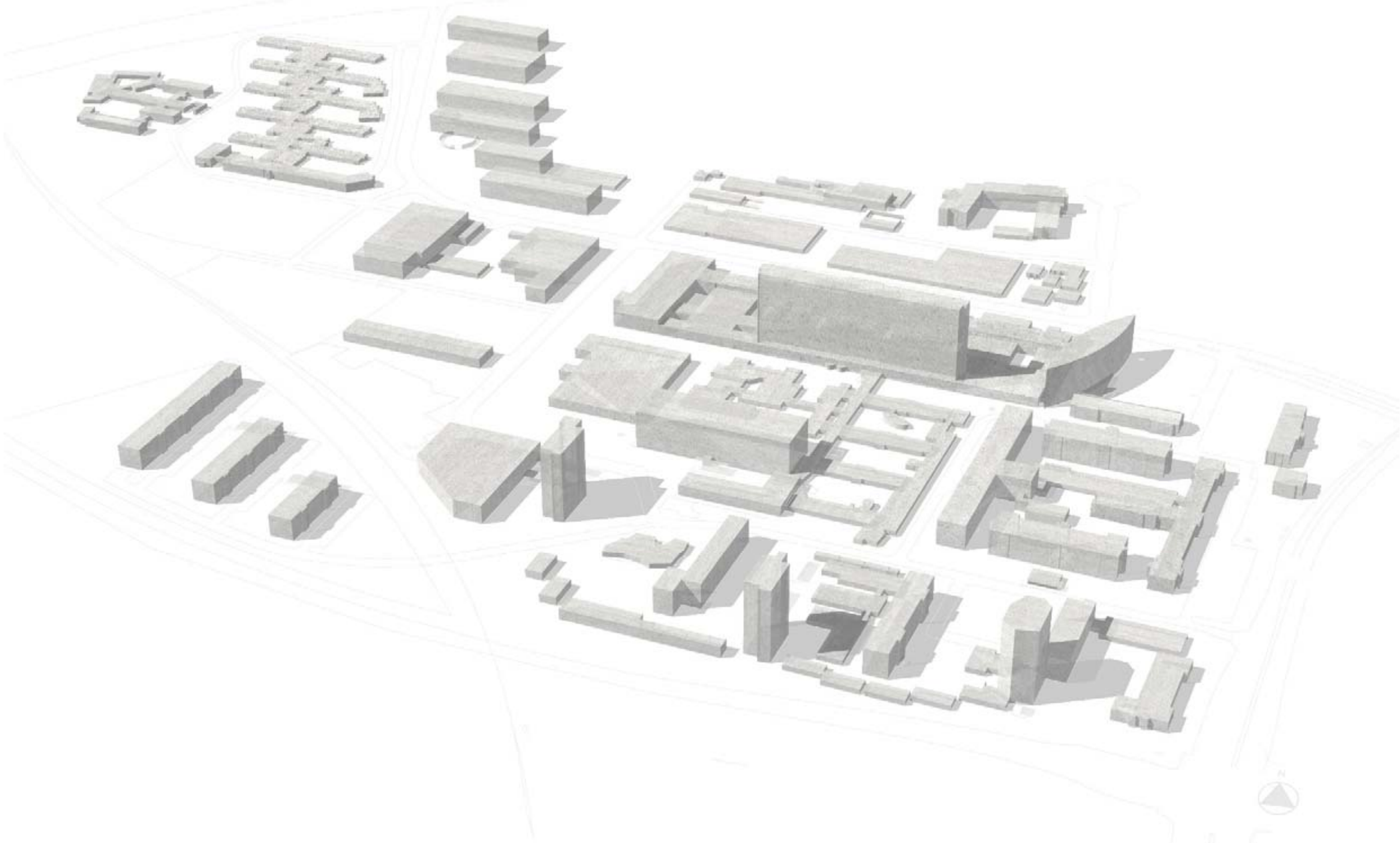
# ODENSE UNIVERSITY HOSPITAL

## REPORT

BUILDING REFURBISHMENT AND URBAN RENEWAL
OF COMPLEX AND DIVERSE BUILDING STOCKS
- INTEGRATION OF LCA IN ANALYSIS AND DESIGN PROCESSES

*PART 1*



TECHNICAL UNIVERSITY OF DENMARK, DTU

**AUTHORS**

Kathrine L. Møller, s123740, DTU Civil Engineering - Architectural Engineering
Sarah C. Andersen, s123528, DTU Management Engineering QSA, DTU Civil Engineering - Architectural Engineering
Simon W. Jørgensen, s123583, DTU Civil Engineering - Architectural Engineering

**SUPERVISORS**

Lotte Bjerregaard Jensen, Associate Professor at DTU Civil Engineering – Architectural Engineering
Morten Birkved, Associate Professor at DTU Management Engineering – QSA

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Technical University of Denmark
Anker Engelundsvej 1, Building 101A
2800 Kgs. Lyngby - DK

**SUBMITTED**

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**DATE AND SIGNATURE OF AUTHORS**

_________________________________________
Kathrine L. Møller

_________________________________________
Sarah C. Andersen

_________________________________________

Simon W. Jørgensen

# ABSTRACT

This project contains the investigation and suggestions for renovation and transformation of Odense University Hospital (OUH), Denmark. The idea for the project originated from the knowledge of the establishment of a new Super Hospital/Medical Center and the following concern of what was supposed to happen to the original hospital area. As an elongation to other courses taken during the study in Architectural Engineering at the Technical University of Denmark, a study of possibilities within renovation and transformation needs of both the urban area and a specific building is performed, by using the sustainable issues, Life Cycle Assessment and multi-criteria decision making as a decision tool. In this first part of the project, only the urban area has been of focus and an overall review of the area is made. The multi-criteria decision analysis takes into account a number of weighted parameters of which all buildings are evaluated. The analysis is carried out by an approach through TOPSIS and hereby compares each building with an ideal solution and through that help deciding what buildings should stay and which ones to demolish.

This report comes along with an additional mapping which presents the results of the investigations in a graphical way, whereas this report contains technical background with explanations, considerations, calculations and theory.

# PREFACE

This report is made in cooperation by three students at DTU during an individual course for investigating the potential for renovation and transformation of Odense University Hospital (OUH) during the spring semester 2016. The course is nominated to 10 ECTS points and consists of two stages, an analytical phase and a design phase. The report can be read separately or together with the “Odense University Hospital Mapping” which contains a more visualized presentation of the results.

In connection with this project will be given a big thank to the Facility Management department at OUH, including special thanks to Ivan Schjødt Nielsen, Section Manager, for helpful background knowledge and an inspirational tour of the hospital and to Kirsten Skytte, Technical Assistant, for being helpful providing countless drawings of the different building types.

Finally big thanks to Lotte Bjerregaard Jensen, Associate Professor at DTU Civil Engineering – Architectural Engineering and Morten Birkved, Associate Professor at DTU Management Engineering, for professional guidance and references to good tools during the project.

# LIST OF CONTENT

# 1. INTRODUCTION

This project contains the investigation and suggestions for renovation and transformation thoughts of the Odense University Hospital (OUH), Denmark. The idea for the project originated from the knowledge of the establishment of a new super hospital and the following concern of what was supposed to happen to the original hospital area.

Throughout the spring semester of 2016 several analyses of the existing buildings at Odense University Hospital have been made. The results of the different analyses are also presented in the booklet "Odense University Hospital – Mapping – Building refurbishment and urban renewal of complex and diverse building stocks – Integration of LCA in analysis and design processes – part 1", while this report contains technical descriptions of the analysis made of the Hospital buildings.

One of the analysis made on each building are the SAVE-method where each building is evaluated in the five categories; architectural, cultural, environmental, originality and condition. Furthermore, an estimated lifetime and floor area of each building have been made as well as the Embodied Energy and Global Warming potential of each building.

