users' needs, it is necessary to look at the activities and how interactions between users take place and when. Overall, the activities that take place in healthcare districts determine the required building volume and following the installation capacity, thus the supply. By detailed description of activities demand and supply of spaces can be matched.

The description of activities needs to be done in a structured method. The factor time plays a crucial role in this, There is a distinction in operational short term description and a strategic long term vision on how activities will change during time. In a day-to-day basis and operation management there is a challenge how to match supply and demand for existing healthcare districts. To match the demand and supply of spaces we need to answer the questions *what, how, who* and *when* to get an detailed insight about the activities. This is the operational level to achieve an efficient use of spaces, resulting in a demand for amongst others energy. For the long term the question *why* activities take place needs to be answered. After all, the life cycle of the built environment is several decennia but the activities change constantly. Flexibility is one of the solutions to make sure the buildings are fit for purpose in the future.

The answers to these questions provide the inputs necessary to define the information required for the correct characterization of the spaces in a healthcare district. The result is the description of a 3-dimensional space detailed with a variety of properties and connection with the environment.

Below are two examples to illustrate the importance of describing the activities and the spaces. The starting point is to list the activities and then align them with spaces . And then to describe how the space is connected to other spaces. It can be a primary (1), secondary (2) or tertiary (3) connection which means how close and on which level the rooms are connected. In the first example there are three activities which take place in an outpatients' unit. Presented are two different ways to accommodate the activities. The combination of office work and consult in a room and a separate examination room sets different sizes, temperature, lighting, etc. to these rooms.

ACTIVITY	SPACE	CONNECTION
office work doctor	consultation- / office room	(1) examination room
consult patient - doctor		
examination patient - doctor	examination room	(1) consultation- / office room

Or:

office work doctor	office room	(2) consultation-/ examination room
consult patient - doctor	consultation-/ examination room	(2) office room
examination patient - doctor		

Two activities in an inpatient unit are listed in the second example. The two solutions vary a lot with different consequences for the layout of the unit and in the end for the key performance indicators.

ACTIVITY	SPACE	CONNECTION
stay over patient	3-beds patient room with ensuite bathroom	(3) family- / guest room
stay over family / guest	family- / guest room with ensuite bathroom	(3) patient room

stay over patient	1-bed patient room with ensuite bathroom and rooming in family / guest	
stay over family / guest		

Summarized, for optimizing energy efficient buildings it is necessary to relate spaces to the sequence of activities they accommodate over a period of time. **For the building, the lowest level of information is a space with properties and interdependencies to its surroundings and other spaces.**

The next step is to identify a methodology to relate the properties of space to all the levels of an healthcare district in order to define how spaces should be grouped together. In this sense, it is necessary to make some considerations on how the breakdown system should be approached to reach the aim of defining the typology. Considering these premises, STREAMER identifies two different methodologies. The aim is to combine these two methodologies in order to find an univocal approach to be adopted as the design criteria to be followed for the definition of the typology of healthcare districts.

From the designer view, a **top-down "outside/in" approach** could be applied. It defines the typology basing on the building characteristics such as hot floor, hotel, office and industry, as well as the campus-building taxonomy (e.g. backbone, pavilion, central hall, etc.) and organizational categories (e.g. patient flows and logistics, standardized or complex and acute or elective patient care). From the engineers view, instead, a **bottom-up "inside/out" approach** that defines the typology based on the technical properties of the rooms (e.g. the energy-related features of an operating room, a patient room, a nurse office, etc.) and building/MEP systems (e.g. the energy-related features of a sandwich-panel façade system, a certain type of ventilation system etc.) could be applied.

The **"outside/in" approach** starts from the definition of the main typologies of Healthcare District. Typologies, matrix of relationships, interdependencies and functional aggregative configurations are analyzed starting progressively from the district level to the single spaces level. This approach makes easier the definition of a method for functional classification. The progressive breakdown of each level, from the District to the single spaces, creates groups (particularly Functional areas and Space units) always homogeneous that allow a congruent and logical identification of the relationships as they are related to spaces and areas characterized by similar functions. Consequently a clear and congruent scheme of relationships, interdependencies and functional aggregative configurations allows to analyze and identify the non-technical "energy features" (e.g. how much an incorrect location of a space or activity may be an indirect factor of an increase of energy consumption). On the other hand, the definition of relationships, interdependencies and functional aggregative configurations could be suitable for the functional classification rather than for the energy-related features definition. Since the classification of Space units and Functional areas do not depend on energy-related features, this approach could implement Functional areas including Space units not homogeneous from an "energy-related point of view"; it means that it could be difficult to define EeB Performance Indicators able to be applied, with the same criteria, to the different levels of the typology models (District/Building/Functional areas/Spaces and Component as well).

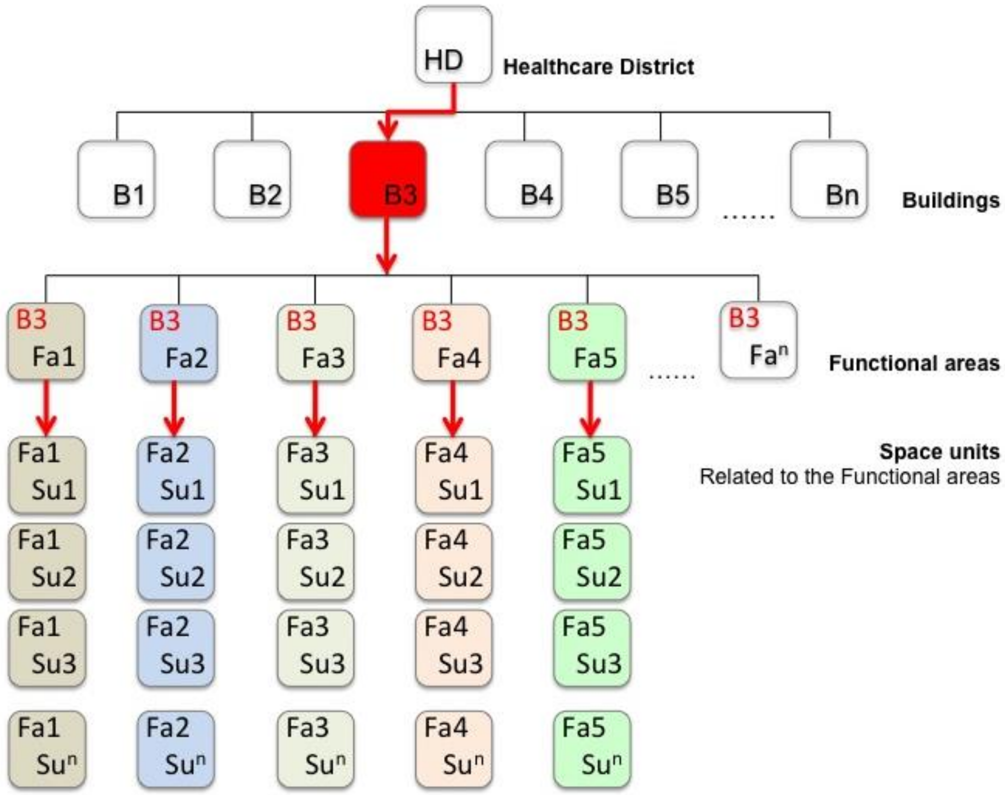


Fig.6.1 Outside/In approach: the breakdown of the system, from the Healthcare District level to the single spaces, is based on the functional approach. The Space units are grouped and labelled considering their relationships and interdependencies within the Functional Areas.

The **"inside/out" approach** takes the definition of Space units and Functional areas included in the Healthcare District as the starting point for the design methodology. It is based on the categorization of Functional areas depending on the relationships, interdependencies and functional aggregative configurations of Space units in each Functional area. In turn, the building typologies is categorized according to the schemes of relationships, interdependencies and functional aggregative configurations of Functional areas in each building. The same method is applied up to the District level. Starting from the technical properties of Space Units (single spaces, rooms, etc.) allows the definition of energy performance at the early stage of analysis, entailing a classification of spaces on the basis of energy-related features. Moreover, data on energy-related features of Space units depend on a smaller number of parameters, which besides can be defined unambiguously. Therefore, the definition of energy-related features at Space units level allows a better control of the energy efficiency indicators a the highest level (Building and District level).

Moreover, at this level it is possible to define further characteristics not necessarily related to energy characteristics. Among these cleaning information, levels of access (e.g. restricted or not restricted), activity information. This information is highly relevant for the definition and evaluation of KPIs.

On the other hand, the "inside/out" approach can jeopardize the definition of the functional aggregative configurations based on the proximity and the interdependencies between spaces and functions, as the aggregations of Space units with equal energy-related characteristics do not correspond to the

Functional areas of a hospital Building. In addition, the technical properties of the single spaces are not enough to define the energy-related characteristics at the upper levels (Functional area, Building and District), as this is purely based on activity levels. To relate to total energy consumption factors also the “outside/in” approach should be taken into account.

