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REUSE OF EXISTING STEEL STRUCTURES. A ROMANIAN CASE STUDY

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Study Program: **SUSCOS_M**

Academic year: **2016 / 2017**

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ACKNOWLEDGMENTS

This thesis was finished in The European Erasmus Mundus Master Program SUSCOS (2015-2017) with the Department of Steel Structures and Structural Mechanics (CMMC), from Politehnica University Timisoara Romania.

My sincere thanks to Professor Dan DUBINA, Professor Luís Simões da Silva, and Professor František WALD as coordinators of our SUSCOS_M (2015-2017) for organizing the master degree in Coimbra, Prague and Timisoara.

This dissertation work would not have been possible without the support of many people. I really appreciate my supervisor, Professor Daniel-Viorel UNGUREANU, and Professor Adrian CIUTINA, for constant guidance, encouragement and support throughout research work. During the research activity, Professor Daniel-Viorel UNGUREANU showed me lots of materials and taught me patiently about professional knowledge related to my thesis for improving my research skill. Professor Adrian CIUTINA takes care of me all the time and gave me constructive comments for my thesis.

Thanks also to all the academic staff of the Department, especially to Professor Florea DINU, Ioan BOTH, Daniel Luis NUNES, and Andra Floricel for collaboration and helping my work all the time.

Specially thank to my colleagues Pierre Darry VERSAILLOT and Ghazanfar Ali ANWAR and Eliana Inca CABRERA in Naples for supporting me and accompanying me for the whole period of study program.

Moreover, I would like to thank to my parents, my uncle and my friends, Li ZHAO and Yalan LI in China for supporting me.

Finally, I would like to acknowledge the European Union, for giving me the opportunities and scholarship to finish my master degree and making nice friends. I would like to express my apologies that I could not mention each one personally, who was involved in the successful elaboration of this thesis.

ABSTRACT

In recent years, about waste and consumption of resource due to construction every year have been identified key issue. Even though now we already developed some high technologies during the construction to relieve this situation, there still be large waste and consumption of resource happening leading to environment damage. So development of the reuse building is so important, because reused building can decrease the waste and consumption at the same time.

This paper focuses on the steel reuse structure research based on a real case in Romania. Aims to study the case both in **structure analysis** and **sustainable analysis**. It consists of two parts, previous building built in 2004, Craiova and new building in 2012, Bucharest. The new building had been designed with the idea of partially employing elements recovered from the old building which is no longer used.

The **structure analysis includes two parts**. First is structure analysis, just studying the **difference about the design code between the previous project and new project** due to the fabrication happened in different time and different places. Second is **structure verification focuses on the new project in different Model A and B based on Eurocode**. Model A is designed by reused purpose, it means the elements of the new building will be as much as possible reused from the old building. But in Model B, the new building will be designed under the standard process. That means do not need to consider about the reused members, any member can be made from the steel making factory.

The **sustainable analysis concentrated on the Model A and Model B**, to analyse and compare the two design processes about the material saving, economic and environmental concerns.

As a general conclusion based on the current study, reused design obviously is better because the steel production will produce less waste and impact to environment.

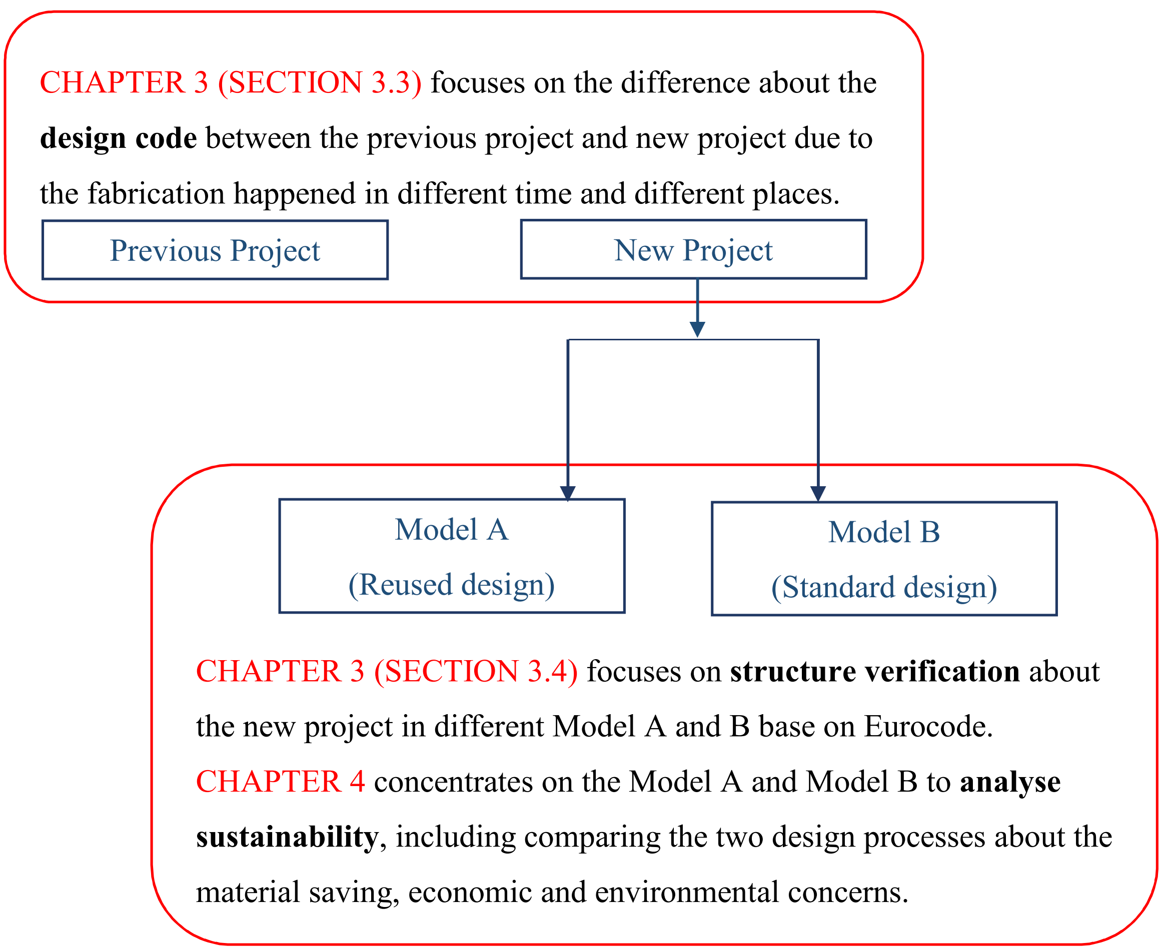
ORGANIZATION OF PRESENT THESIS

CHAPTER 1 presents the general introduction and literature review about the reused building, sustainable construction, steel structure and sustainable design.

CHAPTER 2 shows the information about the case study.

CHAPTER 3 illustrates the structure analysis and verification.

CHAPTER 4 illustrates the sustainability analysis.



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1. INTRODUCTION AND LITERATURE REVIEW

1.1 Overview

Construction is the largest industrial sector in Europe (10-11% of GDP) and in the United States (12%); in developing world it represents 2-3% of GDP. (UNEP Industry and Environment, 2003)

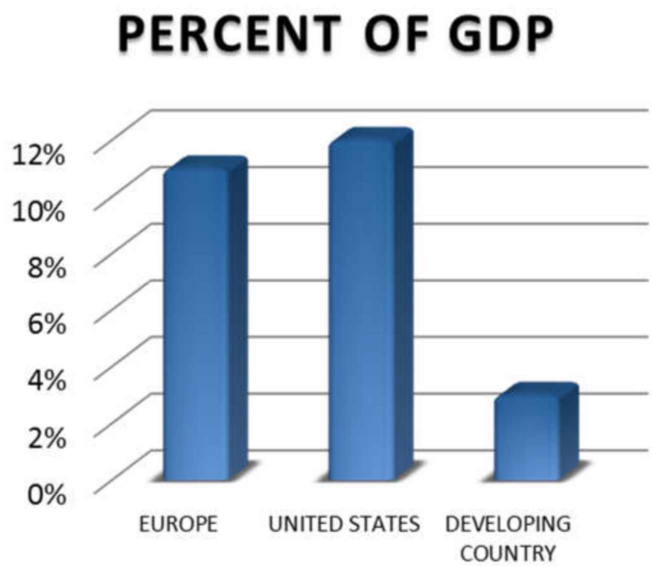


Figure 1.1 Percentage of GDP in world

The waste and consumption of resource due to construction every year have been identified key issues now that we must address so that protect our next generation.

Construction activities can produce a large amount of CO2, even though now there are so many advanced technologies about construction to reduce the greenhouse gas emissions. For example, improving the advanced technologies about the construction, like CO2 Capture Technology, lightweight concrete and cold-form materials. But because these technologies have certainly limitation to some extents, it cannot solve the problem in wide range. Then taking other aspect into consideration, it is solving problems at their source. That means better to decrease the construction activities, or prolong the lifespan of building. However, there still be a lot of countries whose building's life is rather short, not only in the developing countries, but also some high-risk natural disaster country. Short-lived structure will make so much waste and impact to the environment greatly. There is a survey about the production of waste from building conducted by the University of Cambridge (Cooper & Allwood, 2012)and the University of Toronto (Gorgolewski & Straka, 2006). So **development of the reuse building is so important, because reused building is another way to prolong the lifespan of the building.** At least for primary elements of the building. From several studies, the larger materials be reused, the more environment-friendly. It showed that a perfect design about reused steel can save 30% in energy and CO2 reduction with respect to new building.