In order to compare the buildings to each other and taking all analyses into account a 'Multiple Criteria Decision Making' method (MCDM-method) has been made. A technical description on the TOPSIS theory used for the MCDM can also be read in this report.

# 2. BACKGROUND

The existing Odense University Hospital (OUH) is situated in the center of Odense partly surrounded by dwellings and green areas. The layout consists of an established floor area of around 300.000 square meters built in the period of 1912 till 2014.

OUH is the largest stand-alone workplace on Funen with over 8000 full-time workers. The Hospital treats more than 1.100.000 outpatients and 100.000 discharged patients a year, which roughly means more than 13.000 people visits the hospital on a daily basis. [1]

In order to cope with the high amount of daily visitors, large parts of the previously green and undeveloped area are converted into parking spaces. The area is also connected to a local train station as well as a couple of bus stops in order to ease the high car traffic.

The hospital area can roughly be divided into five functions which are the somatic department, dwellings for the medical staff, teaching facilities, supply and maintenance department and psychiatric department.

According to the district plan the coefficient of utilization must not exceed 0.85 and with a ground area of around 400.000 square meters. This means that additional 40.000 square meters floor area can be added to the existing.[2]

As a result of the limited space to expand the building area, and several other factors as e.g. outdated facilities, a new hospital area is planned. The first sod was cut the 28th of April 2016, and the new hospital ('Nyt OUH'), is expected to be finished by 2022. [3]

The area where the new hospital is build has a ground area of 780.000 square meters, and the new buildings have a total floor area of 250.000 square meters. As the current hospital's total floor area is about 300.000 square meters, it is already known that the new hospital will not have as much space from the beginning, hence it is designed in a constellation which allows for a 100% expansion. [3]

In addition to the spacing and the facilities, the new hospital is build closer to the main highway of Funen, given faster access, as OUH is the main hospital for Funen and the region of Southern Denmark as well.[4][3]

Another outcome of the moving is a closer cooperation between hospital and the Southern University of Denmark, as the new hospital is built in elongation of the relatively new built university area, Cortex Park. The vision is, by placing these instances beside each other, all will benefit from this by creating common projects and research and over time this will give societal gains. The total 'knowledge area' is planned to be about 500.000 square meters, only developed to co-exist and provide knowledge and research.[3]

# 3. METHODS AND PART RESULTS

## 3.2. REGISTRATION AND ANALYSIS

A registration of the 70 buildings at Odense University Hospital has been made and can be seen in appendix A. The registration is used to get knowledge about the area, buildings, structures etc. In the registration all buildings within the hospital area are listed and for each building, facts are written which are used as additional tool to develop the mappings which are also shown in the booklet "Odense University Hospital – Mapping – Building refurbishment and urban renewal of complex and diverse building stocks – Integration of LCA in analysis and design processes – part 1".

The registration is based on several visits to the hospital site, among other with the facility manager of the entire area, and papers about the hospital, amongst given by the facility management department.

## 3.2. MAPPPINGS

The mappings which are to be found illustrated in the booklet, are also shown and explained in the following section. Some of the mappings have a further technical or mathematical theory, which is also explained in the following sections.

## 3.2.1. BUILDING NUMBERS

All buildings at OUH have a number. The number is given somewhat chronological for each completion with variation. The numbers can therefore help indicate which buildings are the oldest and which are the newest. However some old buildings have been demolished and might have been replaced with a new building which means there can be some exceptions in the chronological numbering. The number of each building is illustrated on FIGURE 1.


*FIGURE 1 – MAPPING OF BUILDING NUMBERS AT OUH*

## 3.2.2. BUILDING FUNCTIONS

On this mapping, see FIGURE 2, an overview of the purposes of each building is illustrated. The area of OUH contains buildings both out of and within hospital functions. The buildings within hospital functionality are somatic care facilities, offices, facility management and residential apartments for doctors. The buildings which are not within the hospital functions are university buildings used by The University of Southern Denmark, The Danish Cancer Society and psychiatric care facilities.

The mapping is created to get an overview of the distribution of functions across the site of OUH.


*FIGURE 2 – MAPPING OF BUILDING FUNCTIONS AT OUH*

### 3.2.3. TUNNELS

The site of OUH is more than 100 years old and throughout this time period the hospital has developed both above and beneath the ground. As many other hospital sites, OUH has built several tunnels beneath the buildings across the entire site. These tunnels are used for internal transportation of e.g. laundry, patients, mail and installation.

The mapping of the tunnels, see FIGURE 3, shows the pattern of the tunnels in context with connecting buildings.


*FIGURE 3 – MAPPING OF THE TUNNELS AT OUH*

## 3.2.4. GREEN AREAS

The mapping of the green areas, see FIGURE 4, is used to get an overview of the amount of areas which could be used for recreational time or just enjoying nature and also to give an idea of the surrounding areas. Odense University Hospital is situated in the middle of Odense City and the entire hospital area is surrounded by larger green areas. However, within the hospital areas only limited amounts of vegetation can be found.

The mapping shows the areas with higher vegetation within OUH. The hospital buildings have been increased in size, both in area and floor size, through many years, which has led to decrease in amount of recreational/green areas on the hospital site.


*FIGURE 4 – MAPPING OF THE GREEN AREAS AT OUH*

## 3.2.5. FLOWS

The mapping of flows, see FIGURE 5, show how one is assumed to be able to get around at the hospital site.

Today Odense University Hospital is rather closed with two 'entrances' from the surrounding roads. This probably limits heavy traffic and ensures better safety. Nevertheless, the site is enclosed and has the feel of being a 'city within a city'. This is ideal for a hospital, but when considering the future and possibilities, the space might not seem integrated in the rest of the city. This 'issue' might change automatically with the change of functions and by this creating a more open flow pattern for the site.


*FIGURE 5 – MAPPING OF WALKING AND DRIVEN FLOWS AT OUH*

## 3.2.6. CONSTRUCTION PERIODS

The mapping of construction periods in FIGURE 6 shows which time period the buildings were constructed in.

Odense University Hospital has been situated by Sdr. Boulevard in Odense since 1912. It was built far away (as the existing hospital at the time was too small for the increasing number of patients) from the center of Odense where a lot of space for further expansion was possible. As the city of Odense have expanded heavily ever since, the area has been surrounded by the city and is now a part of the inner city.

In the beginning only red masonry buildings existed and large grass areas were found around the site. Since then a lot has changed. A few buildings were added at times until 1960. In the 1960-1970s major constructions appeared. This period was dominated by concrete buildings including some of the high-rise constructions, which are characteristic parts of the hospital today. The development has continued ever since and until 2014 where the latest construction was build. Today, around 300.000m$^2$ floor area exists.


*FIGURE 6 – MAPPING OF CONSTRUCTION PERIODS OF THE BUILDINGS AT OUH*

### 3.2.7. BUILDING TYPES

As said the hospital was constructed throughout longer periods of time. This is also evident in the different building types found on site. The main parts are concrete and masonry buildings.

On the map in FIGURE 7 the distribution of building types is shown, according to construction and materials. These divisions are based on registration and the main construction materials.


*FIGURE 7 – MAPPING OF THE DIFFERENT BUILDING TYPES AT OUH*

### 3.2.8. SAVE-METHOD

SAVE (Survey of Architectural Values in the Environment) [5] is an approach to identify, record and evaluate preservation values in urban environments and buildings. The SAVE method was developed by the Danish Plan Protection Agency. The development first started in 1987 and after a period of trial registrations a final SAVE method and guidance was published in 1992. SAVE assessment of buildings is based on five different parameters:

Architectural quality
Cultural-historical quality
Environmental quality
Originality
Condition

Values are given for each parameter on a scale of 1 to 9, where 1 is good and 9 is bad. The five parameters and their evaluation helps 'grading' each building to one preservation value.