Therefore different parameters should be analyzed at each level. This gives great advantages as these level interact with EeB-solution that could be applied at each level; allowing several steps in optimization to be possible.

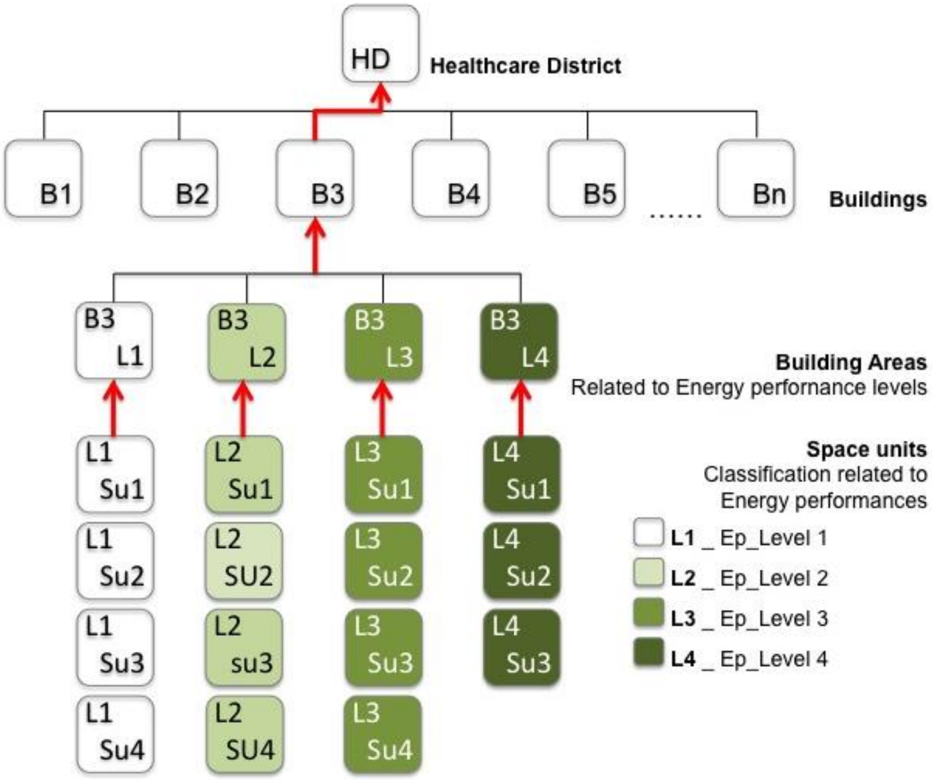


Fig.6.2 In an Inside/Out approach the system’s breakdown starts from the Space units that – as well as in this example – could be grouped, within each building, according to their energy performances. This approach give homogeneous groups of Su, according to the parameter applied, but can jeopardize the definition of the functional aggregative configurations based on the proximity and the interdependencies between spaces and functions.

To summarize, outside/in and inside/out approaches generate two different design criteria for the classification of spaces. The outside/in approach could operate a classification of spaces in terms of “The Layers Approach at Building and District level”. This classification does not strictly depend on energy-related features, rather it depends on functions. The classification of spaces is not homogeneous from the “energy-related point of view”, entailing a difficulty in the definition of EeB Performance Indicators to be applied to the different levels of the typology models (District/Building/Functional area/Space units/Component). On the other hand the inside/out approach starts from the analysis of the energy characteristics and performances of the single rooms. Therefore, classifying the Spaces on their technical properties and energy-related features (e.g. Class of energy performance) could frustrate the definition of the functional aggregative configurations based on the proximity and the interdependencies between spaces and functions. Aggregation of Space units having the same energy related characteristics could be not corresponding to the Functional Areas of a Hospital Building.

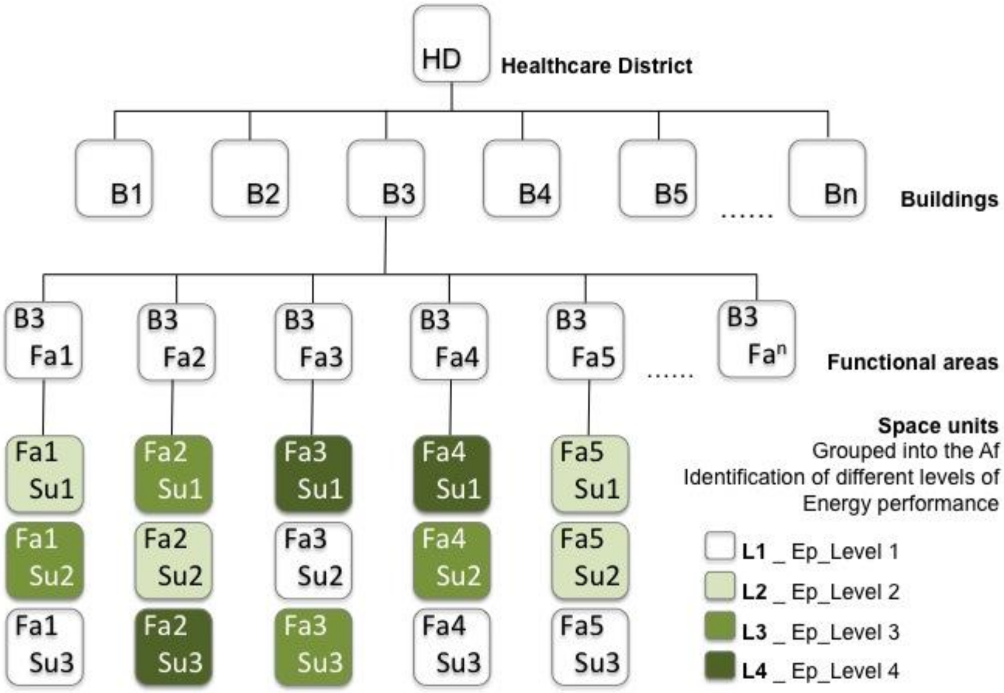


Fig.6.3 Indication of Energy performance levels of Su grouped according to their functional homogeneity.

Therefore, STREAMER proposes a methodology based on the **combination of these top-down and bottom-up approaches**, with the aim of adopting them in parallel in order to define the typology. A method for analyzing and classifying the Space units compatible with the two approaches can be implemented crossing different criteria of classification (e.g. Bowcollege layers, energy consumption, etc.) with the levels defined in the STREAMER breakdown of Healthcare Districts. This would allow iterative optimization of EeB-technologies on different levels.

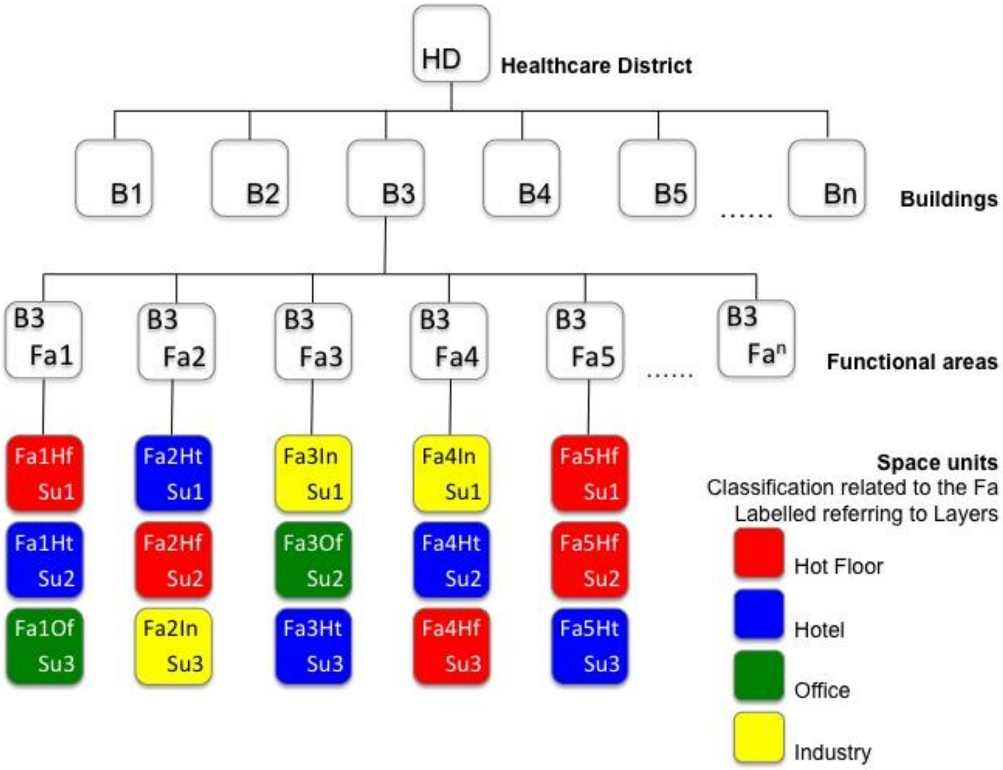


Fig.6.4 Crossing of Layers approach categories with functional breakdown of the HD system (Outside/in)

The five levels, described in detail in the next paragraph, are based on a basic breakdown of the HD systems. The intermediate levels can be broken up or grouped depending on the technical, administrative or organizational criteria that a HD can be based on.