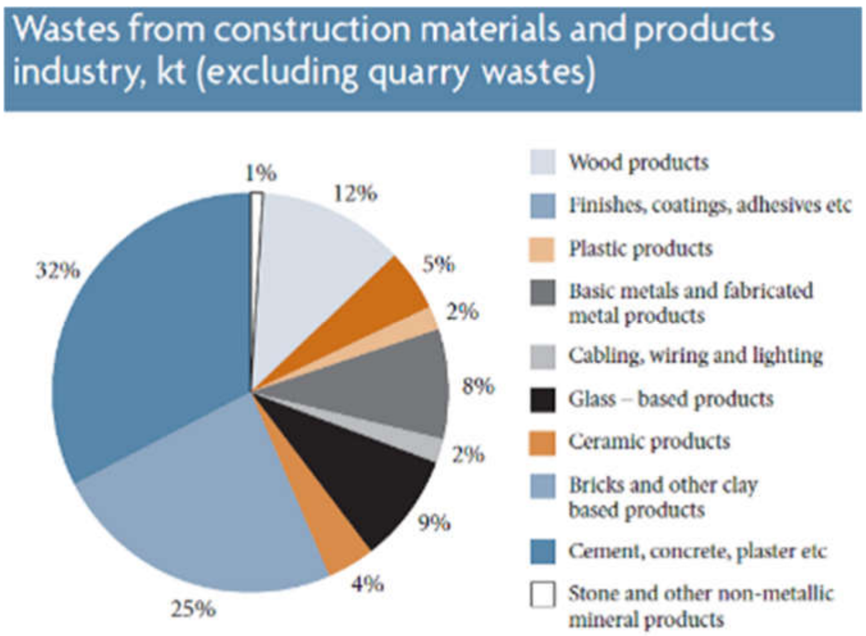


Figure 1.2 Waste from Construction materials and products industry(http://equella.nottingham.ac.uk/uon/file/1c4d7433-74db-9779-b605-7681374bc79a/1/Eng_sustainability.zip/Engineering%20Sustailability/63_construction_waste.html)

The following **literature review** will demonstrate the background information about the reused building and steel sustainable design in structure and analysis method of LCA of building.

1.2 The importance of reusing building

In past, it is difficult to put the reusing building into practice, because most of construction materials are rock, brick and concrete and their production was slow and expensive. further reason is that with the mass production of building and with the high safety, quality requirements, like satisfy all the current standards, sometimes it is even impossible to make a building reusing. But the need for innovation in building materials recovery is more important for the contractors in building industry. So in recent years, the research of the reusing building is international strategies, especially in construction sector.

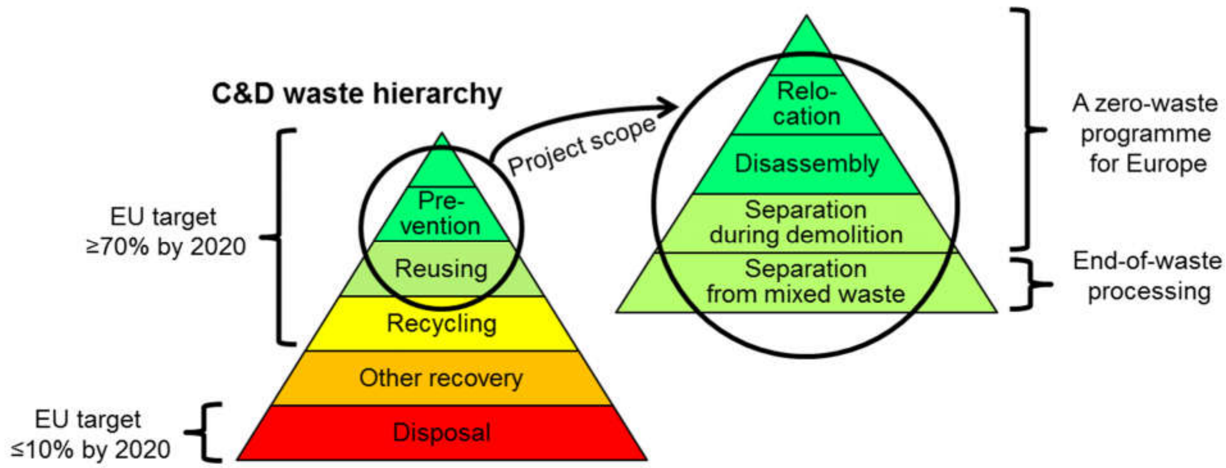


Figure 1.3 Project scope in the terms of waste prevention and material recovery

Nowadays, it has already achieved the goal about reusing building, most of them are existing building, which can lessen the demolition waste and at the same time decrease the fabrication about new building, sometimes the only work is just renovate and refurbish the building. in addition, reusing the existing building can preserve the culture and historic value of older building.

Global indicators

Necessity to cover eight major areas:

1. Reduce the number of different materials and choosing the most appropriate materials;
2. Reduce the environmental impact of the production phase;
3. Optimize the use phase;
4. Reduce the environmental impact of the use phase;
5. Extend the useful lifespan of the product;
6. Simplify the disassembly of the product;
7. Product design for reuse and reuse;
8. Product design for recycling.

Indicators allowing to take into account these areas:

1. Reusable parts
2. Recyclable materials

3. Reversible joints
4. Tools for disassembling
5. Time for disassembling

About existing building, it includes **reused in-situ or dismantled and re-erected at a different location**.

1. **In-situ reuse**

   It means the reused building locating the original place. For many buildings, they always have failure or deterioration of the envelop instead of structure as time goes on. This can be aesthetic deterioration, changing fashion, and sometimes it still need to update the envelop to modern standards and fulfil the thermal and acoustic performance. for example, the redevelopment of Kinnaird House which achieved an excellent BREEAM rating.(The free encyclopaedia for UK steel construction information, 2016)

Figure 1.4 Retained façade of Kinnaird House (The free encyclopaedia for UK steel construction information, 2016)

Figure 1.5 Slim-floor behind the retained façade (The free encyclopaedia for UK steel construction information, 2016)

2. **Reuse at a new location**

   It means the reusing building will be erected again but in a new location. The main structure elements will be transported to new place and reused again. Here the example is steel car park in Munich, Germany. It was dismantled and re-erected at a new location.

Figure 1.6 Dismantled and relocated steel car park, Munich (The free encyclopaedia for UK steel construction information, 2016)

Another example is a warehouse which was dismantled and re-built elsewhere on Slough Trading Estate to make way for the new Leigh Road bridge. (http://www.segro.com/media/press-releases/2016/20-01-2016) The building was demolished and materials reused in line with SEGRO's sustainability targets, making it one of SEGRO's greenest buildings. It took just 11 months to dismantled and rebuilt.

Figure 1.7 Reusing warehouse on Slough Trading Estate

1.3 The Contribution of Steel to Sustainable Design

Steel is infinitely recyclable and its by-products and waste energies are valuable resources. (Association, 2013). In the Life Cycle thinking, steel is manufactured from raw materials, use, sometimes reuse and remanufactured, then to recycling.

Figure 1.8 (Association, 2013)

Regard to the favour of steel construction, after interviews, website visits and survey by European Commission. There are almost twenty arguments sorted out.

1. Recycling
2. Durability
3. Strength to weight ratio
4. Embodied energy, embodied carbon
5. Material efficiency
6. Water recycling rate
7. Suitability to several applications
8. Long-spans
9. Reducing operational energy, energy-efficiency
10. Indoor air quality
11. Extended service life
12. Rapid erection
13. Reducing co2 emissions
14. Deconstruction, dismantling
15. Off-site manufacture
16. Input to the building stock
17. Input to energy technologies

18. Input to transport technologies
19. Input to economies

The most important arguments are about environmental impacts of steel production and steel construction, like recyclability, reusability, resource-efficiency. **The critical issue is the carbon footprint of the steel production**. (Heli Koukkari Ewa Zukowska et al. 2013) So, about the sustainable design. The steel was considered as a great potential structural material. Of course, there still be some drawbacks about the steel. it can be solved by combining with other materials to overcome the possible weaknesses of steel products.

1.3.1 Steel Recycling

Recycling is the method about reducing the consumption of fresh raw materials by converting useless materials into reusable items. Further reducing the energy usage and greenhouse gas emissions. Sometimes, it will abate the water pollution and relieve the pressure of landfilling.

Steel is a material which has unique capacity of without loss of properties or performance when it is melt. That means however many times changes the shape of steel, it will be same property.

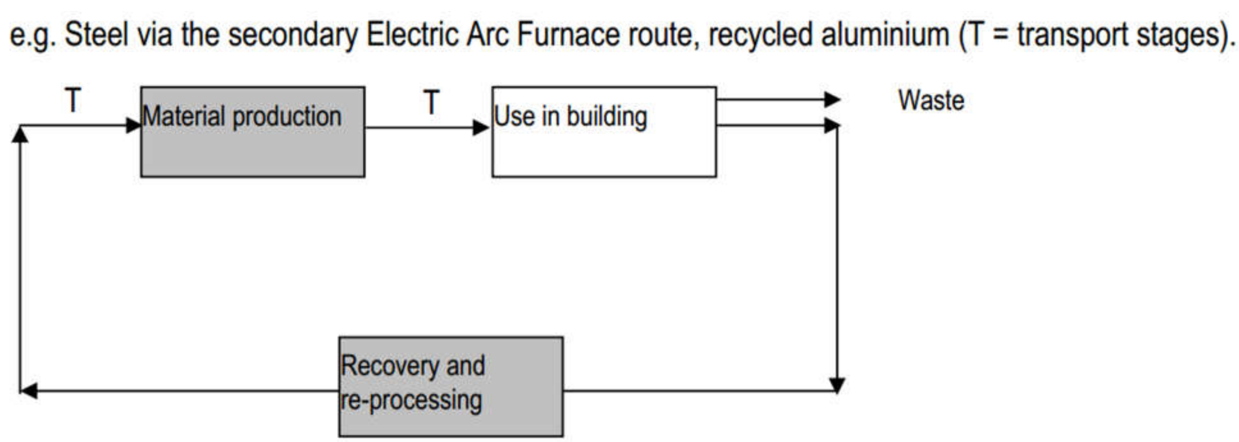


Figure 1.9 (Edmonds, Mackinnon, Humphries, Straka, & Edmonds, 2006)

About the steel structure in the modern world, due to its widespread use, it is necessary to consider the influence to the environment or society. For instance, about the manufacture industry, the average household appliance contains about 65% steel (Ferrous Processing Trading, 2012). In order to produce steel, it needs to melt the iron ore which is mined from the ground in furnaces where remove the impurities and add the carbon. In this process, there is much CO2 generated. However, recycled steel is just melt or sometimes mixed with iron, then pour into new moulds. It will more save energy and reduce the gas emission. Moreover, the key point is about steel scrap, it can be sourced from different components, construction, manufacture industry or household. Anyway, recycled steel already plays the important part in sustainable design worldwide.

1.3.2 Steel Reuse and Remanufacturing

Reuse and remanufacturing are the two fields of sustainable design. Different from recycling, it focuses on transferring some disused or unavailable items to be useful without melting, and the melting process will cause substantial CO2 emission. So, reusing and remanufacturing will cause less environmental burden to some extent.