### 3.2.8.1. ARCHITECTURAL QUALITY

The mapping in

FIGURE 8 shows the architectural quality which is evaluated on the basis of the buildings proportions, facade rhythm, the architectural treatment degree and the interaction between form, material effect and function. The architectural assessment is also looking at whether the building in the local context is a good, mediocre or less fortunate copy of a given building type.


*FIGURE 8 – MAPPING OF THE ARCHITECTURAL QUALITY OF THE BUILDINGS AT OUH ACCORDRING TO THE SAVE-METHOD*

### 3.2.8.2. CULTURAL-HISTORICAL QUALITY

The mapping in FIGURE 9 shows the cultural-historical quality.  In the cultural-historical assessment a number of different aspects are included. The first aspect is whether the building is a manifestation of the local building style, whether it is representative of a particular style period and whether it represents special craftsmanship capability. The building's rarity is also a consideration. The second aspect is whether the building reflects technical innovations in design and material terms such as an early concrete prefabricated house. The third and last aspect is whether the building is an example type of housing of a particular social group.


*FIGURE 9 – MAPPING OF THE CULTURAL-HISTORICAL QUALITY OF THE BUILDINGS AT OUH ACCORDING TO THE SAVE-METHOD*

### 3.2.8.3. ENVIRONMENTAL QUALITY

The mapping in FIGURE 10 shows the environmental quality which is evaluated on the basis of the building's significance or support value of the neighboring buildings and for the whole. It is evaluated how the building is located and adapted to the landscape, row of houses, streets or the environment in which it is a part OF.


*FIGURE 10 – MAPPING OF THE ENVIRONMENTAL QUALITY OF THE BUILDINGS/OUH SITE ACCORDRING TO THE SAVE-METHOD*

### 3.2.8.4. ORIGINALITY

The mapping in FIGURE 11 shows the originality which is evaluated on the basis of the extent to which the building's original expression is preserved or whether the overall impression that one has sought to create by any major alterations appear original. Changes in relation thereto are assessed under this section. In practice, considerations often go on whether later building modifications support or detract from the building's dominant elements.


*FIGURE 11 – MAPPING OF THE ORIGINALITY OF THE BUILDINGS AT OUH ACCORDING TO THE SAVE-METHOD*

### 3.2.8.5. CONDITION

The mapping in FIGURE 12 shows the condition values. The condition is evaluated on the basis of whether the building is properly and well maintained, including the general construction matters.


*FIGURE 12 – MAPPING OF THE CONDITION OF THE BUILDINGS AT OUH ACCORDING TO THE SAVE-METHOD*

### 3.2.8.6. PRESERVATION VALUE

The mapping, see FIGURE 13, shows the preservation value which is evaluated on the basis of the five SAVE parameters (architectural, cultural-historic, environment, originality, condition). The assessment of the preservation value is based on the overall impression of the building quality and condition. The preservation value should be regarded as a summary, specific evaluation of the five parameters. It is weighted which conditions are paramount and should be given the greatest weight in the overall preservation value. It is not a mechanical, analytical mean of the characters that have been offered in the part evaluations.

Usually, the architectural, cultural-historical and environmental values prevail in the preservation value. The preservation value is linked to the building's architecture and history. It is linked to whether the building is a good example of period architecture or a special style of building, the building type or building shape is rare, the building has served as a model for other buildings, whether it is intact or whether replacements and refurbishments are adapted to the building's expression and finally, if the building is indispensable in the street, in the countryside or for the whole.


*FIGURE 13 – MAPPING OF THE SUMMED PRESERVATION VALUE OF THE BUILDINGS AT OUH ACCORDING TO THE SAVE-METHOD*

## 3.2.9. TEMPORARY BARRACKS

At the existing hospital a number of barracks or so called 'cardboard boxes' are found. These barracks were always intended as temporary and were only meant to last for 30-40 years. These buildings will most likely be demolished in any case. The mapping in

FIGURE 14 shows the temporary barracks at the area.


*FIGURE 14 – MAPPING OF THE PLACEMENT OF THE TEMPORARY BARRACKS AT OUH*

## 3.2.10. BUILDING (MAIN) MATERIALS

The main materials of each building are mapped in FIGURE 15.


*FIGURE 15 – MAPPING OF THE MAIN BUILDING MATERIALS OF THE BUILDINGS AT OUH*

## 3.2.11. EXPIRATION TIME

Considering the different decades and different building materials shown on the previous mapping, it is inevitable to consider the different lifetimes of the materials. Most materials have limits on their life span. SBi has a database for the lifespan of construction materials.[6] Based on this database, a mapping of the expected remaining life years of each building is made and can be seen in FIGURE16.


*FIGURE 16 – MAPPING OF THE EXPECTED EXPIRATION TIME OF THE BUILDINGS AT OUH*

## 3.2.12. FLOOR AREAS

The floor areas of each building have been measured and are showed in intervals on the following two mappings.

### 3.2.12.1. ABOVE GROUND

The floor area in each building above ground is mapped in FIGURE 17 and shows that most of the floor area is concentrated at the center of OUH. Nearly a third of the hospital's entire floor area is placed in building 1 (above and below ground).


*FIGURE 17 – MAPPING OF THE TOTAL AREA ABOVE GORUND OF THE BUILDINGS AT OUH*

### 3.2.12.2. BASEMENT

The basement area in each building is mapped in FIGURE 18 and shows that most of the basement area is concentrated at the center of OUH. Most of the buildings do not have any basement other than a small access to the tunnels underneath the hospital. Most of the basement area is concentrated at building 1 where the basement is two stories deep.


*FIGURE 18 – MAPPING OF THE TOTAL BASEMENT AREA OF THE BUILDINGS AT OUH*

## 3.2.13. LIFE CYCLE ASSESSMENT APPLICATION

When considering a renovation or a transformation of a building or a building site, an aspect which is gaining interest and should be of relevance and consideration is LCA's - e.g. environmental impacts which the buildings have already emitted due to the construction or life time.

In this project, as a tool to consider demolition/renovation/transformation patterns and decisions, an LCA concerning the impact potentials, 'Embodied Energy' - in the form of 'Energy (Gross calorific value)' and 'Global warming' are used.

### 3.2.13.1. STRUCTURES

All the buildings are different of size, structures and materials. To evaluate the buildings at the hospital area, an evaluation and assumption of the materials used, and masses of those, are made based on technical drawings given by the facility management of OUH and the registration made, which can be seen in Appendix A.

The main types of wall constructions which are considered are built up as seen in TABLE 1.

Further the same registrations are made for respectively the roofs, decks and windows. These can be seen in Appendix B, on the tab 'Construction types'.

#### 3.2.13.1.1. MASONRY WALLS

Looking at the masonry walls in TABLE 1, 3 main types of construction appears. One is the construction of brown bricks, which is a double brick layered structure with insulation. The other two are regular brick walls, however dependent on the decade of construction.

Back in the beginning of the 20th century, masonry walls were built of solid brickwork, where the upper two levels always were constructed with a depth of 1,5*length of a brick, 228 mm. The layers below then adjusted with half a brick length. As the brick buildings at OUH are a maximum of 4 stories, hence there are only two pending thicknesses of the solid masonry wall; 1,5*brick length and 2*brick lengths.

The modern masonry wall was constructed with insulation and another back wall material. From the drawings received it is estimated/assumed that the amount of insulation behind one layer of bricks (108mm) is 125 mm and the back wall, which consists of concrete, is 150 mm thick.