In particular:

- the categories of the Layers approach can be crossed with the levels depending on the specific needs required for the implementation of the semantic model of an existing HD;
- in addition to the relationships with levels and layers, the single spaces can be classified and labelled according to energy-related features;
- different and "customized" labelling methods can be implemented according to existing databases or organizational systems based on specific criteria or levels for grouping the spaces (departments, campus, centres, etc.)

The advantage from such an approach is that design clash detection is possible on the levels of the different views that are created; giving support to design decision support tool.

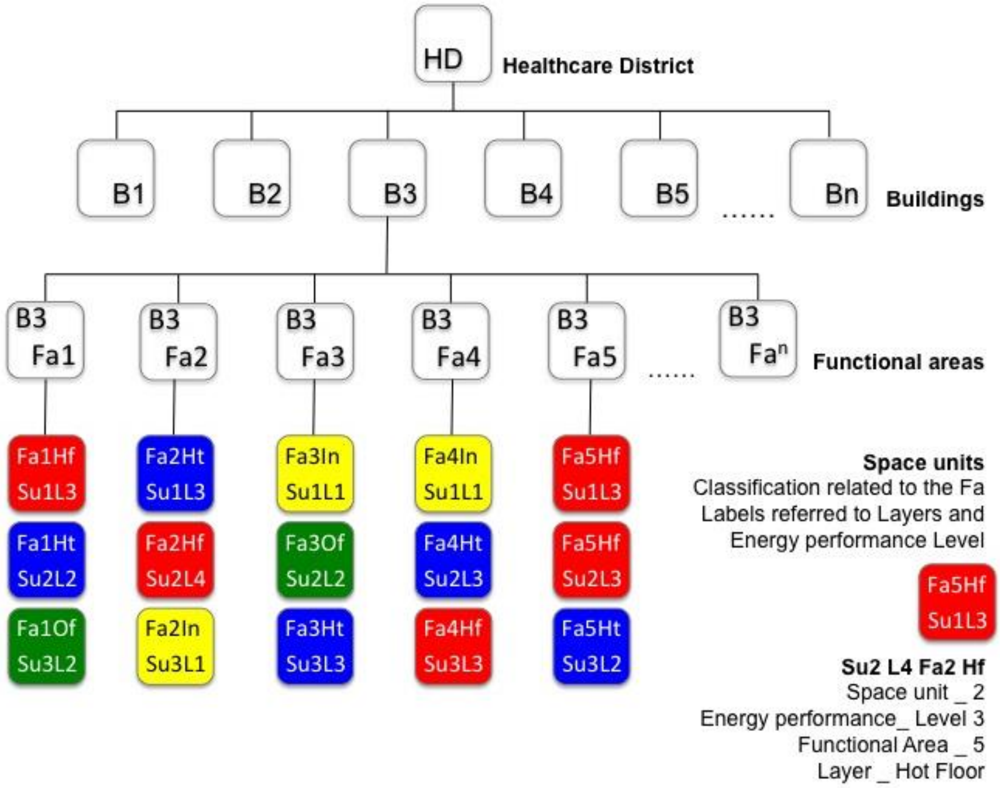


Fig.6.5 Labelling of Su referred to Energy performance levels and Layers approach applied to the HD system's breakdown based on Outside/In approach.

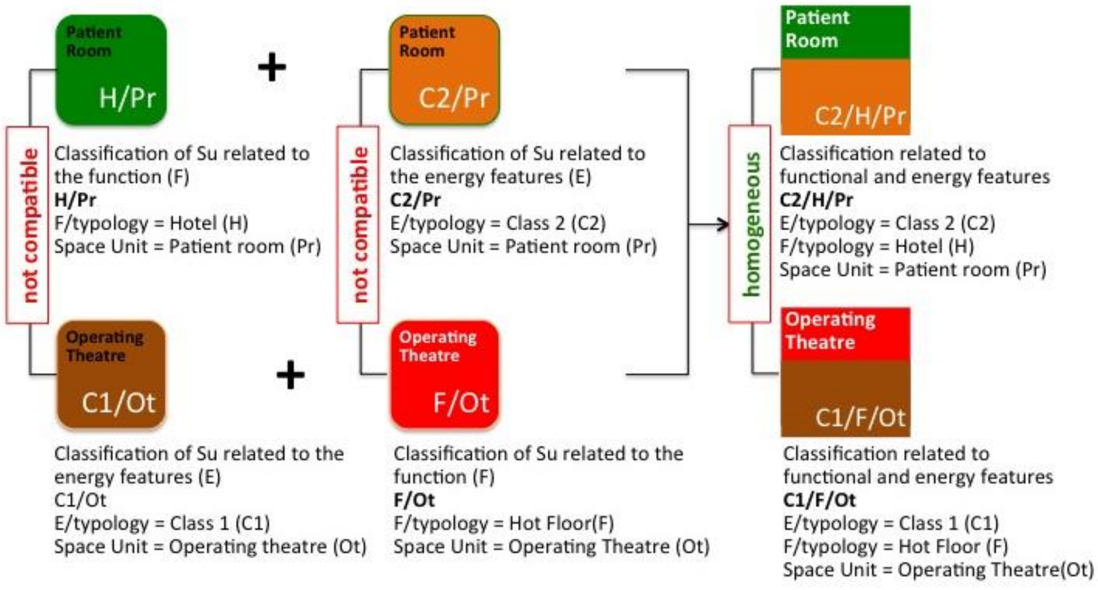


Fig.6.6 Example of a labelling procedure

6.3 Scale level from Districts to components

Looking at the spatial organization and the functional aggregative configurations of the existing typologies, five main different levels can be considered to build up a Healthcare District within STREAMER. These levels identified are:

- Level 1: Component
- Level 2: Space-unit
- Level 3: Functional area
- Level 4: Building
- Level 5: District

The breakdown of healthcare districts in different levels is crucial for the definition of the semantic BIM model through which the objective of STREAMER should be reached. At each level, inherent parameters and factors are identified. Thus, at each level different design decision to be made could be applied, different KPIs can be identified, different energy-related issue could be tackled.

These parameters and factors operate as the data that will inform and build the BIM model of the healthcare district.

As a result, the breakdown system developed here in STREAMER provides a suitable basis that allows to approach the typology independently from the specific methodology each healthcare district choose to define the typology, thus independently from the specific organization of each hospital.

Moreover, this system entails the typology to be engaged from a multidisciplinary perspective, as each level can be informed by different kind of data (e.g. both technical and non-technical related issues).

Here, a description on each level identified in the STREAMER breakdown of healthcare district follows.

The description involves the identification of the parameter and factors that can be defined at each level that will inform the semantic BIM model, focusing mainly on the energy-related characteristics.

Level 1: Component

The components (both the building and the MEP components) are included into a **“not spatial level”** necessary for the implementation of data for the BIM model.

The relationships between this level and the other ones, are related to the technical performances – including the energy performances – that the spaces have to satisfy according to the functions that they host.

The data collected at this level are directly interfaced with the KPIs of the single spaces and the whole buildings.

Level 2: Space unit

The Space units (Su), single spaces or rooms, are the lowest spatial entity that can be identified by specific functions and properties (e.g.: operating rooms, patient rooms, nurse offices, etc.). Spaces can be classified considering both their functional and their technical properties and characteristics, including their energy-related features.

Each spatial unit can be described according to its dimension (minimum flat area, height, etc.), the level of equipment required in terms of power, medical gasses, ICT, etc., the level of protection needed from electricity, contamination, radiation, etc, the accessibility of patients, staff and goods.

The spatial units can be grouped according to the flow of patients, staff and goods required for the patient safety (emergency relation), the effective and efficient treatment (medical relation), the travel time for the patients (patients relation) and the supply of materials (logistics relation).
On this level the data are compatible with the semantic model. It might not have GIS properties, but has anyway properties regarding the orientation and position for the energy calculation.

Level 3: Functional area

The Functional area (Fa) is a group of spaces generally related to homogeneity of interdependencies between functions and spaces (wards, operating theatre blocks, etc.). As well as the spaces, a functional area can be classified considering both its functional and technical properties and characteristics, including their energy-related features.
Each functional area can be described mainly according to the functional and aggregations aspects, more than the technical aspects. The technical aspects of a functional area mainly depend on the characteristics and performances of the spatial units present in the functional area (e.g. building physics, infrastructure needed, level of comfort, etc.).
Moreover, each functional area can be described according to the relationships required with other functional areas and with the external environments in terms of functional and spatial relations. And it has GIS properties (orientation, position etc.)