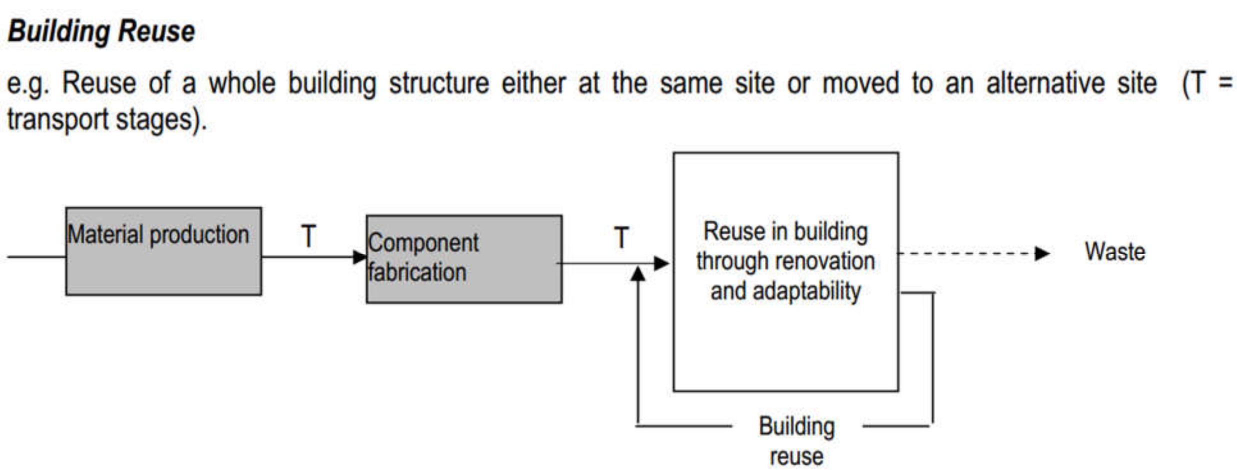


Figure 1.10 (Edmonds et al., 2006)

Compare to concrete and brick. Steel is easy to install and dismantle. Concrete is one-time material. If it is broken, the capacity of resistance will decline, even lost. Brick need to be glued by mortar or other civil adhesive, it is difficult to unglue every brick. It will take so much work force. On the contrary, connection of steel is just bolt and weld. Bolt can be dismantled anytime without damage the useful part. Even the weld connection, because of it is still the same property, it can be recycled by melting at the final steps.

1.3.3 The advantage of steel construction

The use of steel framing in housing and residential buildings is a recognized growth area. The advantages of steel framing include speed of on-site construction, achieved by pre-fabrication of the wall panels and easy assembly on site. This creates a dry working environment for following trades, allowing the brickwork cladding and roof tiling to follow off the critical path.

About the favour of light-steel framing house, it will be shown below:

1. **Build ability**: lessens on field works, decreases material wastage and enhances the quality of the structure.
2. **Speed**: takes less construction time with comparison to bricks or concrete blocks construction.
3. **Strong but Lightweight**: possess high strength to weight ratio than any other material. easily handled and moved from one place to another.
4. **Safety**: possess huge safety for inhabitants. Fire resistant and non-combustible. Cold-formed steel buildings perform better during natural disasters.
5. **Easy to Remodel:** easily attained, especially for partition walls can be easily shuffled, detached or even changed.
6. **Consistent Material Costs**: price fluctuations are minimum. Reduced construction duration, labour costs, scrap and construction waste

These properties are all aspects of durability and maintenance-free construction. Particularly important to the owner and builder is the reduced number of call backs. Therefore, this solution represents a sustainable technology of high performance and qualitative technology both for fabrication and erection.

1.4 Current situation about sustainable construction

Nowadays, the potential impacts related to construction industry demands, need and drivers got much attention over the world, but the impacts are different from one country to another, developed and developing countries.

Requirement of the construction is divided fairly equally between the private and public sectors. In the developed countries, it relates mainly to housing, roads and non-residential fixed investment. While in developing world it relates mainly to new infrastructure and housing. Like schools, hospitals and roads.

Developed countries could devote greater attention to creating more sustainable assets through upgrading existing facilities using innovative technologies for energy and material saving. While about developing countries, they are still under construction. They have a low degree of industrialization, so that construction activities will affect much more environment issues. (Development, Force, & Boswell, 2003)

About the measures addressing environment issues and policies promoting sustainable practices, every country faces different barriers, both developing country and developed, promising steps are being taken, but to deal with consequences such as the rebound effect will require strong supranational efforts. (Rovers, 2003).

1.4.1 Sustainable construction development in world

From the paper *the role of policies in promoting sustainable practices,*(Rovers, 2003), it got the comprehensive survey of situation about sustainable construction development. It will show below.

In Europe, one of the main barriers to sustainable building and construction is that the building and construction sector is not recognized as a responsibility to be shared by different countries. At EU level, for example, there is no mandate to develop common policies on construction or housing. The Plan of Implementation adopted at the 2002 Earth Summit in Johannesburg does commit governments to use low-cost and sustainable materials and appropriate technologies for the construction of adequate and secure housing." While many countries in Europe have not reached this stage yet, the European Council has taken a major step towards doing it for them. In the communication issued following the Council's Gothenburg summit in 2001, European leaders strongly endorsed sustainable development. They declared, among other things, that relationship between economic growth, consumption of natural resources and the generation of waste must change. Strong economic performance must go hand in hand with sustainable use of natural resources and levels of waste, maintaining bio- diversity, preserving ecosystems and avoiding desertification."

Countries in transition face special problems, especially those that will join the European Union. They will have to adopt EU standards for building and construction, a move that will mean significant progress in many areas. But these standards are not yet in place for all aspects of sustainable building and construction, and they are not sufficiently stringent in some areas. The building and construction sector in the accession countries will need to adapt to EU legislation even as they learn to cope with open borders and free trade.

In developing countries, lack of planning (especially in fast-growing countries) inability to keep up with the speed of growth is one the most pressing problems at regional and municipal level. In developing countries where traditional, often more sustainable construction materials and methods persist, it is rapidly becoming difficult to take advantage of them owing to the rate at which local building material industries are disappearing. People and industries act within the boundaries set by policy and economics, which in much of the world do not favour sustainable options. Some political awareness of such options exists here and there, but development of this awareness is often impeded by unpredictable political situations and/or corruption at many levels, with officials unlikely to be interested in better legislation. On the positive side, the cultures of many developing countries still preserve their tradition always if only in people's memories. Where their cultural values stress balanced use of natural resources, such countries may have a head start towards adoption of sustainable approaches. It is essential to include this element in new policies and approaches, just as it is essential to find ways to include the informal sector. In each case this is conditional on getting government officials and political leaders involved.

Developed nations export their technology and skills and in turn the developing nations are highly desirous of the functionality of construction that the developed country can offer. The problem is the technology and skill often intended to improve quality of life, has not led directly or indirectly to an increase in energy consumption. Indeed, some innovations intended to reduce energy consumption have had the opposite effect. So we need to find the best-fit technologies.

Here below will show the benefits and shortcoming of energy saving technologies for developing countries.

Technology	Characteristics	Functionality	Degree of fit-and-forget (reliability)	Buildability	Maintenance requirement	Overall suitability for developing countries	Intelligence: 1 star = stupid, 5 stars = smart
Natural ventilation	Uses natural pressure differences to ventilate internal spaces	High for simple buildings, but pollution/daylight conflicts need to be managed	High, but vents, cowls and windows are not fit-and-forget	Very good, no need for services plant	Low, but vents, windows and any automated actuators need maintenance	High, but dusty air in hot climates cannot be easily filtered	*****
Mechanical ventilation	Uses fan energy to control air flow into the building	Medium to high, needs fan power, but heat can be recovered	Medium, complex controls require good management	Good if kept simple	Medium, plant needs maintaining and a supply of filters is needed	High where a system can be used for active thermal storage and powered by renewable energy	***
Mixed mode ventilation	Uses a combination of fans and windows as needed, for ventilation	Medium to high, offers flexibility between natural and mechanical ventilation	Medium, needs careful attention to controls	Good if kept simple	Medium, plant needs maintaining and a supply of filters is needed	High where a system can be used for active thermal storage and powered by renewable energy	****
Rainwater recovery	Recovery of rainwater for drinking or flushing	High, but dependent on rates of rainfall	Medium	Good (simple and component-based)	Low for flushing, high for drinking	Medium to good, depending on rainfall	****
Greywater recovery	Recovery and storage of washing water for flushing purposes	High, for areas with low rainfall or with unreliable supplies of drinking water	Low	Reasonable (component-based)	High (for monitoring, filters, and disinfectant)	Low to medium, depending on the severity of context	**
Composting toilets	An alternative to the flush toilet where effluent is stored and composted	High, for areas without a sewerage system	High	Good (few moving parts, self-assembly)	Low and easy	Very good, for systems not reliant on an electrical supply to heat the compost	****
Passive thermal storage	Exposed building structure that controls solar gains and stores heating and cooling energy	High, climate dependent	High	Good, but may be dependent on materials availability	Low	High	*****
Active thermal storage	Mechanical or semi-mechanical system to control rates of energy storage and discharge	Medium, may need energy for fans and controls; climate dependent	Medium, can fail to perform without good control	Good, but requires fine tuning to deliver results	Low to high, depending on complexity	Good, but may be fragile without robust controls, needs facilities management ability	***
Ice stores	Maximizes off-peak refrigeration energy to charge an ice store for release of cooling energy during the day	Low , higher overall energy penalty	Very low, complex systems need constant management	Medium (component-based, but takes up much space)	High: chillers, pumps, pipework and ice vessels	Low, often fragile without skilled management, needs good controls and financial acumen	*
Ground-source heat pumps	Uses latent heat in the ground to power a heat pump in cooling or heating mode	Medium to high	Medium	Low to medium (component-based, but boreholes can be high cost)	Medium, heat pump and controls need maintaining; boreholes can silt up	Low to medium, closed circuit boreholes most reliable, open circuit may provide flushing/irrigation water	***

Figure 1.11 (Bsria, Bracknell, West, Rg, & Bunn, 2003)

1.4.2 Sustainable construction in Romania

In Romania, about the waste from construction and demolition in 2000 was nearly 27 million tonnes(Sarsby & Meggyes, 2001). The main reason is that most demolition waste is not separated and recycling, just landfill. 20 years ago, only some basic elements, such as windows, frames, doors, heating radiators, water pipes have been recovered from demolished building. It is not only in Romania, all over the world, the construction waste is the big problem.