*TABLE 1 – WALL CONSTRUCTION TYPES OF THE BUILDINGS AT OUH*

| Wall type | Brown brick wall | Old (red) brick wall (Build 19-12-1930s) | | New (red/yellow) brick walls (1930s~) | Concrete walls | Steel cladded walls | Fiber cladded walls | Wooden cladded walls |
|---|---|---|---|---|---|---|---|---|
| | | *1-2 lower floors* | *2 top floors* | | | | | |
| Outside | 108 mm masonry | 456 mm solid masonry | 342 mm solid masonry | 108 mm masonry | 200 mm concrete | 20 mm steel plates | 10 mm fiber slates | 20 mm wooden cladding |
| | 125 mm insulation | | | 125 mm insulation | 100 mm reinforced concrete | | | 45*22mm wooden laths with a 900mm distance |
| | 108 mm masonry | | | 150 mm reinforced concrete | 100 mm insulation | | | 100 mm insulation |
| Inside | 3 mm mortar washed surface | | | | 13 mm gypsum plasterboard | | | 45*22mm wooden laths with a 900mm distance |
| | | | | | | | | 1 mm vapor retarder |
| | | | | | | | | 5 mm hardwood fiberboard |
| | | | | | | | | 13 mm gypsum plasterboard |

#### 3.2.13.1.2. CONCRETE WALLS

When looking at the concrete walls, several of the walls are accounted as one. This, as all the walls with for instance fiber- and steel cladding, were not received and the main structural element of these walls is hence assumed to be and accounted for as concrete.

From the drawings received the buildup of the concrete walls (e.g. the high rises) were estimated to be cladded with a concrete layer, followed by a reinforced layer of concrete and ending with a layer of insulation and gypsum plasterboards. As the drawings were very poorly showing the structure, the estimation is done roughly and might lack some parts, for instance distance laths.

In the absence of structural drawings from the buildings cladded with e.g. fiber and steel, the rough estimates from the concrete buildings are transferred to those, hence some details might be missing as well. However, it is assumed tolerated as this assessment of LCA is only done on first hand to get an easy overview/idea of the impacts of the different building.

Further, several of the buildings have different kinds of claddings, like the high rises which have both brown bricks and concrete as cladding. In cases like these, it is assumed that the supporting structure is as registered in the main fraction of cladding. An example could be that in the high rise of building 1, it is estimated that 47% of the façade is cladded with concrete, 37% are windows and 17 % is cladded with brown bricks. Therefore, the supporting structure is registered as reinforced concrete.

#### 3.2.13.1.3. ROOFS

As seen in Appendix B, on the tab ‘Construction types’, the roofs are estimated/assumed into three main types of roof structures: bitumen roofing of building 10, bitumen roofing on the concrete building and clay tiled roofs of the brick building.

These types of roof structures are applied to respectively all the buildings with bitumen roofs and all the building with tiles. However, the concrete deck of building 10 is only assumed used in building 10.

#### 3.2.13.1.4. DECKS

As seen in Appendix B, on the tab ‘Construction types’, the decks are estimated into 3 types; concrete deck of building 10, a 2-part concrete structure of the concrete building and a wooden deck as in the masonry building.

The concrete deck of building 10 is only assumed used in building 10, hence that 2-parted deck as read in the drawing of building 1 and 40 are assumed in all buildings which are not masonry buildings. The deck is assumed 2-parted due to a drawing showing both:

- a deck construction build of concrete and cellular concrete
- a deck build as a Roma-deck.

From this it was estimated that each of the constructions types were 50% of the total deck construction in coherent buildings.

The deck in the masonry buildings are shown as wooden flooring, with insulation and supporting steel beams. The drawings show I-profiled beams throughout the deck structures, and as the buildings are rather 'old' it is assumed that timber I-profiled beams were not used at that time, hence the beams are assumed to be steel beams.

#### 3.2.13.1.5. WINDOWS

All of the buildings have windows, only varying in how large a fraction of the façade contains of windows. As told by the facility management of OUH, the masonry building had all their windows changed recently, therefore these are assumed to be 3-layered windows.

As the concrete buildings are not as old as the masonry buildings, but have not had their windows changed either, it is assumed that the windows consists of 2-layered glass windows.

Finally, the areas of the façade, which are covered by blue glass, are assumed to contain only one layer of glass, but with a main supporting structure behind.

#### 3.2.13.1.6. FACADE FRACTIONS

As already mentioned shortly, estimates of the façade claddings were made. By using the registration, an estimation of the fractions of the façade are made, which is used to conclude how much of the total façade area consists of e.g. windows.

In Appendix B, on the tab 'Fractions of the material needed', the estimated fractions of all claddings (both walls/facades and roofs) are written.

When having found the fractions of cladding and knowing how the constructions are build up, these two values are multiplied with the area (respectively total façade or roof/floor area) found by using a digital model in Rhino.

### 3.2.13.2. INVENTORY

When knowing all the masses of the different materials used for all buildings, very simplified though, these are multiplied with the impact potentials found per kg (or per $m^3$ for wood) of the materials.

In appendix C the processes, which are chosen to represent the building materials, are shown.

### 3.2.13.3. IMPACT POTENTIALS

The impact potentials assessed in this project are as mentioned earlier 'embodied energy' - in the form of Energy (gross calorific value), measured in MJ, and Global warming, measured in kg-CO2-equivalents to air.

When considering looking at embodied energy, the thought is to evaluate the energy needed for production of the buildings materials (from raw-material to plant or site).

As one of the main focuses at the moment is global warming and CO2 emissions, the other impact evaluated is global warming impact potential. The life cycle impact assessment methodology used for this project is IMPACT 2002+. IMPACT is short for 'IMPact Assessment of Chemical Toxics'. [7]

The methodology delivers impact potentials divided into 14 midpoint, see FIGURE 19, categories (from GaBi[1] 15 midpoint outputs are given, as the midpoint category 'Human toxicity' is given as both 'Carcinogens' and 'Non-carcinogens'), combining a midpoint/damage approach in a practical implementation. These midpoint categories are used in this project, however if a further assessment of all impact potential categories were to be performed, the midpoint categories could further be summed up into 4 damage categories. [8] [9]

The impact categories from IMPACT 2002+ methodology are adapted from different other methodologies, among other[10]; Eco-Indicator 99[11] and CML 2002[7]. However, some impact categories are developed within IMPACT 2002+. For the comparative assessment of toxicities (both human and eco-) new methods have been produced. The new potential effect factors are now based on mean responses instead of conservative assumptions.

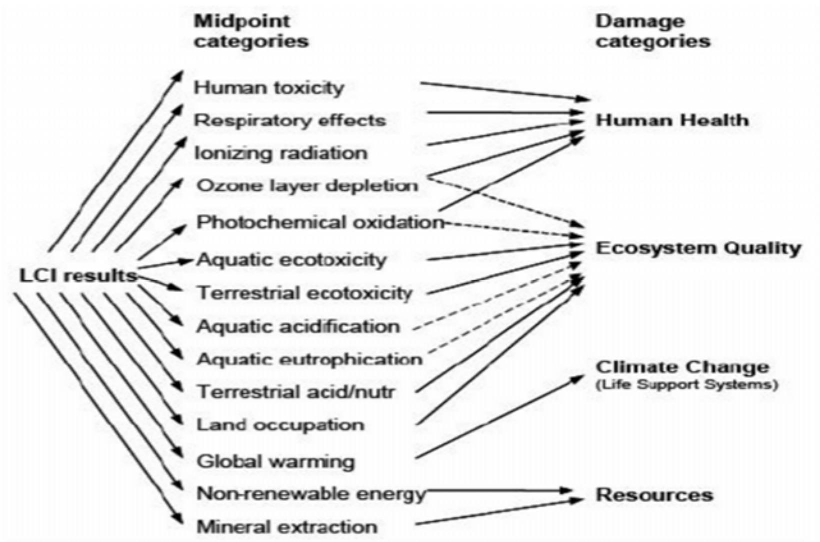


*FIGURE 19 – IMPACT CATEGORIES AS GIVEN BY LCA METHODOLOGY IMPACT2002+*

[1] GaBi is the software used to assess these processes

Even though this analysis/assessment is 'limited' to some of the easiest understandable and most common known impact potentials, it should be noted that a further investigation might contain further investigation of other impact potentials, as other impact potentials such as e.g. eco-toxicity of different types might have an important decision factor.