Level 4: Building

The building is a system that includes several functional area. Relationships, interdependencies and functional aggregative configurations between functional areas depend on the characteristics of the building.
Properties and energy-related features of the buildings may be related to their typological and technical characteristics, to their functions, to their shape. And it has GIS properties (orientation, position etc.)

Level 5: District

The district consists of several buildings. This level can be further partitioned or organized, depending on the administrative, functional or technical characteristics of a Healthcare District. Therefore the structure of a HD can include: compounds, centres, departments, etc.

6.4 Parameter for labelling

As mentioned in the previous paragraphs using a system with semantic labels as value for the level 2 space units (of the activities that take place within the units) makes it possible to attach properties and characteristics to the different spaces, which allows optimizations to be made, not only for energy performance, but also for activity levels, cleaning information or levels of access. For instance, concentrating spaces with the same user-profile label U1 (a limited use of the space per day) makes it possible to realize a building area with a limited energy use for a large part of the day.
Labels that carry implicitly a lot of semantic information and have a relation to the energy demand can be:

I. Hygienic classes (has a relation with amount of ventilation, air tightness, cleaning, materials),
II. Accessibility (has a relation with the position in the hospital, safety/protective/security device),

III. Equipment (has a relation with the type of function, high electric power needed, medical gases, ICT data points),
IV. Construction (has a relation with floor strength, shielding against radiation, floor height, air tightness),
V. User profile (has a relation with the type of use).

But also labels related to other aspects of the design could be created to bring in essential information during the design process. Such as:

I. Flexibility of spaces (has a relation with the adaptability of the design)
II. Emergency routes/rooms (has a relation with safety)
III. Patient pathways for high volume patients (has a relation with logistics)
IV. Connectivity / adjacency (has a relation with the distance between functions)
V. Etc.

Within these labels a number of levels can be defined, as is shown in the table below for the five labels related to energy. Using these labels and levels most of the requirements related to a specific activity (and thus the related rooms in hospitals) can be defined. With a combination of the building physics and the labels (giving information on the required properties: hygienic class, equipment and user profile) the energy demand of a room, and at a higher level the building block, can be calculated.

Label	Level
Hygienic classes (has a relation with amount of ventilation, air tightness, cleaning, materials)	▪ H1 (corridor, reception, toilet , etc.) ▪ H2 (office, bath room, etc.) ▪ H3 (patient room, examination room, treatment room, etc.) ▪ H4 (operating room, insulation room, etc.) -> additional air tightness and ventilation extra ductwork is necessary ▪ H5 (laboratory, production pharmacy, etc.) -> additional air tightness ventilation extra ductwork is necessary
Accessibility (has a relation with the position in the hospital, safety/protective/security device)	▪ A1 (Public) ▪ A2 (Patients, visitors and staff) ▪ A3 (Patients and staff ▪ A4 (All staff members) ▪ A5 (Specific staff members)
Equipment (has a relation with the type of function, high electric power needed, medical gasses, , ICT data points)	▪ EQ1 (Office level) ▪ EQ2 (EQ1 and medical gases) ▪ EQ3 (EQ1 and extra electric power) ▪ EQ4 (EQ1 and extra ICT data points) ▪ EQ5 (EQ2, EQ3 and EQ4) ▪ EQ6 (High electrical safety) ▪ EQ7 (special equipment)

Label	Level
Construction (has a relation with floor strength, shielding against radiation, floor height, air tightness)	· C1 (Office level) · C2 (Office level with extra floor strength) · C3 (Office level with extra floor height) · C4 (C2 and C3) · C5 (Accessible from the outside with heavy load) · C6 (Shielding against radiation) · C7 (high level of air tightness)
User profile (has a relation with the type of use)	· U1 (Monday to Friday from 8:00 – 18:00) · U2 (U1 extended till 20:00) · U3 (U1 with emergency function outside this timeslot) · U4 (24*7)

Table 6.1. Proposal for semantic labels and levels.

As mentioned above the labels could be used to optimize the performance of buildings, but it is also helpful in understanding the implications of design choices (detecting conflicting / incompatible interest) in an early phase. It can be assumed that the parameters for labelling the activities and the space units normally represent the optimal situation: a construction type, energy use and spatial lay out that is optimal for providing the intended activity in that space.

But when multiple spaces with different label-properties are concentrated in one single building area there will be the effect of transferring properties of the predominant label to (all) other space units. For instance concentrating space units with different label-properties for ceiling height (a single floor with rooms that require at least a 2,5 m high ceiling together with rooms that require a ceiling height of 3,5 m) often leads to constructing the building according the predominant requirements: in this case the building area will be likely to be constructed with a ceiling height of 3,5 m. The effect of replacing the original optimal parameter (a ceiling height of 2,5 m) with the inherited parameter (a ceiling height of 3,5m) tells us something about the implications of this design choice on the single space units.

The careful preparation of labels and the corresponding parameters provides the design with the necessary information at all levels and gives insight into opportunities for optimization and design implications. A first step is to define the labels and add levels to the labels. Based on this structure a database shall be established with the relation between health care functions or activities, the KPI's and these label structure which is applicable for the European hospitals. Semantic rules can be added to this database to enrich the information. This database can be used in different phases of the design in the BIM structure to help design teams.

6.5 Streamer functional layering approach

In this paragraph, the methodology described in the previous paragraphs of this chapter is related to several key steps in the architectural design process. The layer theory is a dominant concept within this methodology. Because the hospitals within the Streamer consortium were not designed with the layer theory in mind, Bernhoven hospital* has been selected as an example.

Two considerations must be kept in mind:

- there is a strong overlap between these key steps; the design process is often a cyclical process
- these steps to not describe a specific Streamer process, just the workflow during the design of Bernhoven hospital. Streamer Task 4.1 is expected to focus on the development of the Streamer (design)process.

The following key steps are described

6.5.1 Translation of the programme of requirements (PoR) to functional areas (FA) to be used in the design

The PoR contains the functions the hospital thinks it needs. It is a very detailed description of the functional areas and the space-units in the hospital that belong to these functional areas. Bernhoven hospital used a method similar to the functional outside/in approach as described in Figure 6.7, with an emphasis on the functional properties of the space units.

First step is to evaluate if the space-units are assigned to the correct functional areas, when considering a broad range of parameters, such as:

- layer properties, which represent;
- energy requirements
- structural requirements (e.g. height, expected floor load)
- medical requirements
- usage times indication
- relation to other functions
- size (area)
- etc.

For example, if the hospital would like to have an operation room within the in the polyclinic area, the architect would advise against this because of the mismatch in layer properties between the operation room and polyclinic space-units. This mismatch represents inter alia a conflict between the height of the operation room and the other polyclinic rooms, and might cause an entire building level to be made higher, raising costs.
However It is not always possible to create homogeneous functional areas. Sometimes the other parameters can overrule the layer properties.

When the space units have been assigned to the correct functional areas, the total net area of the space units within a functional area is multiplied by a factor specific for this functional area, which covers for expected traffic, MEP space and wall areas. The result is a collection of functional areas with an estimated gross area. By adding all the functional areas, the estimate gross floor area of the entire building can be estimated.

6.5.2 Applying layer labels to functional areas and organizing these functional areas

In the case of a hospital, designing on the level of space-units is difficult in an early design phase, because there are simply too many space/units to consider. In the Bernhoven design process, the functional areas are the main building blocks for the design. Just like the space-units, these functional areas have been labelled.

The range of parameters to be considered on the level of functional areas is:

- layer properties, which represent;
- energy requirements
- structural requirements (e.g. height, expected floor load)
- medical requirements
- usage times indication
- relation to other functions
- need for daylight
- size (area)
- etc.

In the Bernhoven design, functional areas with similar layer properties have been grouped together. From these groups, a sub-building has been created for each layer type (hotel, hot floor, office, industry). Within this sub-building, the functional areas can be placed (building level, position in floor plan) in such a way that the medical relations between the functional areas are met. For example: the operation area (hot floor) can be in close proximity to the maternity ward (hotel), although they are in different sub-buildings.