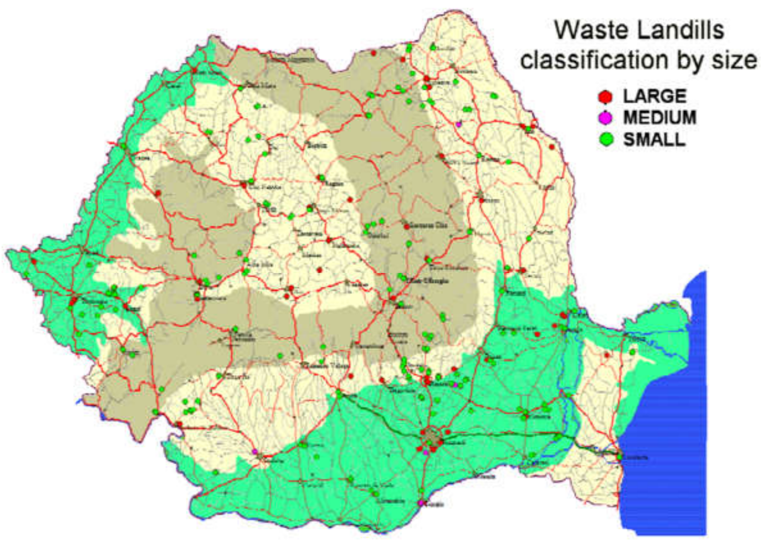


Figure 1.12 (Iacoboaea, Luca, Aldea, & Sercaianu, 2010)

Now in Romania, more and more activities about green construction and energy saving have been launched. The consortium of three universities (The Academy of Economic Studies, The Technical University of Civil Engineering and The University of Medical and Pharmaceutical Studies) and two research institutes (The Institute for Computers and The Institute of Prognosis) elaborated a research proposal that was supported by The Romanian National Research Authority. The research aims to establish database for material and equipment used in construction and demolition and present the solutions about how to storage and manage the waste.(Iacoboaea et al., 2010)

In 2012, there was a plan that build a reused industrial and office in Bucharest, from an almost dismantled structure in Craiova.

1.4.3 Green building assessment system

Currently, the contemporary high-performance sustainable building develops faster than before. There are almost 60 countries establishing their assessment systems. Each rating system provides detailed criteria and grading rules. In United State of America, the Leadership in Energy and Environmental Design (LEED) green building rating system was a success because over 1 million building have been registered for certification. LEED aims to improve environmental performance and economic returns from buildings.

There is another success building assessment system known as BREEAM (Building Research Establishment Environmental Assessment Method) in United Kingdom. It had about 200,000 navigated certificate process. Canada and Hong Kong subsequently adopted BREEAM as the platform for their national building assessment systems. (Charles J. Kibert, 2013)

In addition to this, there are CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) in Japan (2004) and Green Star in Australia (2006).

Nation	Label
Australia	Nabers / Green Star
Brazil	AQUA / LEED Brasil
Canada	LEED Canada / Green Globes / Built Green Canada
Czech Rep	SBToolCZ
China	GBAS
Finland	PromisE
France	HQE
Germany	DGNB / CEPHEUS
Hong Kong	HKBEAM
India	Indian Green Building Council (IGBC) / (GRIHA)
Indonesia	Green Building Council Indonesia (GBCI) / Greenship
Italy	LEED / Italy / Protocollo Itaca / GBCouncil Italia
Japan	CASBEE
Jordan	EDAMA
Malaysia	GBI Malaysia
Mexico	LEED Mexico
Netherlands	BREEAM Netherlands
New Zealand	Green Star NZ
Philippines	BERDE / Philippine Green Building Council
Portugal	Lider A
Taiwan	China Green Building Network
Singapore	Green Mark
South Africa	Green Star SA
South Korea	KGBC
Spain	VERDE
Switzerland	Minergie
United States	LEED / Living Building Challenge / Green Globes
UAE	Estidama
UK	BREEAM

Figure 1.13 (Charles J. Kibert, 2013)

1.5 Structure Analysis

The structure analysis in this thesis is based on the EN 1990 Eurocode 0: Basis of structural Design. The theory of stability of beams and columns, verification of buildings, principles and requirements for safety and serviceability in all circumstances, including the seismic events, reviewed from the Eurocode.

The structural Eurocode program comprises the following standards generally consisting of a number of parts:

- EN 1990 Eurocode 0: Basis of Structural Design
- EN 1991 Eurocode 1: Actions on structures
- EN 1992 Eurocode 2: Design of concrete structures
- EN 1993 Eurocode 3: Design of steel structures
- EN 1994 Eurocode 4: Design of composite steel and concrete structures
- EN 1995 Eurocode 5: Design of timber structures
- EN 1996 Eurocode 6: Design of masonry structures
- EN 1997 Eurocode 7: Geotechnical design
- EN 1998 Eurocode 8: Design of structures for earthquake resistance
- EN 1999 Eurocode 9: Design of aluminium structures.

Furthermore, the National Standards implementing Eurocodes will comprise the full text of the Eurocodes. The National annex contains information on those parameters which are left open in the Eurocode for national choice. For instance, the different spectra about seismic design may be defined in the National Annex.

In the case study, the building is located in Romania. The National Standards consist of a number of parts:

- COD DE PROIECTARE: SEISMICĂ P100: PARTEA I - P100-1/2006 PREVEDERI DE PROIECTARE PENTRU CLĂDIRI **(SEISMIC ACTION)**

• COD DE PROIECTARE: BAZELE PROIECTARII CONSTRUCTIILOR Indicativ CR 0 – 2012

(BASIC OF DESIGN)

• COD DE PROIECTARE: EVALUAREA ACŢIUNII ZĂPEZII ASUPRA CONSTRUCŢIILOR Indicativ CR 1-1-3/2012 **(SNOW)**

• COD DE PROIECTARE: EVALUAREA ACTIUNII VÂNTULUI ASUPRA CONSTRUCTIILOR Indicativ CR 1-1-4/2012 **(WIND)**

1.6 Life-Cycle-Assessment

Life-cycle-assessment is a method try to address the environmental aspects and problems by assessing the impacts through a product's life cycle from raw material acquisition to production, use, end-of-life treatment, recycling and final disposal. By integrating LCA into the building design process, design and construction professionals can evaluate the life cycle impacts of building materials, components and systems and choose combinations that reduce building's life cycle environmental impacts. (Reiter, 2010)

In this project, the analysis is included the material production, construction, end-of-life for the materials as well as a maintenance scenario for a life-time period of the house of 50 years.

Based on ISO 14040 and 14044-standards, there are four phases in a life-cycle-assessment.

a. The goal and scope definition phase
b. The inventory analysis phase
c. The impact assessment phase
d. The interpretation phase

1.6.1 Goal and scope definition phase

The scope, including the system boundary and level of detail, of an LCA depends on the subject and the intended use of the study. The depth and the breath of LCA can differ considerably depending on the goal of a particular LCA. (Iso 14040, 2006)

Impacts of macro-components

The first step about Life-cycle-assessment is defining the impact of product on the environment from cradle to grave. According to the CEN standards EN 15978:2011(CEN, 2011b) and EN 15804:2011 (CEN, 2011a), it is quantified to potential environmental impacts of macro-components. It will be shown below about the modules of life cycle.

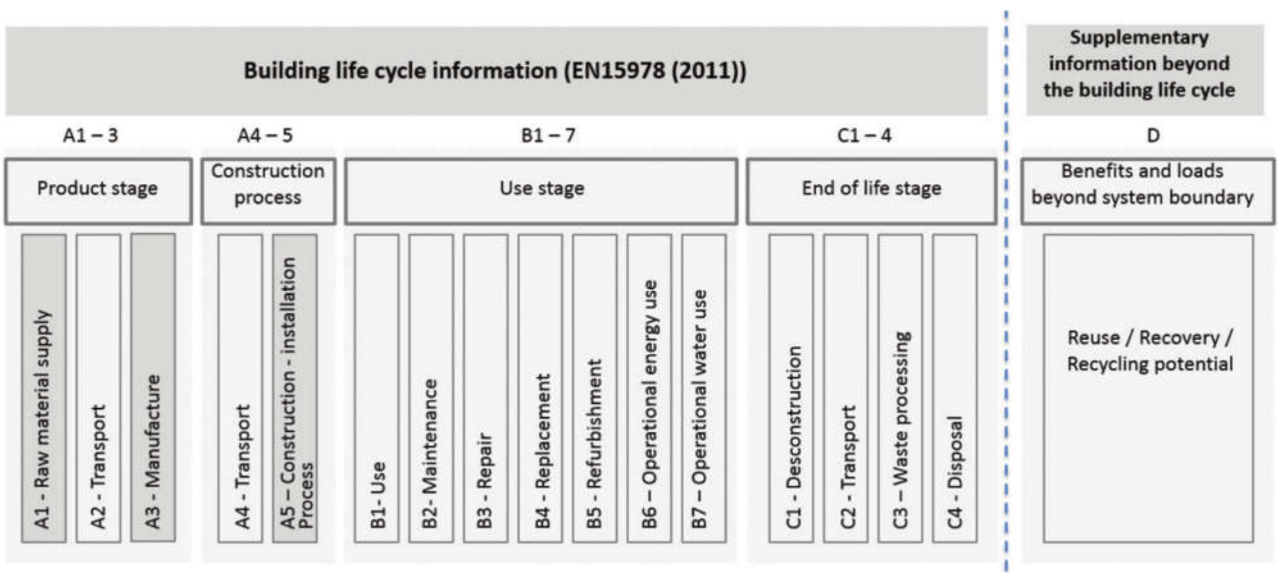


Figure 1.14 (Saade, Silva, & Silva, 2014)

The module A, B, C and D actually are four stages in building life cycle system. The product stage (module A1-A3), construction process stage (module A4-A5), Use stage (module B1-B7) and End of life stage (module C1-C4). Here note that module D is an expansion and sometimes could be outside of the life cycle of the building, because currently the products does not fulfil requirements in present state. It only can be used when steel reaches to the functional equivalency of the substituted primary material. According to EN 15978, after module C, the end of life stage of building, *all outputs from dismantling, deconstruction or demolition processes* *are first considered to be waste. This output reaches the end of waste status when it complies positive economic value or elements fulfils the technical requirements for the specific purposes and meets existing legislation and standards applicable to the product.* **This 'waste' here in the end of life stage seemed as resources such as sustainable materials managements instead of a real waste.** Here it should be considered the reused structure, so module D which is an optional module will be taken into account**.**

The degree of reusability (so called reuse potential indicator) defined in WP1 is developed further by UPT to aid management decision-making about waste based not on perception but more objectively on the technical ability of the elements to be reused in commerce.

Actually now there are several methods to account for the demolish and reuse of buildings and components. According to studies from (Yeung, Walbridge, & Haas, 2015)It will be show below. The graph showed the use of Module D approach to account steel for future reuse.