It is often assumed that, when looking at one material, a conclusion can be drawn whether or not a building is environmentally sustainable by just looking at the impact potential per kg material. However, this might give a wrong idea of the impact that the entire building has provided as the needed amount of one material might vary. Hence the impact potentials per kg or $m^3$ materials are not assessed further in this project, as these are only a middle step to find the impact potentials of all the buildings at the hospital site.

When looking into the impact categories shown in the mapping, listed as a total for each building in FIGURE 20 and FIGURE 21, it is seen that most of the buildings with highest impact are the high rise and concrete buildings. It is also seen that the buildings with large façade areas also have the biggest impacts because of larger amount of materials used for construction.

From FIGURE 20 and FIGURE 21 the conclusion to be drawn must be that the buildings with highest total impact should be the ones to preserve, as they have already impacted our environment significantly and hence, if they could be left standing and utilized a further impact from tearing down and building new could be avoided.

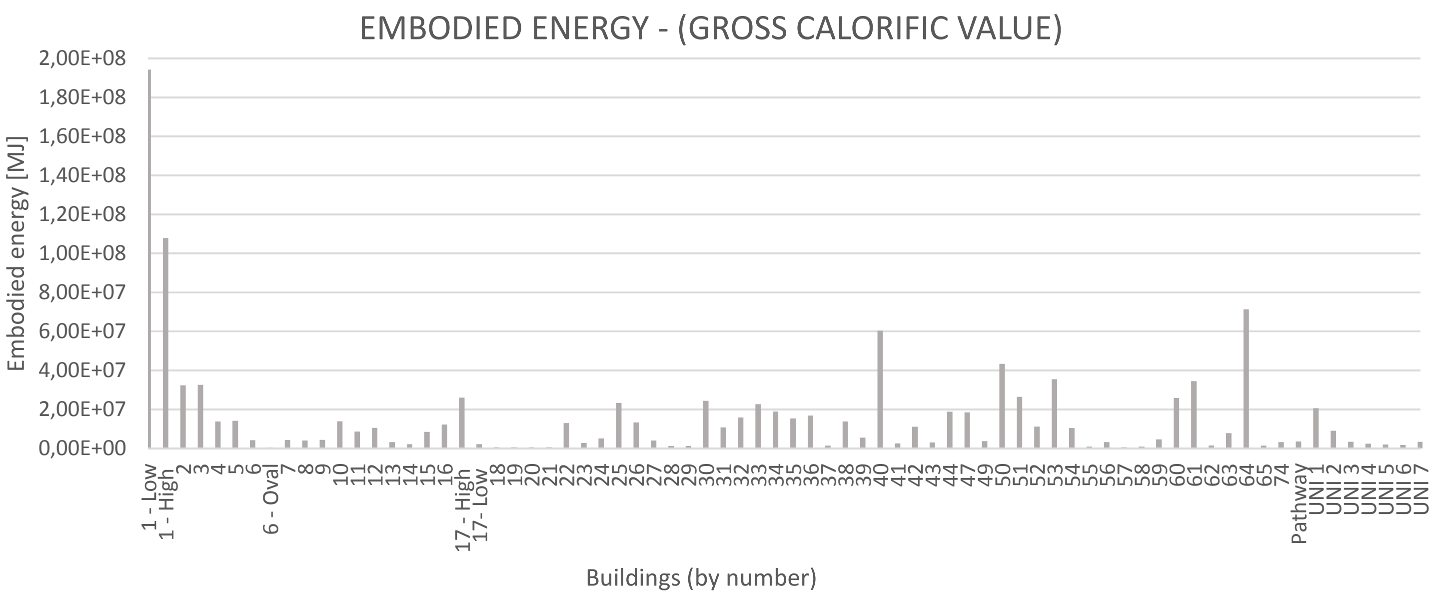


*FIGURE 20 – TOTAL EMBODIED ENERGY IMPACT FOR ALL BUILDINGS AT OUH*

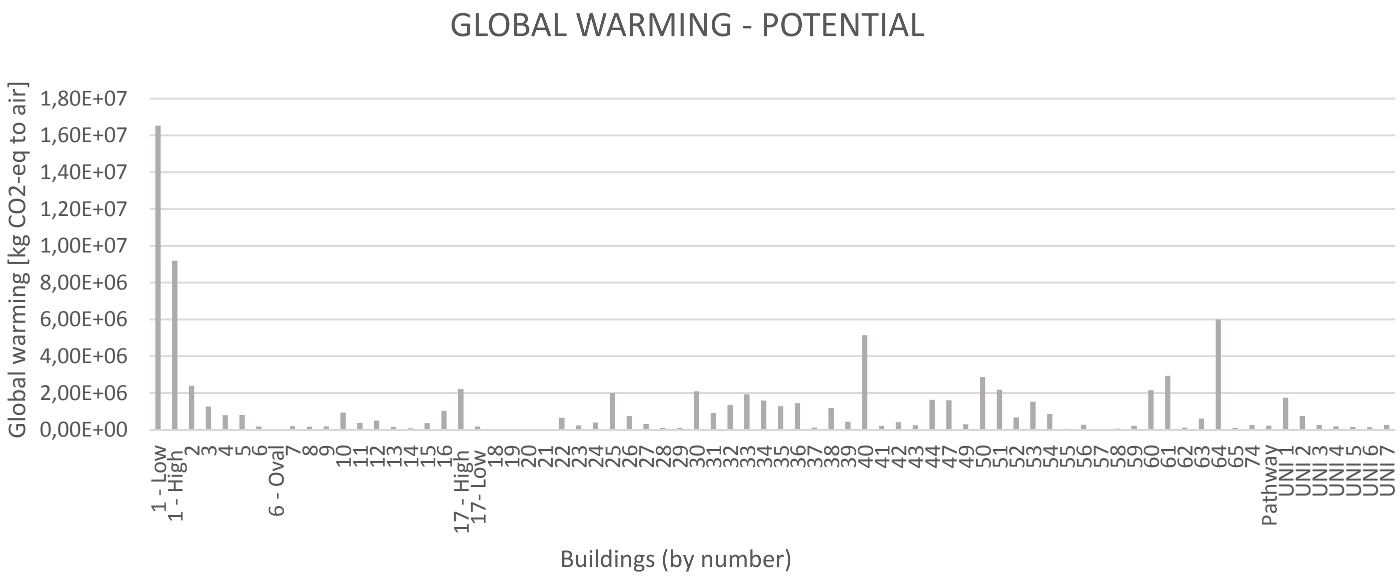


*FIGURE 21 – TOTAL GLOBAL WARMING POTENTIAL FOR ALL BUILDINGS AT OUH*

However, when looking at the impact potentials per square meter building, as shown in the mappings, FIGURE 22 and FIGURE 23, it is seen that the distribution of impact differs compared to FIGURE 20 and FIGURE 21. The reason that the impacts for the buildings, which are mapped, are shown per square meter is, that the building varies greatly in total floor area. A pattern shows in Appendix B – the "Area and Perimeter" tab, that buildings with large façade areas also have large floor areas.

By dividing the total impact with the total floor area, the impact is now changed to correspond and take into account the connection between facade area/amount of materials needed for construction and floor area. The buildings with high total impact have proven to also have a highly utilized floor area. From this, it is seen that when dividing the impact potentials of the building throughout the total floor area, the buildings which had the highest total impact are no longer the 'impact heaviest' buildings.

From the mappings of FIGURE 22 and FIGURE 23, the conclusion to be drawn is that the buildings with the lowest impact per square meter have been the most environmentally efficient and hence they. From this, and FIGURE 22 and FIRGURE 23, it shows that the buildings which should most likely be preserved, might be the ones with the highest impact per square meter as these impacts are not well utilized and would be a shame to waste/tear down.