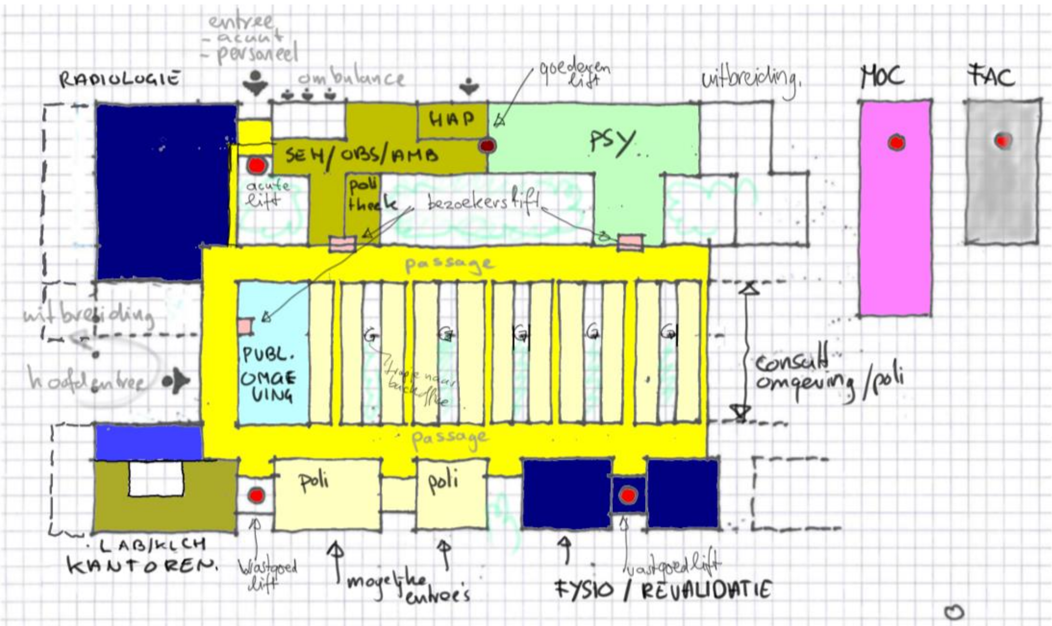


Fig. 6.7 Conceptual design sketch; functional areas

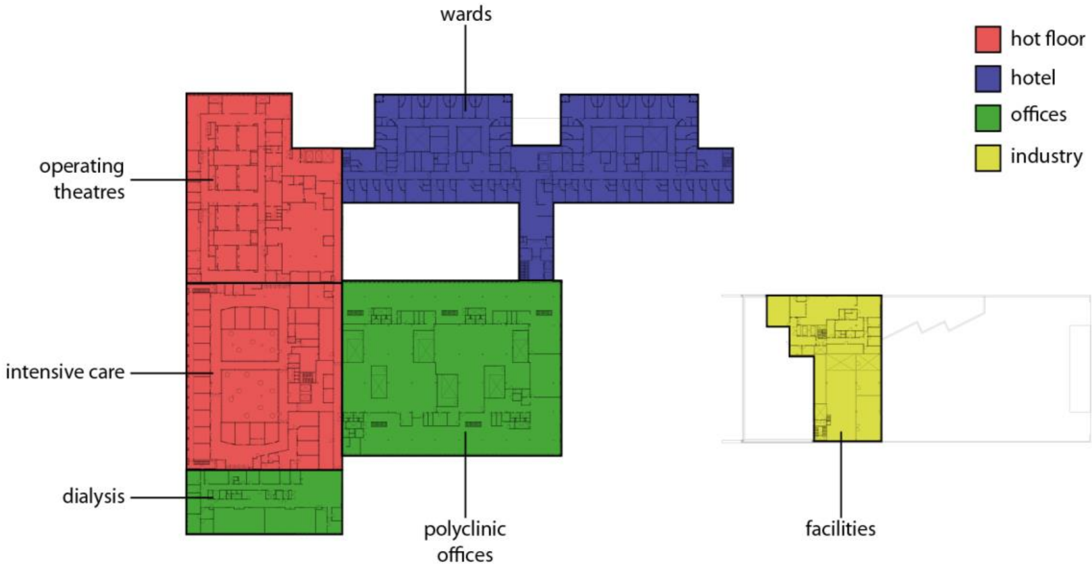


Fig. 6.8 Main functional areas in the final design

These sub-buildings together form the hospital. Some of the parameters used to determine the configuration are:

- general appearance and architectural experience
- site logistics
- hospital logistics
- regulations (e.g. building height, accessibility for fire brigade)
- urban masterplan (e.g. building footprint, parking spaces)
- daylight
- deep or narrow plan layout
- etc.

Fig. 6.9 Conceptual design sketch

Fig. 6.10 Site plan

6.5.3 **Arranging the space-units within the functional areas**

After the functional areas have been positioned, an extensive period of floor plan design began, in which the users were often consulted. In many projects, discussions often arise about the content of the PoR in this design phase, for various reasons;

- for the first time, users will see a translation of the requirements into a visual plan
- there may be a difference in vision about working processes between the management and the users, who are not always involved with the development of the PoR
- due to personnel change a different vision may develop during the process

Major changes made to the PoR often conflict with decisions already made, and can have great impact on the design progress.

Also, the creativity of the designers will provide new insights into the arrangement of space-units.

Important design parameters at this stage are:

- the PoR
- user workflow requirements
- the amount and type of daylight (direct, indirect,…)
- walking distances
- safety
- view outside
- visual relations between space units
- regulations (e.g. evacuation)

- size and position of components to be placed within the space-units
- etc.

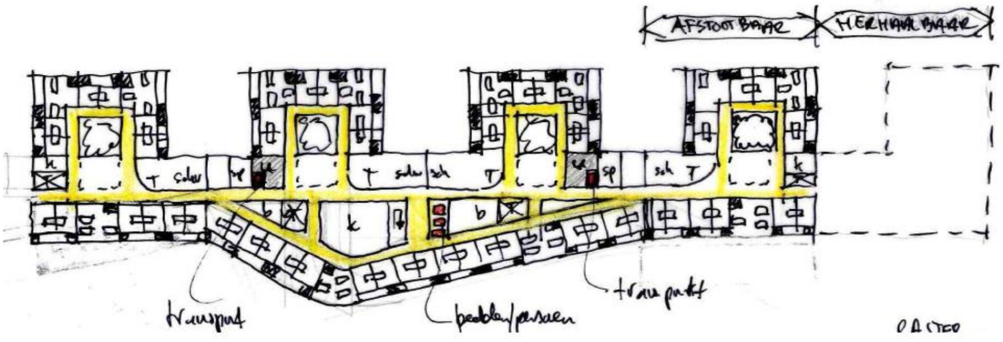


Fig. 6.11 Preliminary design sketch

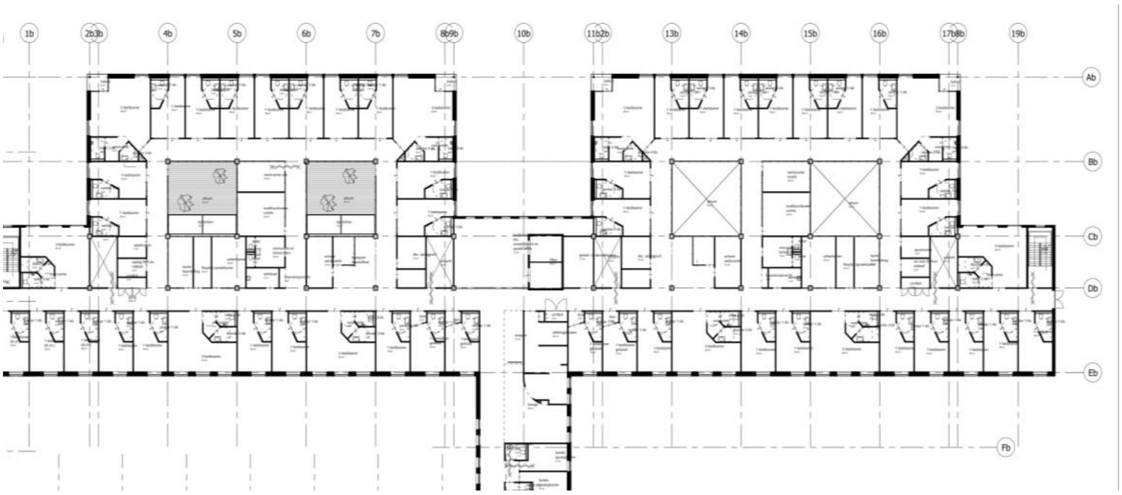


Fig. 6.12 Developed design floor plan

6.5.4 Placement of components within space-units

For specific space-units such as patient rooms, polyclinic rooms and operating rooms, the placement of components (beds, operating robot) has a big impact on their size and form, so these space-units are designed using a bottom-up approach.

The size and shape of more flexible space-units such as a restaurant, waiting area or storage can be developed independent of the components.

Choices concerning the placement of components are based on the following parameters:

- free space around the component
- accessibility of the component
- relations between components
- visual organization of components within the space-unit
- etc.

An example of creativity on the level of space-unit and component is the development of a birth suite. In the PoR, several rooms that traditionally are separate (rooming-in, delivery room) were merged. This resulted in a reduction of floor area and higher patient satisfaction.