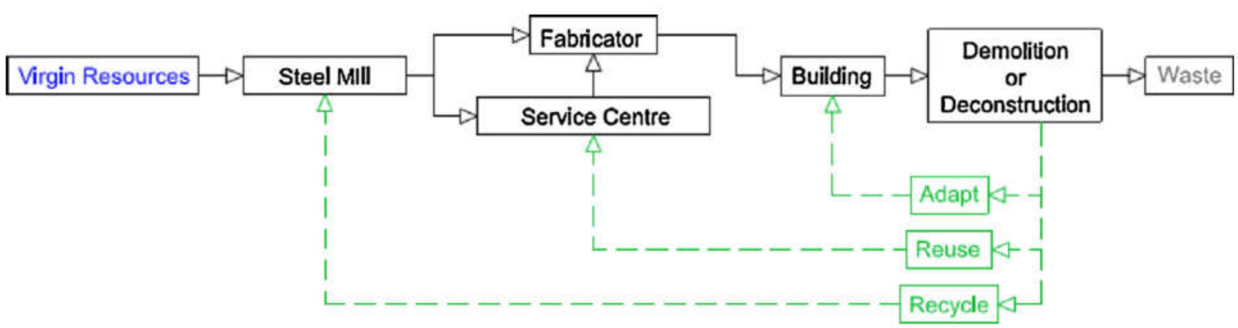


Figure 1.15 Process model for structural steel construction (Yeung et al., 2015)

System boundary

Before LCA study, it should determine the system boundary which is partly based on a subjective choice, because different requirements. It is made during the scope phase. About system boundary, it includes several stages of the life cycle. In a cradle-to-grave analysis the general system boundary of the macro-component is shown below.

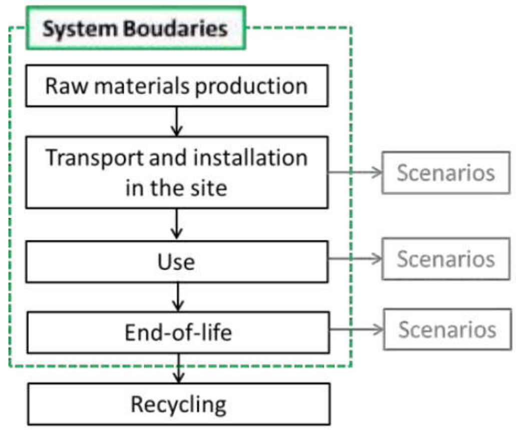


Figure 1.16 System Boundaries

There are several key points about the boundary and it will be shown below. ("More about LCA," 2006):

a. Before the production, a life cycle usually starts from the nature, for instance, the extraction point of raw materials and energy carries. In this stage, there will be waste generation. But in this project, it will not be considered.
b. Geographical area. It plays a crucial role in most LCA studies. It is related to the region, for example, from one place to another. It will affect so much environmental problems. Moreover, ecosystems sensitivity to environmental impact differs region too. So in this project. It should think about the transportation.
c. Time horizon. Basically LCAs are carried out to evaluate present impacts and predict future scenarios. Sometimes, the limitations to time boundaries are given by technologies involved, etc. In this project, the previous building is erected in 2004 and the new building is in 2012, about the data of LCI in two different time also is not same. This will influence the result, so setting the starting boundary here is more important.
d. Boundaries between the current life cycle and related life cycles of other technical systems. Most activities are interrelated, and therefore much be isolated from each other for further study.

Function unit

The most important factor of LCA is the function unit. It is a measure of the function about the studied system and it provides a reference to input/output. The advantage of function unit is that it can compare two essential different systems.

The functional unit specifies the function performed by the system studied and it can be used to analyse the impacts on a common unit (for example: the product impacts during a year of use). For buildings, the chosen functional unit is often a unit of living area (1 m²) per year because it allows the comparison of different projects on a homogeneous basis (Lyashenko, Belov, & Shcherbakova, 2008)

1.6.2 The inventory analysis phase

About the life cycle inventory analysis (LCI phase), it is an inventory of input/output data with regard to the system being studied. It involves collection of the data necessary to meet the goals of the defined study. (Iso 14040, 2006)

About the LCI data of steel, in general, published by steel industry, based on the steel production from iron ore and steel scrap. It includes not only material mining and manufacturing but also benefits and loads of recycling steel from products at the end of life.

Date quality requirements

Reliability of the results from LCA studies strongly depends on the extent to which data quality requirements are met. Here is the parameters should be taken into account("More about LCA," 2006):

a. Time-related coverage
b. Geographical coverage
c. Technology coverage
d. Precision, completeness and representativeness of the data
e. Consistency and reproducibility of the methods used throughout the data collection
f. Uncertainty of the information and data gaps

In this process, every detail, step from system's flow is sensitive for the result. For example, the waste of construction, it will be emission gas to air, dirty water to sea or land. Most of existing technical systems yield more than one product.

Reliability of data is also highly dependent on sufficient data documentation. Here the comparative life-cycle analysis was used by Simapro software ("SimaPro 7," 2008) , the database is Ecoinvent (Ecoinvent, 2000)

1.6.3 The impact assessment phase

The life cycle impact assessment phase (LCIA) is the third phase of the LCA. The purpose of LCIA is to provide additional information to help assess a product system's LCI results so as to better understand their environment significance.(Iso 14040, 2006)

Based on the ("More about LCA," 2006), it concludes two elements.

Mandatory elements:

1. Selection of impact categories, category indicators and characterization models.
2. Classification. For instance, in this thesis, CO2 is assigned to Global Warming. Common impact categories are Global warming, Ozone Depletion, photo oxidant formation, Acidification and Eutrophication.
3. Characterization. Conversion of LCI results to common units within each impact category, so that results can be aggregated into category indicator results.

Option elements:

1. Normalization. The magnitude of the category indicator results in calculated relatively to reference information.
2. Weighting. Indicator results coming from the different impact categories are converted to a common unit by using factors based on value-choices.
3. Grouping. The impact categories are assigned into one or more groups sorted after geographic relevance.

1.6.4 The interpretation phase

About the last phase, interpretation is the results of an LCI or an LCIA or both, are summarized and discussed as a basis for conclusions, recommendations and decision-making in accordance with the goal and scope definition. (Iso 14040, 2006)

According to ISO 14043, there are three steps in the interpretation:

1. the identification of the significant issues: important inventory data, significant impact categories, dominant contributions from one life cycle stage, etc.
2. the evaluation. The objectives of the evaluation are to establish the reliability of the results of the study, with particular attention to the significant issues identified in the first step of the interpretation. Sensitivity check or uncertainties analyses are needed. They determine whether the LCA results are affected by uncertainties in the data, allocation methods or calculation of category indicator results, etc. A sensitivity analysis estimates the effects of the chosen data and methods on the results and conclusions of the study.
3. the recommendations, conclusions and reporting. Limitations of the LCA are described and recommendations are formulated. All conclusions are drafted during this phase. A search for improvements can then be performed, identifying opportunities to reduce environmental impacts

2. INFORMATION ABOUT THE CASE STUDY

2.1 Background

The research work is a real project located in Romania. It includes two parts, previous building built in 2004, Craiova and new building in 2012, Bucharest. The new building had been designed with the idea of partially employing elements recovered from the old industrial building which is no longer used.

Figure 2.1 New building in Bucharest

The building consists of two parts. one is the industrial factory building which is made of steel profiles, while the roof of the structure is diaphragm, and the other is an office building combining steel profiles and cold-form channel. The two buildings are adjacent to each other. About the appearance, it was shown below.

INFORMATION ABOUT CASE

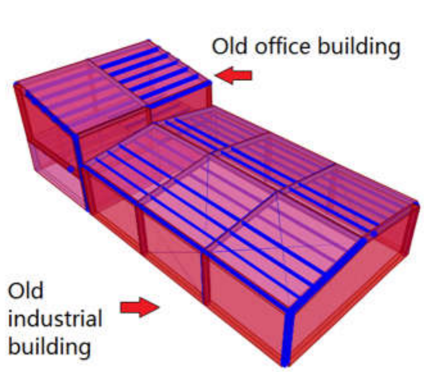
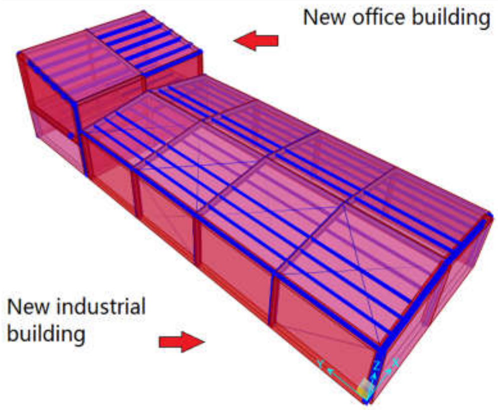
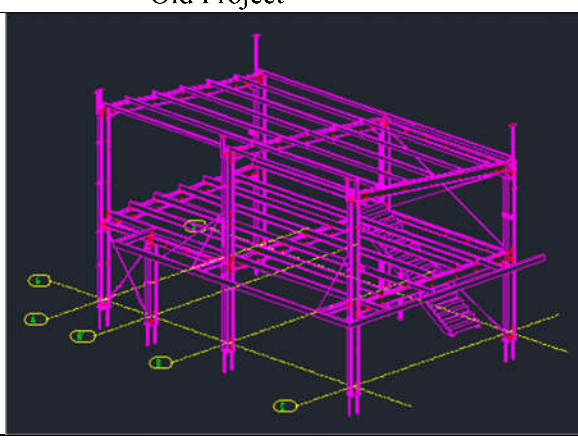
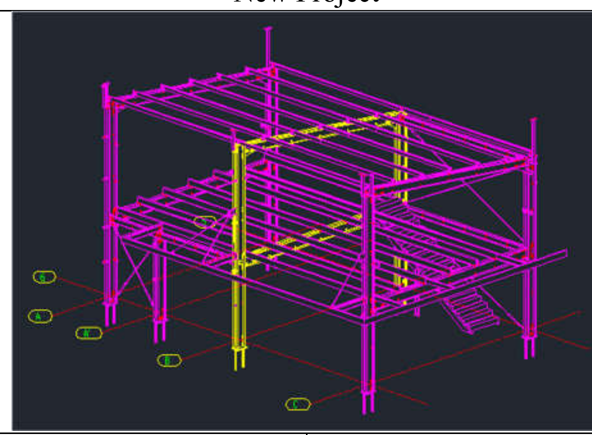
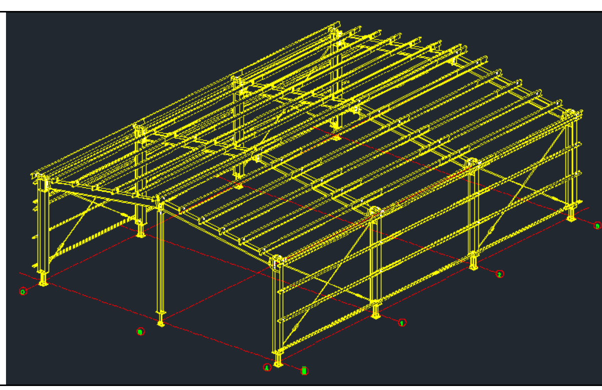
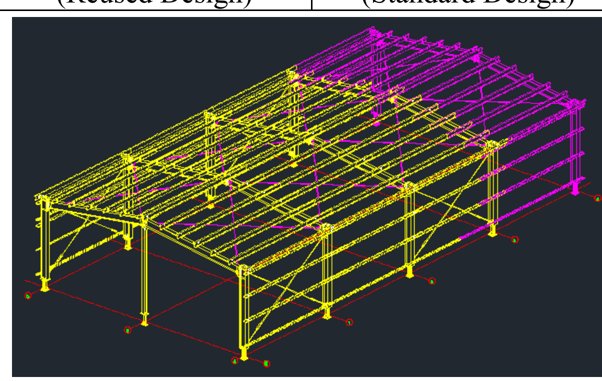
<table>
<tr><td>Model</td><td></td><td colspan="2"></td></tr>
<tr><td>Time</td><td>2004</td><td colspan="2">2012</td></tr>
<tr><td>Location</td><td>Craiova</td><td colspan="2">Bucharest</td></tr>
<tr><td>Material</td><td>Office: Part of Steel, Part of Cold-form
Industrial building: Steel plate</td><td colspan="2">Office: Part of Steel, Part of Cold-form
Industrial building: Steel plate</td></tr>
<tr><td colspan="2">Old Project</td><td colspan="2">New Project</td></tr>
<tr><td>Office</td><td></td><td colspan="2"></td></tr>
<tr><td>Weight</td><td>6436.3kg</td><td>6965.58kg
(Reused Design)</td><td>6441kg
(Standard Design)</td></tr>
<tr><td>Industrial</td><td></td><td colspan="2"></td></tr>
<tr><td>weight</td><td>8799.67kg</td><td colspan="2">11561.7kg</td></tr>
</table>