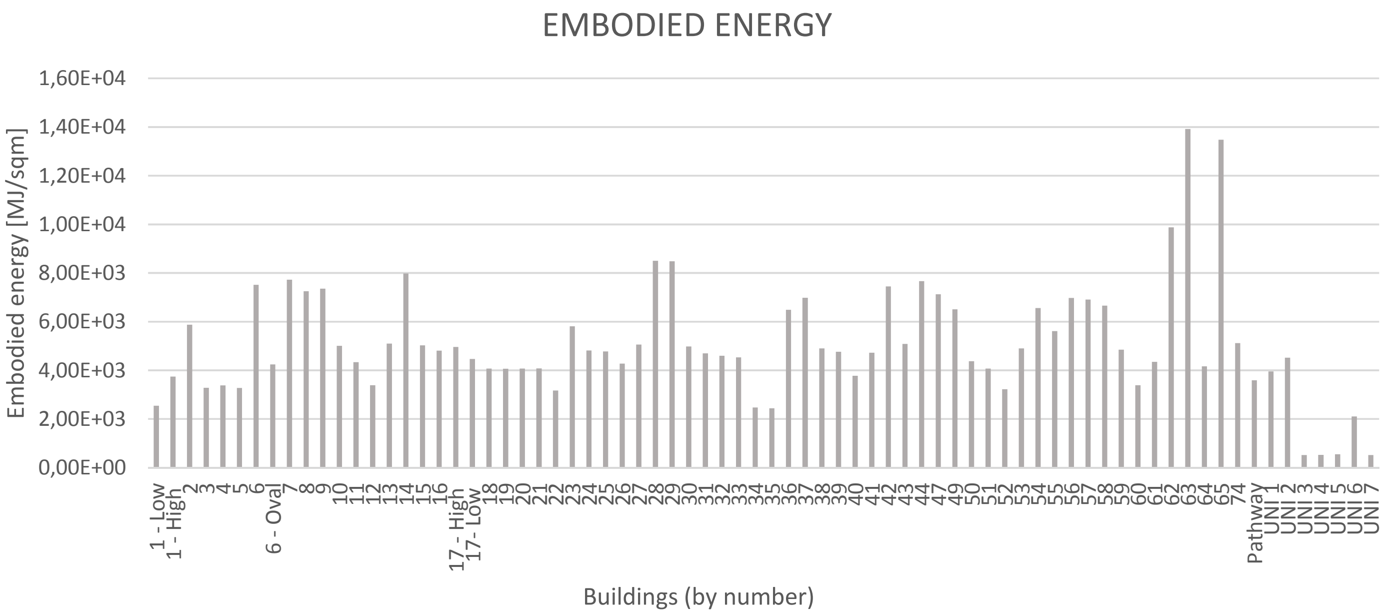


*FIGURE 22 – EMBODIED ENERGY PER SQUARE METER FOR ALL BUILDINGS AT OUH*

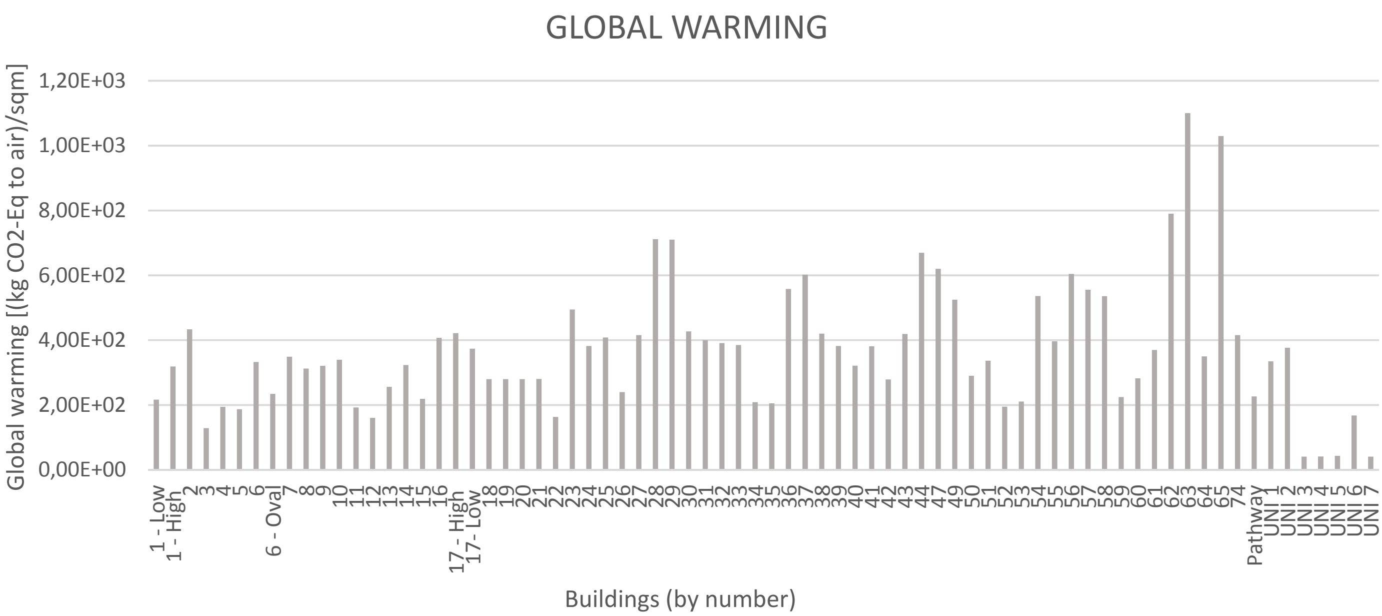


*FIGURE 23 – GLOBAL WARMING POTENTIAL PER SQUARE METER FOR ALL BUILDINGS AT OUH*

## 3.2.13.4. LCA MAPPINGS

### 3.2.13.4.1. EMBODIED ENERGY

The embodied energy of each building is mapped with the value per square meter floor area. The map in FIGURE 24 shows that the buildings with most embodied energy are some of the storage buildings.


*FIGURE 24 – MAPPING OF THE EMBODIED ENERGY PER SQUARE METER, IN MJ, OF ALL BUILDINGS AT OUH*

#### 3.2.13.4.2. GLOBAL WARMING

The global warming of each building is mapped with the value per square meter. This map, see FIGURE 25, shows similar tendencies as the one with embodied energy.


*FIGURE 25 – MAPPING OF THE GLOBAL WARMING POTENTIAL PER SQUARE METER, IN CO2-EQUIVALENTS TO AIR, OF ALL BUILDINGS AT OUH*

### 3.2.14. MCDM

To get an optimal solution of the analysis, a multiple-criteria decision-making (MCDM) has been made. For this, the TOPSIS method has been used. TOPSIS is short for Technique for Order of Preference by Similarity to Ideal Solution.

The theory of the TOPSIS tool is to evaluate how close a solution of the given problematic, is from the ideal solution [12] [13]. It is based on the assumption of having 'm' alternative solutions (buildings), and 'n' criteria (mappings). The mathematics behind the method is based on linear algebra.

### 3.2.14. 1. MCDM-METHOD

The exact calculations can be seen in Appendix D, and below the different steps of the method and mathematics are explained along with the name of the tab where the steps takes place in the appendix.

1) 'Input' tab - Defining the components.
   a) When having the alternative solutions (buildings) and the different criteria (mapping types), a matrix can be established, an m*n-matrix, where each component, $x_{ij}$, is a score dependent on the alternative/buildings, i, and the criteria/mappings, j. These scores are shown in the coherent mappings and explained earlier in the report.
      i) The criteria/mappings included in the MCDM are:
         (1) Architectural quality
         (2) Cultural quality
         (3) Environmental quality
         (4) Originality
         (5) Condition
         (6) Area
         (7) LCA - Embodied Energy
         (8) LCA - Global warming
         (9) Years left
   b) Then defining 'Y' as a set of beneficial attributes - the more, the better, and defining 'N' as a set of negative attributes - the less the better.