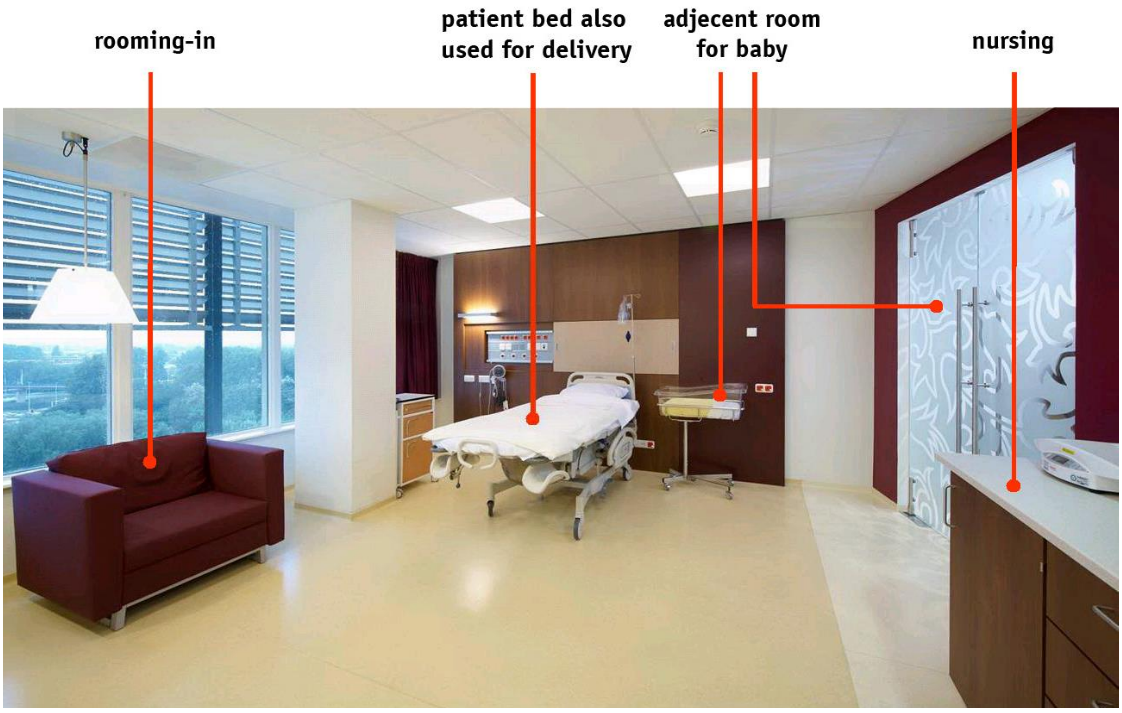


Fig 6.13 Birth suite, St. Franciscus hospital, Rotterdam

* Bernhoven hospital:

Architect: De Jong Gortemaker Algra, built in Uden, The Netherlands in 2013

6.6 Application of functional breakdown and labelling: the AOUC case study

This exemplification aims to validate the flexibility of the system identified, as it should be fit by any configuration of a District. The AOUC District has been taken as the example to test the method.

The analysis follows the progressive breakdown of the healthcare district in levels, focusing thus on one building, San Luca Building C ("San Luca nuovo") and a functional area and the spatial units within it of that building.

Each level of the breakdown in analysis has been then subject to the labeling system; thus each level is crossed by different criteria of classification as described in the previous paragraphs of Chapter 6:

- the categories of the Layers approach. As the building is designed and organized according to functional areas related on the homogeneity of activities done within that area, the labelling could be operated at this level.
- single spaces are labelled according to energy-class they belong to in terms of energy consume level;
- each level is then labelled according to the AOUC organizational criteria of classification of spaces, based on the database developed in the S.A.C.S system. The S.A.C.S system organizes the spaces according to the "activity area (A.d.a in the S.A.C.S)", which mainly correspond to the functional area required for the development of that activity, the

"departments" the A.d.a belongs to in terms of organizational and administrative system (DAI in the S.A.C.S), the "centres" as a grouping of buildings with homogeneous function, etc.

District (Level 5)

The District level here defined is the AOUC campus. The next level of analysis is here highlighted in red.

That correspond to the "Oncological Centre" which consists in three buildings characterized by an homogeneity of functions.

The Centre is an intermediate level between the District and the Building that correspond to the organizational classification of spaces and functions in AOUC.

Building (Level 4)

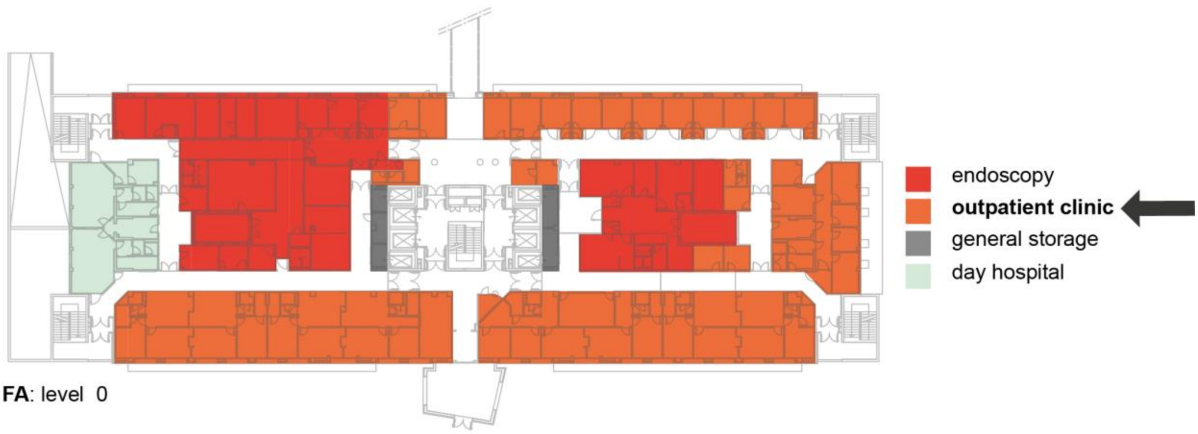
The Building here analyzed is the one highlighted. It correspond to the San Luca Building C ("San Luca nuovo").

As stated, this building belongs to the "**Oncological Centre**", which consists in three different building realized in different time.

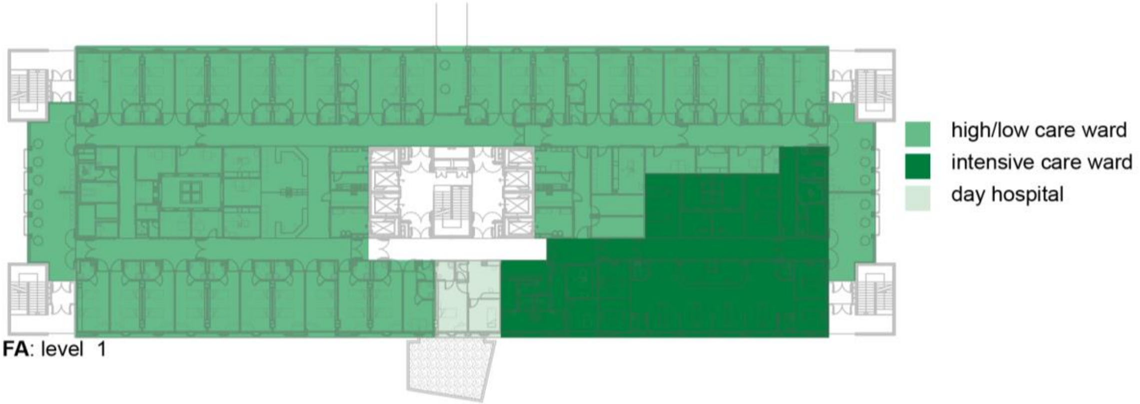
It is a multi-story building that includes diagnostic and treatment functions and wards, in addition to general building facilities.