Figure 2.2 Information about the real case

COMPARISON OF THE MATERIALS

	MATERIALS (INDUSTRIAL BUILDING)			MATERIALS (OFFICE BUILDING)		
PREVIOUS BUILDING	Columns	S355	steel plates and profiles	Columns	cold-form	C350/3 C300/3 Z200/2 C200/2
	Beams			Beams		
	Bracing (wall)		φ27	Floor beams		
	Roof panels	Cold-form	Z200/2.5 Z200/2	Gable Roof frames		
	Roof sheet		LTP 45/0.5	Floor sheet		LTP 45/0.6 LTP 45/0.5
	Wall		LLP20 0.6/0.5	Bracing (wall)	S355	Φ25

	MATERIALS (INDUSTRIAL BUILDING)			MATERIALS (OFFICE BUILDING)		
NEW BUILDING	Columns	S355	steel plates and profiles	Columns	cold-form	C350/3 C300/3 Z200/2 C200/2 S500 MC S420 MC
	Beams			Beams		
	Bracing (wall)		φ27	Floor beams		
	Bracing (roof)		φ20	Gable Roof frames		
	Roof sheet	Cold-form	LTP 45/0.5	Floor sheet		LTP 45/0.6 LTP 45/0.5
	Wall		LLP20 0.6/0.5	Bracing (wall)	S355	Φ25

Table 2.1 Comparison of the load factor between previous building and new building

About the project, the initial plan was erecting a building in reused purpose. because the function and shape of the building are almost same. In general, from the investor's view, this reused design will save more money and be more environment-friendly. But it still need to be considered from a global perspective. The research paper here will focus on this real case. It includes the structural analysis, life cycle assessment, then problem solving and etc. with software.

As said before, the thesis will investigate whether the reused design based on this real project is a good way from a global perspective, in sustainable way. In order to get clearly results, two different structural models for the designed building have been carried out and compared. **One is designing new structure in new elements (standard design). The other way presents the reused structure (reused design).**

The next section will show the details about the differences between the previous building and new building, then between the Model A and Model B.

2.2 Difference between the previous and new building

About the difference between the two buildings, it is shown on the graph below. First, focus on the first column and second column, about the **Industrial factory building,** it is just about the numbers of bay, the dimension about the member cross-section and the distance between each bay is totally the same. New industrial building is four bays but previous is just three. Then about the **office building**, the shape about the office building is same, but the section of the primary members need to be changed (About the changed members, shown in Figure 2.2), because the design code had already updated as time goes on, and the location is also different, based on the new code, about the constant spectral acceleration, Bucharest is higher than in Craiova. So, the cross-section of new building need to be strengthened. It will be explained in the Chapter 3 later.

2.3 Difference between the Model A and B

In this thesis, it will focus on the structure design, with the aim of quantifying the environmental advantages and economic saving related to structural steel reuse. So about the new building design, it will be supposed to two Models. Model A is designed by reused purpose, it means the elements of the new building will be as much as possible reused from the old building. But in Model B, the new building will be designed under the standard process. That means we do not need to consider about the reused members, any member can be made from the steel making factory. So about the cross-section shown in graph in Model B column, it is not necessary C350/3, but in the Model A column, it should be C350/3, same as the previous building, and because the cross-section in new building need to be strengthened, in the Model A, the only one choice is adding the C300/3 inside C-channel. But in the Model B, after calculation and verification, S 500MC can be satisfied.

About the design and verification of the structure, it will be explained in the Chapter 3.

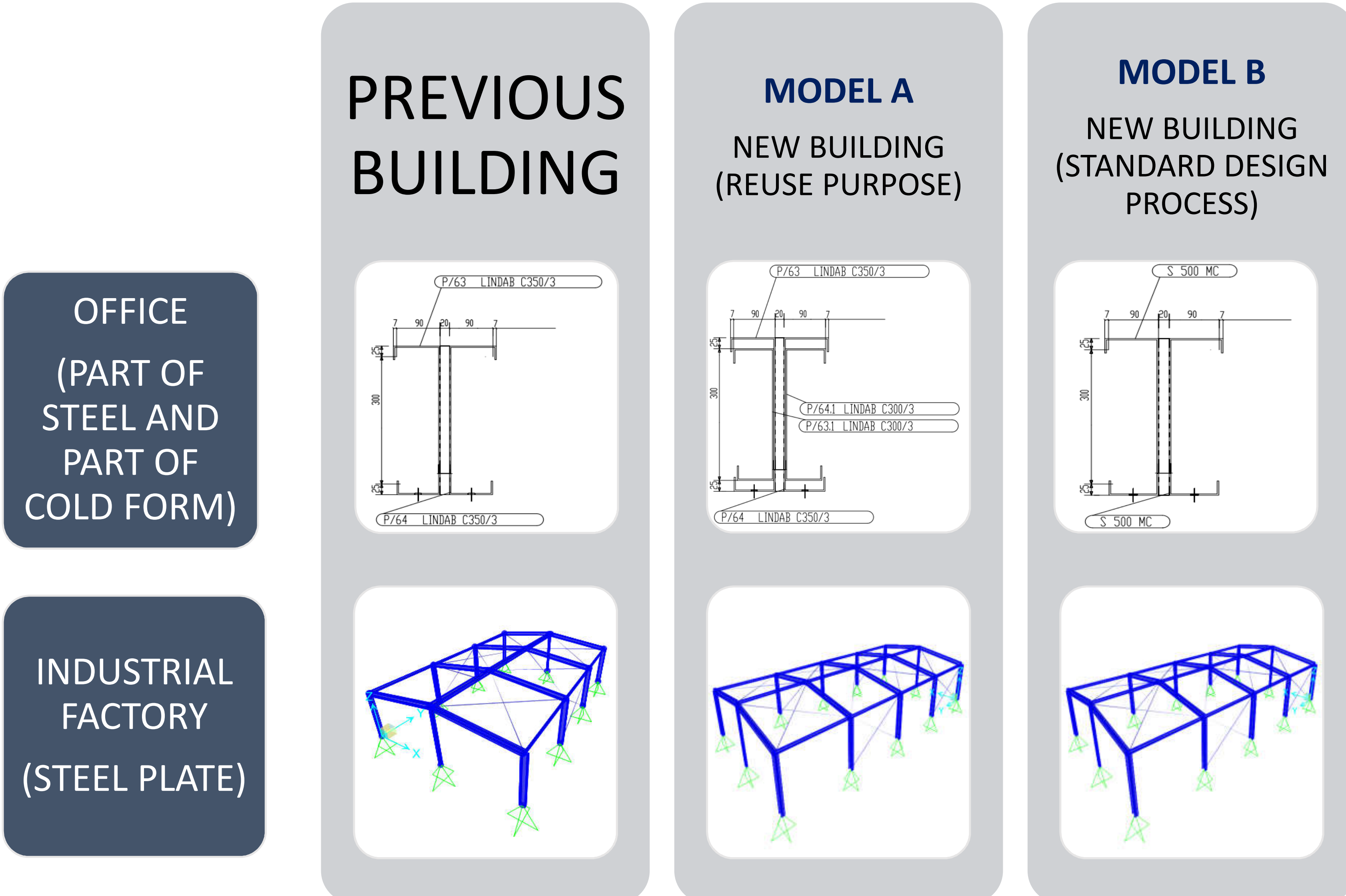


Figure 2.3 difference between the previous building and Model A and B

3. STRUCTURE ANALYSIS AND VERIFICATION

3.1 Background

The previous industrial factory building is located in Craiova, designed and built in 2004. Then in 2012, the new building is planned to build in the Bucharest. Most of elements are reused from the previous building. Hence, it is important to check the bearing capacity of the new building, especially for the reuse elements. Here in this thesis, it will show the structure analysis about the new building including reused design and standard design.

It is noticed that the new building is erected almost 8 years later since the previous building had been built. The part of the code and rules would be changed. This will be taken into account in this dissertation.

3.2 Modelling in SAP2000

SAP2000 is a popular finite element software which generally performs the static, dynamic, linear and non-linear analysis about the structure. Here in this thesis, office building and industrial factory building had been modelled in SAP2000, after analysis, the results will be used to verify the members of the new buildings.

The figure 1 and 2 are modelling views for industrial factory building and office building.