2) 'Normalization' tab - Normalization of the decision matrix (m*n-matrix)
   a) By doing this, the different criteria, which are valued differently, are aligned which allows comparison across all criteria, as their sizes are somewhat equal.
   b) Mathematically, this is done by $n_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}^2} \quad , i = 1, \ldots, m, \; j = 1, \ldots, n$

3) 'Weighting' tab - Weighting of the normalized components
   a) Defining a weighting, w[j], for all the different criteria put up and multiplying this weighting with each normalized $n_{ij}$ component from the m*n-matrix
   b) Mathematically, this is done by $v_{ij} = w_{ij} * n_{ij} \quad , i = 1, \ldots, m, \; j = 1, \ldots, n$

4) 'Ideal&NegativeIdeal solution' tab - Determining the ideal and negative ideal solution value.
   a) The ideal solution can be found by pointing out the maximum $v_{ij}$'s value of beneficial attributes, when using 'Y', and minimum value from the negative attributes, when using 'N'.
      i) Mathematically this is done by $A^+ = \{v_1{}^+, \ldots, v_n{}^+\} = \{(max_j(v_{ij}) | i \in Y), (min_j(v_{ij}) | i \in NJ)\}$. This gives the maximal distance $v_j{}^+$

b) The negative ideal solution can be found by pointing out the minimum $v_{ij}$'s value of beneficial attributes, when using 'Y', and maximum value from the negative attributes, when using 'N'.
   i) Mathematically this is done by $A^- = \{v_1^-, \ldots, v_n^-\} = \{(min_j(v_{ij})|i \in Y), (max_j(v_{ij})|i \in N)\}$. This gives the maximal distance $v_j^-$

5) 'Separation measures' tab - Determining the 'placements' of the alternatives/solutions.
   a) Distance from the ideal solution is found by $d^+{}_i = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j{}^+)^2} \quad , i = 1, \ldots, m,$
   b) Distance from the negative ideal solution is found by $d^-{}_i = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j{}^-)^2} \quad , i = 1, \ldots, m,$
   c) The square root of the summation is however done on the next tab, hence only the subtraction squared are on this exact tab.

6) 'RelativeCloseness to IdealSolut' tab - Determining the relative closeness for each solution (building) to the ideal solution.
   a) Mathematically it is done by: $R_i = \frac{d_i{}^-}{(d_i{}^+ + d_i{}^-)}, i = 1, \ldots, m.$
   b) As $d_i{}^- \geq 0$ and $d_i{}^+ \geq 0$, then the result must be within $R_i \in [0,1]$. Hence, the bigger R[i], the closer to the ideal solution.

### 3.2.14. 2. WEIGHTINGS

The weightings of the TOPSIS-analysis are given as seen in TABLE 2. The weighting from this project are set by the authors, trying to be as objective as best as one can.

*TABLE 2 – WEIGHTING AND EXPLANATIONS OF THE WEIGHTING FOR THE CRITERIA/MAPPINGS APPLIED IN MCDM*

| MAPPING (J) | WEIGHTING VALUE | EXPLANATION |
|---|---|---|
| ARCHITECTURAL QUALITY | 5 | As a part of the SAVE method, 'Architectural quality' often weighs high compared to most of the others. Further it is assumed of great importance that the area and houses are of great architectural and aesthetic quality to ease the appreciation of the area and buildings. |
| CULTURAL-HISTORICAL QUALITY | 5 | As a part of the SAVE method, 'cultural quality' often weighs high compared to most of the others. It is further assumed that the cultural quality and history of the buildings and area, are of importance to maintain some cultural heritages. |
| ENVIRONMENTAL QUALITY | 3 | As a part of the SAVE method, 'Environmental quality' is often weighted high along with the two above. However, it is found that the area of the hospital in general can seem messy without a smooth integration, hence the weighting was set down. |
| ORIGINALITY | 2 | As a part of the SAVE method, 'Originality' is often set lower than the above. As most of the buildings today need ongoing renovations, maintenance and 'improvement' to be able to 'live' longer, the originality might always be tampered a bit. |
| CONDITION | 3 | As a part of the SAVE method, 'Condition' is often set lower than the top ones. As most buildings which are on the edge of collapsing or are damaged in other crucial ways are changed immediately, the category is not assumed of great importance, however the appearance and condition have an influence on the further life time of the building, hence the middle weighting. |
| AREA | 1 | The area is weighted relatively low, as it is not seen as a decisive factor. Further the normalization/span of size is sizable in a way that they dominate the entire MCDM-analysis, without taking the others into consideration. The issue is also discussed further down in the discussion section. |
| EMBODIED ENERGY | 4 | As LCA's and impacts potentials are gaining a greater interest and scarce resources are a focus of various stakeholders, it is seen of importance to evaluate the existing building's primer impacts. |
| GLOBAL WARMING | 4 | As LCA's and impacts potentials are gaining a greater interest it is seen of importance to evaluate the existing building's primer impacts. |
| YEARS LEFT | 5 | The buildings in the area are all of different materials and build in different decades. It is assumed of importance when the buildings 'natural' end of lifetime is reached. |

### 3.2.14. 3. MCDM MAPPING

The mapping shows the buildings which according to these analyzes and weightings are short or far away from an ideal solution. This distance might help deciding which buildings are worth renovating and preserving as well as which buildings are not worth saving and should be demolished.


*FIGURE 26 – MAPPING OF THE RELATIVE CLOSENESS TO*

*THE IDEAL SOLUTIONS OF ALL BUILDING AT OUH*

The MCDM-analysis shown on the map in FIGURE 2 shows that the buildings closest to the ideal solution are building 2, 54, 63 and 65. Looking at our registration in Appendix A, it is seen that these building are a/the original masonry building (building 2), yellow masonry building (building 54), the freezer building (building 63) and a fiber cement cladded office building in between the university buildings (building 65).

Looking at the grading for the buildings they have scored differently in the different criteria. Building 2 has gotten a very good score in both architectural and cultural quality along with many years left of the material lifetime. Looking at building 54, the building scores relatively mediocre in most criteria, but has many years left of material lifetime as this is built of masonry. When looking at the scores for building 63 and 65 it is seen that their scores in both 'Embodied energy' and 'Global Warming' are significant and having mediocre scores in all other criteria. It may be concluded that the buildings have already impacted the environment a lot, hence it would be a waste of impacts/pollution to tear them down.

The buildings absolutely farthest away from the ideal solution are 18, 19, 20, 21, 34, 35, 39 and 41. Looking at our registration in Appendix A, it is seen that these building are all barracks, except 34 and 35 which are the laundry and pharmacy building. The placements of the barracks farthest away from the ideal solution may be explained by the barracks in general scoring badly in architectural and cultural quality, mediocre in the environmental impacts and are not assumed to have many years left of the material lifetime. The placement of building 34 and 35 might be explained by the general bad score in architectural and cultural quality along with a relatively low score in environmental impacts per square meters.

All the buildings in between the top and bottom are gradually, from the buildings farthest away from the ideal solution, getting closer to the ideal solution.

A diagram of the relative closeness to the ideal solution has been created with division between the different building types.