Functional Area (Level 3)

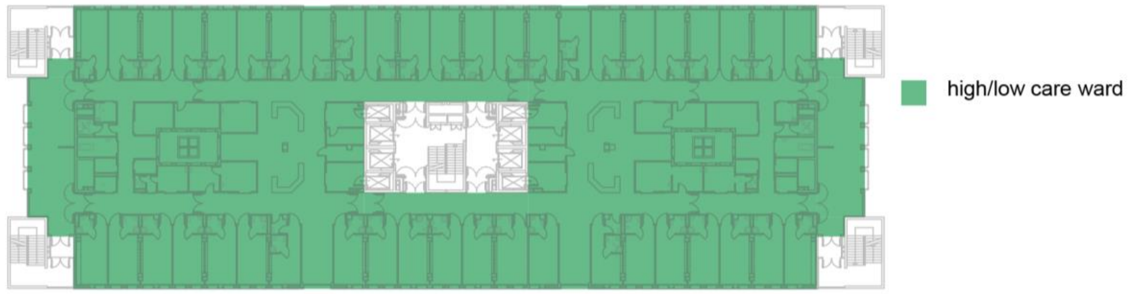
FA: level -1



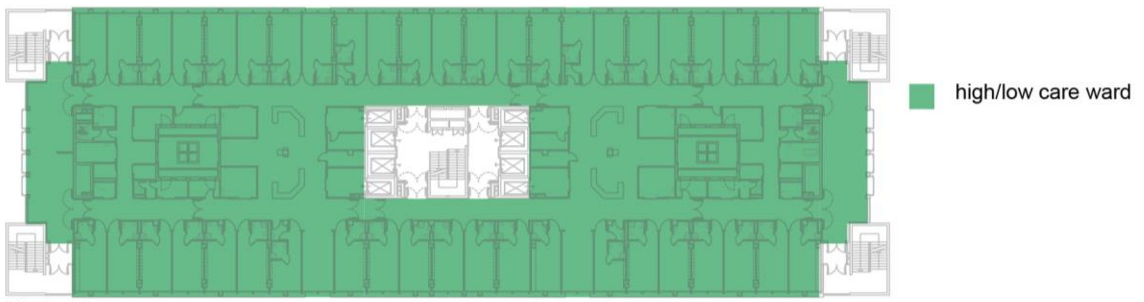
FA: level 0



FA: level 1



FA: level 2



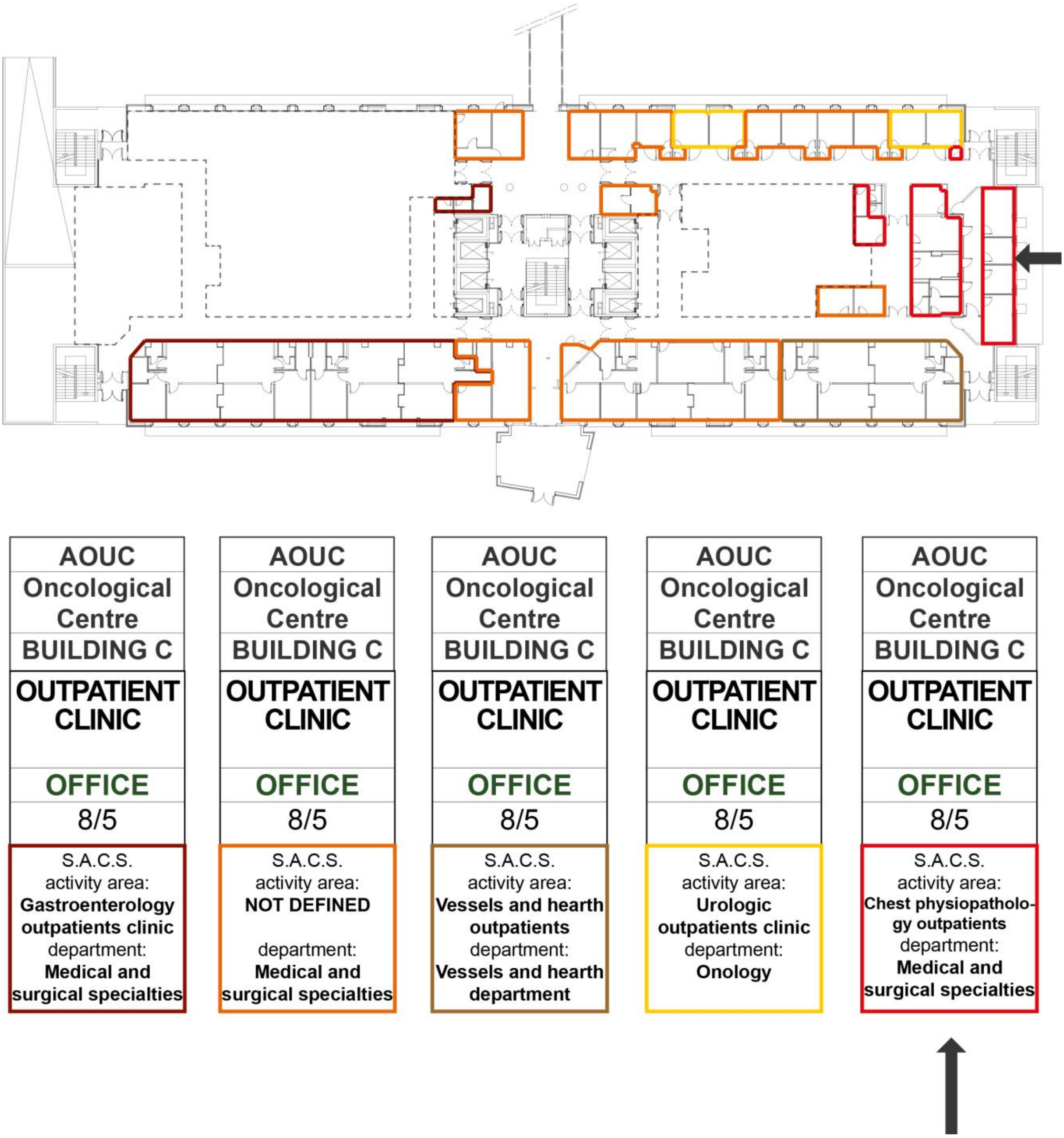
FA: level 3

The functional areas present in the building in analysis are here displayed. Each functional area can be described according to the **Layer approach** classification and the **operational usage** .

AOUC Oncological Centre	AOUC Oncological Centre	AOUC Oncological Centre	AOUC Oncological Centre	AOUC Oncological Centre	AOUC Oncological Centre	AOUC Oncological Centre	AOUC Oncological Centre
BUILDING C	BUILDING C	BUILDING C	BUILDING C	BUILDING C	BUILDING C	BUILDING C	BUILDING C
DRESSING ROOM FOR STAFF	GENERAL STORAGE	TECHNICAL AREA	ENDOSCOPY	OUTPATIENT CLINIC	DAY HOSPITAL	INTENSIVE CARE WARD	HIGH/LOW CARE WARD
INDUSTRY	INDUSTRY	INDUSTRY	HOT FLOOR	OFFICE	HOTEL	HOTEL	HOTEL
24/7	24/7	24/7	8/5	8/5	24/7	24/7	24/7

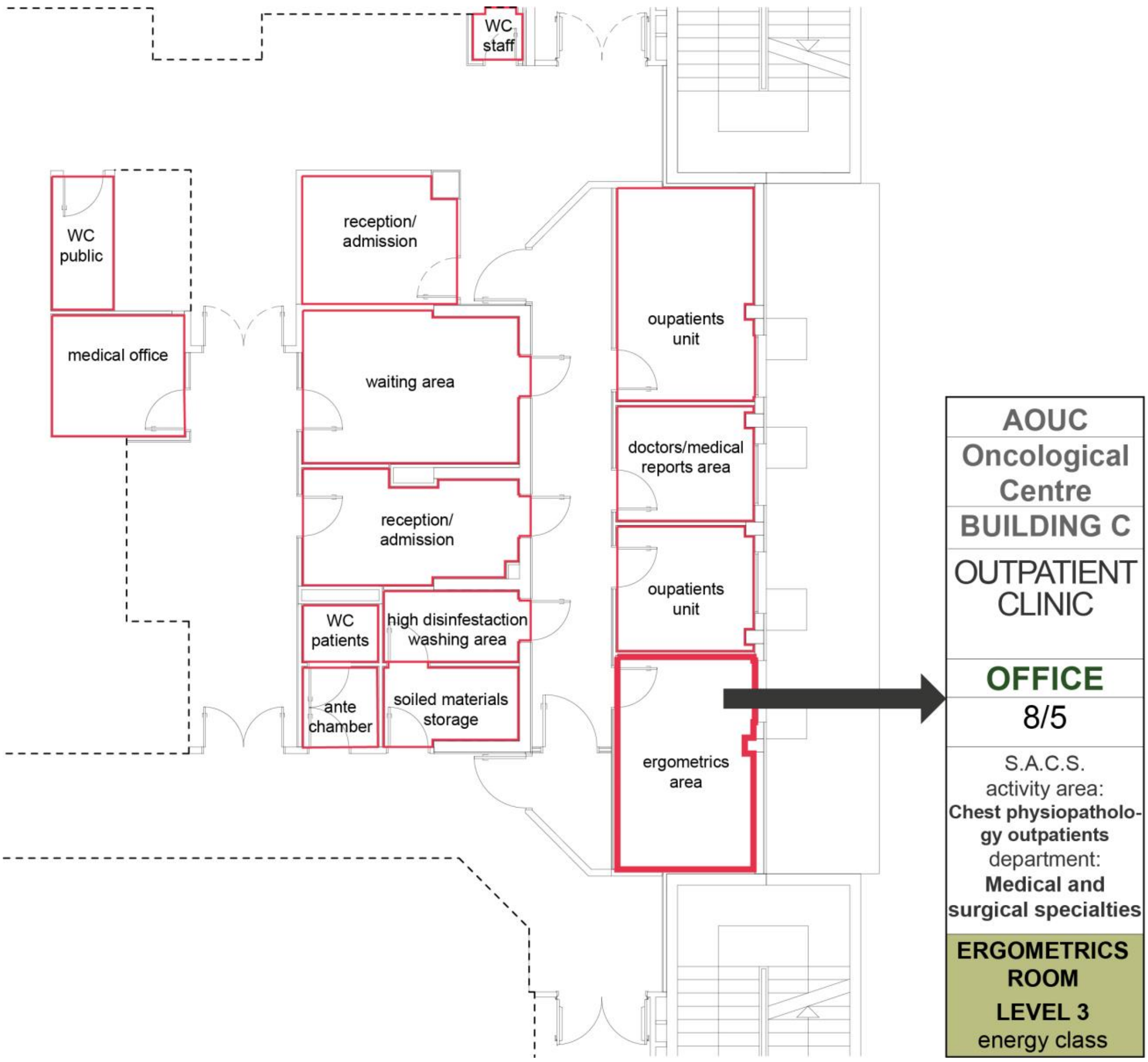
Moreover, this level is then labelled according to the AOUC organizational criteria of classification of spaces, based on the database developed in the S.A.C.S system. The S.A.C.S system organizes the spaces according to the "activity area (A.d.a in the S.A.C.S)", which mainly correspond to the functional area required for the development of that activity, the "departments" the A.d.a belongs to in terms of organizational and administrative system (DAI in the S.A.C.S), the "centres" as a grouping of buildings with homogeneous function, etc.