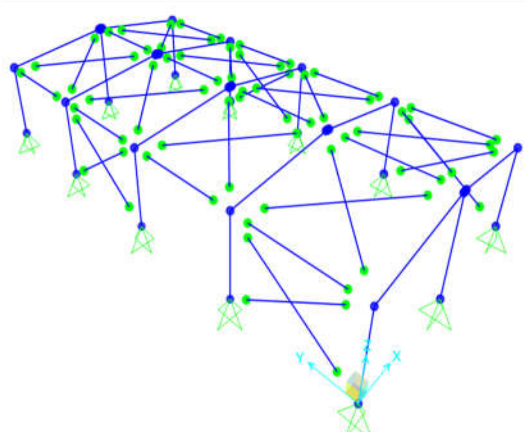
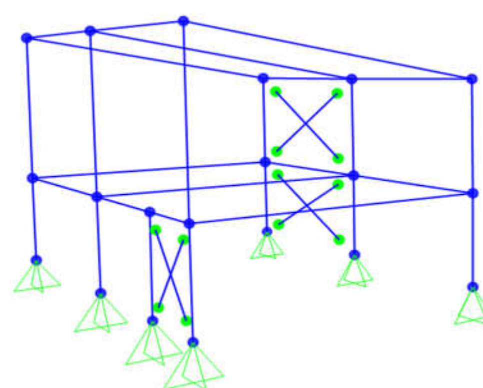
	
INDUSTRIAL	OFFICE

Table 3.1 Modelling about Office and Industrial building in SAP2000

The ground support of the two buildings is pinned and also for the bracing, purlins, but for two rafters to each other and to column is fixed. Because in reality, the connection of the rafter need to be rigid or semi-rigid to support the bending moment due to the external load.

About the bracing here, it is noted that setting them without the compression. Because here the bracing is designed to a rod and in reality the bracing is just against the tension when building got sway.

The diaphragm and floor panel are not defined in SAP2000, because in this paper, just checked the line component, like beam, column and bracing, so the load will just be put on the primary beam instead of slab, besides, compared to SAP2000, SAFE software is much better to analyse slab. But in order to simulate the real load distribution, it should put virtual bracing on the roof.

3.3 Structure Analysis (Previous Project and New Project)

3.3.1 Previous Project (Based on previous code)

3.3.1.1 Materials

MATERIALS (INDUSTRIAL BUILDING)

Columns	S355	steel plates and profiles
Beams		
Bracing (wall)		Φ 27
Roof panels	Cold-form	Z200/2.5 Z200/2
Roof sheet		LTP 45/0.5
Wall		LLP20 0.6/0.5

MATERIALS (OFFICE BUILDING)

Columns	Cold-form	C350/3 C300/3 Z200/2 C200/2
Beams		
Floor beams		
Gable Roof frames		
Floor sheet		LTP 45/0.6 LTP 45/0.5
Bracing (wall)	S355	Φ25

Table 3.2 Materials about previous industrial and office building

3.3.1.2 Load Quantification

A. Permanent Load

PERMANENT LOAD AND LIVE LOAD
Industrial building

	ITEMS	WEIGHT [kN/m2]	LOAD FACTOR
PERMANANT LOAD	Self-weight (Roof)	0,25	n=1,1 for ULS n=1,0 for SLS
	Cladding incl. thermo-insulation (roof and walls)	0,25	
TECHNOLOGY	Additional weight (electrical wires and other device)	0,15	n=1,1 for ULS n=1,0 for SLS

Table 3.3 Permanent load

PERMENANT LOAD AND LIVE LOAD
Office building

	ITEMS	WEIGHT [kN/m2]	LOAD FACTOR
PERMENANT LOAD	Cladding incl. thermo-insulation (roof)	0.3	n=1,1 for ULS n=1,0 for SLS
	Cladding incl. thermo-insulation and Technological loadings(floor)	0.7	n=1,1 for ULS n=1,0 for SLS
LIVE LOAD	Live load	0.2	n=1,2 for ULS n=1,0 for SLS
QUASI-PERMENANT LOAD	partition walls on the slab	0.5	n=1,1 for ULS n=1,0 for SLS

Table 3.4 Permanent load and live load about office building

B. Snow Load

According to the "code STAS 10101/21-92 Actiune Zapada (snow)", the normalized load is calculated follow the formula:

Industrial building

The normalized load from distributed snow

$$p_z^n = c_{zi} \times c_e \times g_z = 1.5kN/m2$$

Where:

$C_{zi} = 1$ Surface Coefficient

$g_z = 1.5kN/m2$ Zone C

$C_e = 1$ The exposure coefficient (Eaves of the building is under the 5m)

Roof abutting and close to taller construction works

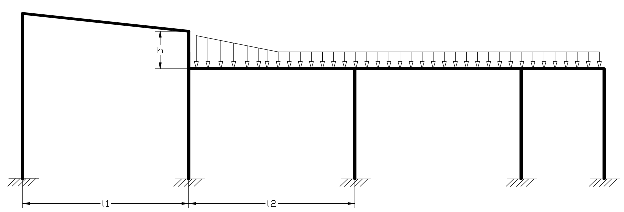
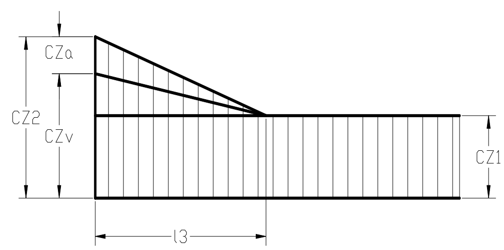


Figure 3.1 Roof abutting and close to taller construction works



$$c_{zv} = \frac{m_1 l_1 + m_2 l_2}{} = \frac{0.5 \times 7.6 + 05 \times 18}{2.1} = 6.1$$

Where:

$m_1 = m_2 = 0.5$ for Roof with slopes $\alpha \leq 200$

$c_{za} = 0$ for Roof with slopes $\alpha \leq 150$ (coefficient of sliding on snow by agglomeration)

$l_3 = 2 \quad = 4.2m$

$c_{z1} = 1$

But $c_{zv} < 4$ for dual bearing elements and

$$c_{zv} < \frac{2.5}{g_z} = \frac{2.5 \times 2.1}{1.5} = 3.5$$

According to STAS 10101/0A-77, section 3.7 forc$_{zv} > 2$, we have a combination of exceptional loads of snow, is $c_{z2=2}$

$$p_z^n = c_{z2} \times c_e \times g_z = 2 \times 1 \times 1.5kN/m2 = 3kN/m2$$

For accidental design situations where exceptional snow drift is the accidental action

$$P_{exc} = 3.5 \times \frac{1.5kN}{m2} = 5.25kN/m2$$

office building

The normalized load from distributed snow

$p_z^n = c_{zi} \times c_e \times g_z = 1.5kN/m2$

Where:

$C_{zi} = 1$	Surface Coefficient
$g_z = 1.5kN/m2$	Zone C
$C_e = 1$	The exposure coefficient (Eaves of the building is under the 5m)

Coefficients for Ultimate limit states and Serviceability limit state of SNOW

Coefficient for ULS and SLS	
Ultimate limit states under the fundamental combinations	$\gamma_F = \gamma_\alpha = 2.13$
Serviceability limit state under the operation state	$\gamma_0 = \gamma_c = 1.37$
Ultimate limit states under the special situation	$\gamma_e = 0.30$

Table 3.5 Coefficients for Ultimate limit states and Serviceability limit state of SNOW

C. Wind Load

According to the "code STAS 10101/20-90 Incarcari Vant (wind), the normalized load is calculated follow the formula:

The normalized load of wind

$$p_n^n = \beta \times c_{ni} \times c_h(z) \times g_v$$

Where:

$g_v = 0.55kN/m2$ Basic dynamic pressure (Tab.1 for Zone C)

$c_h(z) = 1$ Coefficient depending on the height above the ground (Type 1 site with obstacles z<10m)

$\beta = 1.6$ Coefficient of flurry (Construction category C1)

Drag coefficient (c_{ni})(tab.3/STAS) for an angle of 8° is 0.8-walls and roof frames

DRAG COEFFICIENT (Industrial factory)

COEEFICIENT	VALUE	NORMAL PRESSURE ON THE SURFACE
positive face	0.80	$p_{n0}^n = 1.6 \times (+0.80) \times 1.0 \times 0.55 = 0.704kN/m2$
Cn1	-0.37	$p_{n0}^n = 1.6 \times (\ \ 0.37) \times 1.0 \times 0.55 = \ \ 0.326kN/m2$
Cn2	-0.40	$p_{n0}^n = 1.6 \times (\ \ 0.40) \times 1.0 \times 0.55 = \ \ 0.352kN/m2$
Cn3	-0.45	$p_{n0}^n = 1.6 \times (\ \ 0.45) \times 1.0 \times 0.55 = \ \ 0.396kN/m2$

Table 3.6 Drag coefficient

DRAG COEFFICIENT (Office)

COEEFICIENT	VALUE	NORMAL PRESSURE ON THE SURFACE
positive face	0.80	$p_{n0}^n = 1.6 \times (+0.80) \times 1.0 \times 0.55 = 0.704kN/m2$
Cn1	-0.37	$p_{n0}^n = 1.6 \times (\ \ 0.37) \times 1.0 \times 0.55 = \ \ 0.326kN/m2$
Cn2	-0.40	$p_{n0}^n = 1.6 \times (\ \ 0.40) \times 1.0 \times 0.55 = \ \ 0.352kN/m2$
Cn3	-0.45	$p_{n0}^n = 1.6 \times (\ \ 0.45) \times 1.0 \times 0.55 = \ \ 0.396kN/m2$

Table 3.7 Drag coefficient

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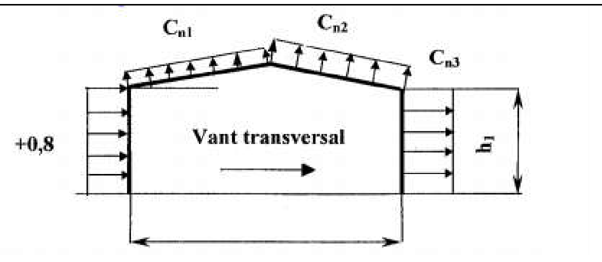
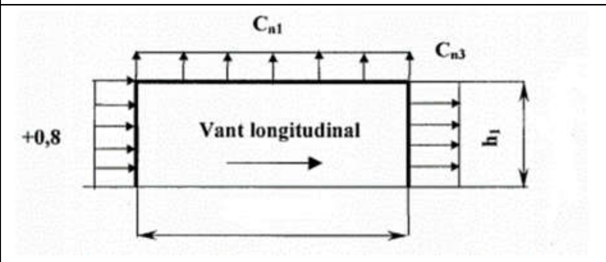
<tr><th>Wind Transversal</th><th>Wind Longitudinal</th></tr>
<tr><td>
</td><td>
</td></tr>
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Figure 3.2 Wind load