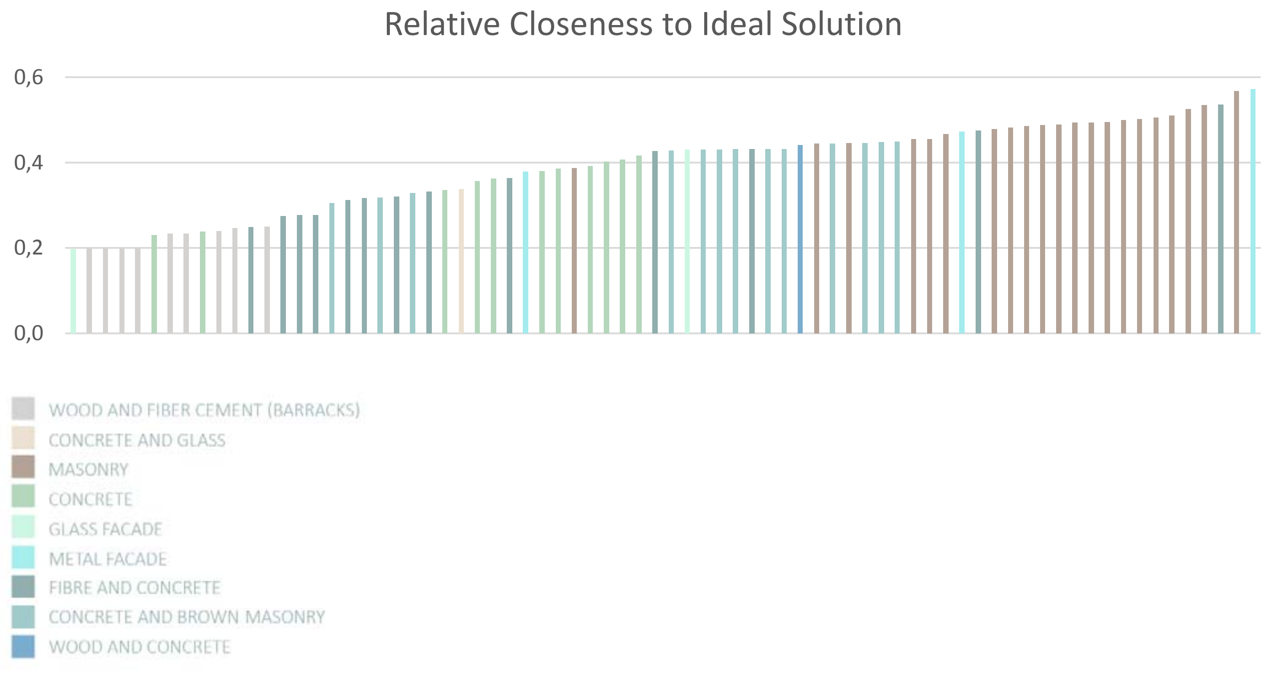


*FIGURE 27: RELATIVE CLOSENESS TO THE IDEAL SOLUTION FOR EACH BUILDING WITH COLOR DIVISION BETWEEN BUILDING TYPES*

As FIGURE 27 shows, most of the masonry buildings are mainly found closest to the ideal solution followed by the characteristic concrete buildings. Afterwards concrete followed by university buildings (fiber and concrete) and finally barracks.

# 4. DISCUSSION AND PERSPECTIVATION

An important factor is a numerical evaluation of qualities which are not exactly numerical. Qualities like architectural, cultural-historic, originality, environmental and condition are difficult to measure but have been quantified through the SAVE method which evaluates qualities with numbers on a scale from 1-9. This method is normally carried out by qualified people and has been interpreted by the group members in order to take into account these factors. They are all very important for an evaluation on preservation quality and have been given rather high weight in the joint evaluation through the TOPSIS system.

A parameter which has proven problematic in the TOPSIS analysis is the floor area. The floor areas between the buildings have a wide spread. The spread between one building of 76.000 $m^2$ and the rest which are between 80-10.000 $m^2$ has proven to have a significant impact on the results. As the floor areas are used directly in the TOPSIS analysis and the optimal solution is with high floor area, all buildings decrease excessively apart from the very big building (the bottom of building 1). The relative distance from the smaller buildings to the very big building is very large and will outrank all other criteria if the weight was chosen above one. This questions the TOPSIS approach, but could be solved by simply grading the buildings on a scale, for instance from 1-9, as in the SAVE method, and the large deviation will be accounted for in a different manner.

The weight of each criterion is important as it has direct influence on the results. In this multi-criteria analysis, the weight has been chosen by the students in an attempt to stay objective. Nevertheless, the weight obviously has been evaluated subjectively and could be completely different in other evaluations. This is an issue as it has great effect but where to find the correct answer. As said, the best solution has been attempted to find, but should be considered carefully were it to be applied in further development of the restoration.

The results presented in FIGURE 26 gives an indication of the ‘distance’ of each building towards an ‘ideal solution’. All buildings however, have ended on about 30-60% of the ideal solution. This quality of each building when taken all these criteria into account can be questioned, but when imagining the actual ideal solution this might be questioned. The ideal building to be kept in this case is a large building with heavy environmental impact. Also the building must comply with all the criteria of the SAVE method, including architectural value, originality and environmental. A building like this might be difficult to find on a hospital site which have been developed through more than a hundred years in the health faculty where standards and technology develops all the time. The analysis does however give an impression on the quality between different buildings and different building types where a pattern has surfaced. The old barracks in general lack quality and since they are small and in relatively light materials they are far from the ideal solutions. These barracks has fulfilled their purpose and time of use and will most likely be taken down no matter what. The buildings closest to the ideal solution are mainly masonry buildings, which are very well maintained, and the most charismatic concrete buildings, which all represent important times of the hospital developments, where big changes and expansions took place.

Is the method actually valid? Many criteria and aspects have been evaluated and more might be important as well. An evaluation on toxic materials might be of importance as some of the old buildings probably contain asbestos and PCB and these toxic materials are hazardous in any renovation case and should be considered with care. This aspect might have an impact on the results. Another important parameter could be the energy consumption of each building. Today the energy demand is rather strict and the level of transformation of each building needed to fulfill todays requirements might be of importance. A third aspect could be an evaluation on possibilities for renewal, in other words; can this building actually have a purpose after the hospital moves out. All the criteria evaluated earlier might not mean anything if no useful function can be applied to the building. This has also been mentioned by Carsten Rasmussen, Director of Development, in FREJA EJENDOMME (FREJA Estates)[14]. FREJA EJENDOMME will most likely be taking over the buildings and deciding what will happen afterwards, when OUH moves out of the area.

As there are many aspects to consider and to be included in the analysis, the results of the assessment should not be evaluated crucial and fulfilled, as there is a certain amount of uncertainties. E.g. it is rather subjective as only the opinions of three students have been taken into account. This does however not mean that the method cannot be useful, but in an actual case, more opinions and experts should be involved and consulted in the application of the SAVE-method for instance, and the results should always be evaluated individually afterwards in case some important factors were not included.

# 5. CONCLUSION

What is to happen to the existing hospital? What buildings will be demolished and what buildings might be given a new neighbor? This is difficult to answer but a starting point could be considering the results presented in this project. However regardless of the results presented in this project the site probably should be transformed into a more open area, which will be well integrated in the surrounding city. The site has a possibility for being a central part of the city due to location and its history as it has been a central part of the history and development of Odense for many years [15].

The buildings closest to the ideal solutions of the evaluation carried out in this project are the masonry buildings and the charismatic concrete buildings, which style is repeated throughout large parts of the site. These buildings are relatively large and have high architectural and cultural quality and are in good condition.

These results were found through the quantitative multi-criteria decision analysis. This method, through a TOPSIS approach, proved an interesting and useful tool. A number of factors in the method can have great impact including the weight and the spread between buildings of each criterion and therefore should be handled with care. The method is good for getting an overview and a comparison between the buildings but should not be crucial as some unknown aspects might be of great importance. Environmental impacts have become an important factor in the building industry and this method gives a chance for evaluating this aspect together with qualities that are not exactly quantitative like cultural quality.

The existing hospital has been an important part of the city Odense throughout a long period. It represents changes in building traditions and periods of the hospital history which have been essential for what the hospital is today. Today it is known to all the citizens of the surrounding areas. By keeping some of the important buildings it will continue to remind everyone of the city history, of which it has had a great impact.

# 6. LIST OF FIGURES



# 7. LIST OF TABLES

# 8. LIST OF APPENDICES

- Appendix A – Registration of OUH
- Appendix B – LCA Calculations
- Appendix C – LCA Inventory
- Appendix D – MCDM_TOPSIS

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