The labelling operated by the S.A.C.S system is described within the Outpatient Clinic, here taken as the functional area to be further analyzed in this example. This classification shows the system of hierarchy that regulates the AOUC organization.



Spatial Units (Level 2)

The **Chest physiopathology outpatients** activity area, within the **Medical and surgical specialties** department is here described according to the spatial units included. The spatial units are labelled according to the their energy-related features and technical properties. In this exemplification, one of the spatial units is described according to the energy class it belongs to. Of course, the single rooms should contain complete information of all the classification that operate at the upper levels (from Spatial Units to District Level), as it is the level that must provide the compatible data with the semantic model.



7. Conclusion

The taxonomy of healthcare districts and the classification of hospital buildings and spaces developed in this report will become the basis for the development of semantic BIM ‘template’ for as-built models.

With this scope the main targets of the analysis have been related to:

- the identification of factors that the “EeB typology models” depend on,
- the definition of the “energy-related features” that allow to compare different typologies and arrangements;
- the implementation of a methodology for classifying and labeling functional areas and spaces, compatible with and suitable for the semantic model;

Since the design of hospitals involves many stakeholders, the approach has been multidisciplinary (i.e. both the technical and non-technical aspects and parameters have been considered).

Two main approaches to the definition of typology have been considered:

- the “Outside/In” approach – so called “designer’s view” – that defines the typology based on the 4 “Bouwcollege spatial classifications”;
- the “Inside/Out” approach – so called “engineer’s view” – that defines the typology based on the technical properties and the energy-related features of single spaces and building/MEP systems.

Working to merge the two approaches, a specific methodology to define the typologies and to classify the spaces has been implemented. The results achieved on this matter include:

- the definition of five levels to be considered to built up a healthcare district within Streamer;
- a breakdown method to be applied in the implementation of the semantic BIM model in WPs 5 and 6.

In particular, the breakdown system has been shaped in a flexible way so to be adaptable to different arrangements of existing HD and buildings and to be integrated into operating database and management tools (for example the SACS system currently used in Careggi, one of the four demonstration projects).

Moreover, the classification and labeling method implemented introduces a set of codes and references that allow to identify the spaces through the relations between spatial, functional and energy related features.

The labeling system will provide the units of each level (in particular the levels 2/3/4 corresponding to spaces, functional areas, and buildings) with parameters and factors that will inform the semantic BIM model on spatial, functional and energy related features.

A first achievement reached in Task1.1 and explained in this report is exactly the implementation of an approach to the typology definition that interrelates:

- the typological, technical, distribution and functional characteristics of each building type;
- the functional aggregative configurations based on the proximity and the interdependencies between spaces and functions;
- the energy-related features and characteristics corresponding to the different building typologies.

A further result of the work carried out in this Task is the application of the energy parameters to the four layers defined by the former Bouwcollege approach, analyzed and implemented in Task 2.2 (see Deliverable D2.4).

What has been confirmed by the interrelation of the different parameters described above is that the energy efficiency of buildings does not depend only on the technical performances of envelopes and MEP systems. Other factors and conditions contribute to make better or worse the energy performances; for example:

- the shape of buildings (see the considerations based on the comparison between the narrow plans and the deep plans developed in the paragraph 2.4);
- the correct location of spaces and functions and the effect of this factor on the energy consumption of those spaces;
- the appropriate destination of spaces to functions and activities compatible with their technical characteristics, their shape, their position and proximity with other spaces, etc.

The classification and labeling method developed in Task 1.1 considers these factors and aims to transfer data and information about their interactions into the semantic BIM model.

The report defines the main parameters and categories to be further analyzed and optimized for the finalization of the semantic labeling system.

The selection of the key parameters to be used in the labeling system – object of the next steps of Task 1.1. – will be related to the specificity of design tools developed in WP5 and WP6 considering the multipurpose functions they will have to provide, as for example:

- supporting the design of new buildings with information and technical data about how to improve the energy performances considering the interactions between functional, operational and technical aspects, as well as: typology, layouts, location of spaces considering the functional aggregative configurations based on the proximity and the interdependencies, appropriateness of technologies and materials, suitability of MEP systems;
- assessing, in the energy-efficiency retrofitting of existing buildings, the correct location of activities in their current position (proximity or distance from other spaces of the same functional area), destination and technical characteristics of spaces, necessity of changes or improvement of the existing technologies and materials;
- deciding about the opportunity of a retrofitting project instead of the replacement of an existing building.

These factors have to be considered and analyzed in the specific context where the project will be implemented.

What we learned from the work done in this task is that there is not an optimal typology that always – in any location and condition – satisfy in the best way the energy efficiency parameters.

Climate conditions, health service organization, position of buildings, connections and circulation system, construction technologies used for the envelope, and many other factors can influence the specificity of each context and the appropriateness of typology as well as of technical and functional design solutions.

There has been a shift in the medical equipment used in the past 50 years and the hospital form has changed. Regarding the building form and energy use in the past 50 years, for example, we have moved from pavilion to deeper plan but we are moving back again given the push towards the therapeutic environment and the integration of natural ventilation, daylight and views.

On the other hand a correct balance between the solutions addressed to the optimization of the energy performances and the satisfaction of other parameters that the users' comfort depend on. A conflict between design solutions considered from different points of view can sometimes occurs (enlarging the glazed surface in a room, for example, reduces the energy efficiency but improves some other parameters related to the user's comfort as daylight, natural ventilation, view outside, etc.).

These aspects has been analyzed in Chapter 3 which focuses on the relations between building typologies – represented as theoretical archetypes referred to nine basic arrangements – and energy related characteristics. The results of this analysis have been collected and summarized in a set of forms corresponding to each typology (see paragraph 3.3).

Some aspects that could seem not completely developed will be deepened and completed in the further implementation and finalization of Task 1.1. Some other topics, on the other hand, has been and will be covered in other WPs and Tasks.

The report, for example, gives just some preliminary and indicative hypotheses to the influence of the geographical location on the shape of buildings. This topic has been analyzed in Chapter 3: in particular the forms collected in the paragraph 3.3 define the suitability of each typology for the European climatic zones.

An in-depth analysis and more detailed data on this issue can be found in D3.1 where a special section is addressed to the geographic/climate factor that highlights the impact of the different geographies to energy use. Four different countries have been considered with associated climates as the basis for developing "climate factors": Sweden in the north, Poland in the east, Italy in the south and UK in the west. This will be to differentiate the geographies in the model but the real proof will be in WP5 when the actual facilities will be tested.

Furthermore these topics will be addressed with a practical approach in relation to the demonstration cases, analyzed in WP7 representing four European regions.

Results achieved in Task 1.1 until now (M1 > M12) and reported in this deliverable provide inputs and generate exchange of information with the following WPs.

An exchange of information and data will be carried on with **WP3** to define criteria and select parameters (related to EeB KPIs established in T3.1) for the implementation of the semantic labels to be used in the BIM model.

The breakdown of the Healthcare Districts based on the five scale levels, the labeling system and the categories of labels will provide inputs for the development of semantic design models (WP1/T1.3) and their implementation with the ontological tools developed in WP5/T5.1, for the semantic design configurator in **WP6** (in particular in T6.1) and for the description and analysis of the typology models of the demonstration projects in **WP7** (in particular in T7.1/T7.2/T7.3/T7.4).

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