Coefficients for Ultimate limit states and Serviceability limit state of WIND

Coefficient for ULS and SLS	
Ultimate limit states under the fundamental combinations	$\gamma_F = \gamma_\alpha = 1.2$
Serviceability limit state	$\gamma_0 = \gamma_c = 1.0$
Ultimate limit states under the special situation	Do not need to consider wind with maximum earthquakes (STAS10101/0A-85 paragr. 4..2 pts.9)

Table 3.8 Coefficients for Ultimate limit states and Serviceability limit state of WIND

D. Seismic

According to the code "Cod De Proiectare Seismica P100-92", the seismic load is calculated follow the formula:

Industrial factory

Calculation of Gravity Load

$$G_k = G_{roof} + +G_{tech} + G_{snow} = 54kN + 32.4kN + 194.4kN = 280.8kN$$

$$G_{roof} = 0.25kN/m2 \times 12m \times 18m = 54kN$$

$$G_{tech} = 0.15kN/m2 \times 12m \times 18m = 32.4kN$$

$$G_{snow} = 3kN/m2 \times 12m \times 18m \times 0.3 = 194.4kN$$

Calculation of Horizontal Seismic Load

The value of total seismic load acting horizontally after any direction on transversal frame is determined:

$S_r = C_r \times G_k = 0.5 \times 280.8kN = 140.4kN$

$S_{rl} = \frac{S_r}{2\times(3+1)} = 17.55kN$ Transversal

$S_{rl} = \frac{S_r}{2\times(2+1)} = 23.4kN$ Longitudinal

Where:

$c_r = \alpha \times k_s \times \beta_r \times \psi \times \varepsilon_r = 0.5$ Global seismic coefficient

According to the P100/92, The construction site is placed in area C, the value is showed below:

$\alpha = 1$ (Class III)

$k_s = 0.2$ (Zone C, T_C=1.5s)

$\psi = 1$

$\varepsilon_r = 1$ Coefficient of equivalence to system with one degree of freedom

$\beta_r = 2.5$ Based on the diagram below (Structure was considered to concentrate

Office

Calculation of Gravity Load

$G_k = G_{roof} + G_{floor} + G_{snow} = 72kN + 63kN + 81kN = 216kN$

$G_{roof} = (\frac{0.3kN}{m2} + \frac{0.5kN}{m2}) \times 12m \times 7.5m = 72kN$

$$G_{floor} = \frac{0.7kN}{m2} \times 12m \times 7.5m = 63kN$$

$$G_{snow} = 3kN/m2 \times 12m \times 7.5m \times 0.3 = 81kN$$

Calculation of Horizontal Seismic Load

The value of total seismic load acting horizontally after any direction on transversal frame is determined:

$$S_r = C_r \times G_k = 0.5 \times 216kN = 108kN$$

$S_{rl} = \frac{S_r}{2\times(3+1)} = 13.5kN$ Transversal

$S_{rl} = \frac{S_r}{2\times(2+1)} = 18kN$ Longitudinal

Where:

$c_r = \alpha \times k_s \times \beta_r \times \psi \times \varepsilon_r = 0.5$ Global seismic coefficient

According to the P100/92, The construction site is placed in area C, the value is showed below:

$\alpha = 1$ (Class III)

$k_s = 0.2$ (Zone C, T_C=1.5s)

$\psi = 1$

$\varepsilon_r = 1$ Coefficient of equivalence to system with one degree of freedom

$\beta_r = 2.5$ Based on the diagram below (Structure was considered to concentrate

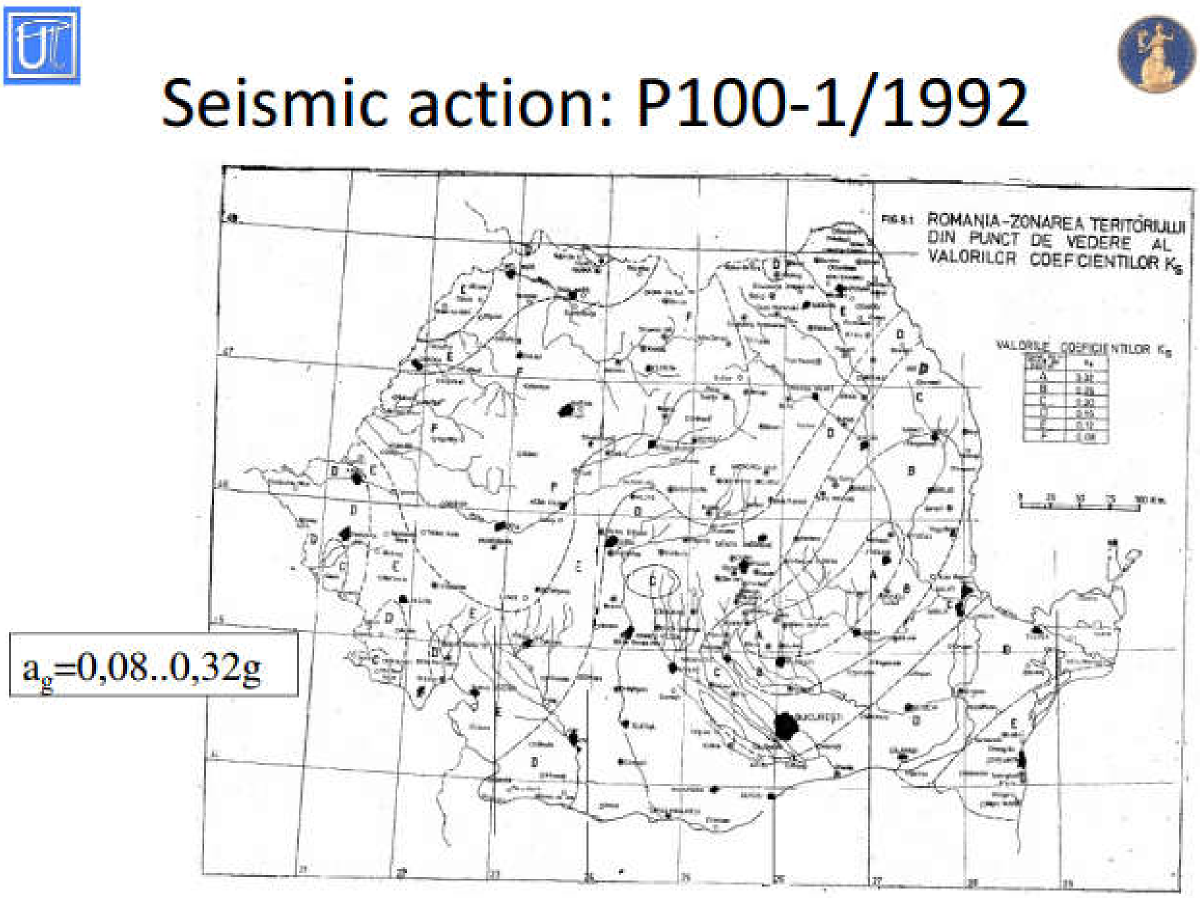


Figure 3.3 Seismic action P100-1/1992

in nodes frames).

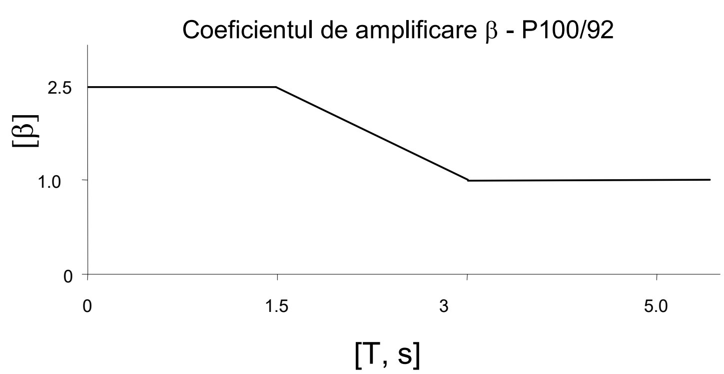


Figure 3.4 Coefficient of amplify

3.3.1.3 Combination of Action (Static analysis)

According to the code STAS 10101/0A-85, the combination of action is grouped as follow:

Loading Assumption

P=Permanent

T=Technology

S=Snow

WT=Wind Transverse

WL=Wind Longitudinal

ET=Earthquake Transverse

EL= Earthquake Longitudinal

Ultimate limit state

THE FUNDAMENTAL COMBINATION (ULS)	
1	$1.1 \times P + 2.13 \times S$
2	$1.1 \times P + 1.2 \times T + 1.2 \times WT$
3	$1.1 \times P + 1.2 \times T + 1.2 \times WL$
4	$1.1 \times P + 1.2 \times T + 0.9 \times (1.2 \times WL + 2.13 \times S)$
5	$1.1 \times P + 1.2 \times T + 0.9 \times (1.2 \times WT + 2.13 \times S)$

Table 3.9 The fundamental combination (ULS)

Serviceability limit state

THE FUNDAMENTAL COMBINATION (SLS)	
1	$1.0 \times P + 1.37 \times S$
2	$1.0 \times P + 1.0 \times T + 1.0 \times WT$
3	$1.0 \times P + 1.0 \times T + 1.0 \times WL$
4	$1.0 \times P + 1.0 \times T + 0.9 \times (1.0 \times WL + 1.37 \times S)$
5	$1.0 \times P + 1.0 \times T + 0.9 \times (1.0 \times WT + 1.37 \times S)$

Table 3.10 The fundamental combination (SLS)

THE SPECIAL SITUATION (ULS)

1	$1.0 \times P + 1.2 \times T + 0.3 \times S + ET +$
2	$1.0 \times P + 1.2 \times T + 0.3 \times S + ET$
3	$1.0 \times P + 1.2 \times T + 0.3 \times S + EL +$
4	$1.0 \times P + 1.2 \times T + 0.3 \times S + EL$

Table 3.11 The special situation (ULS)

3.3.2 New Project (Based on new code)

3.3.2.1 Materials

MATERIALS (INDUSTRIAL BUILDING)

Columns	S355	steel plates and profiles
Beams		
Bracing (wall)		Φ 27
Bracing (roof)		Φ 20
Roof sheet	Cold-form	LTP 45/0.5
Wall		LLP20 0.6/0.5

MATERIALS (OFFICE BUILDING)

Columns	cold-form	C350/3 C300/3 Z200/2 C200/2 S500 MC S420 MC
Beams		
Floor beams		
Gable Roof frames		
Floor sheet		LTP 45/0.6 LTP 45/0.5
Bracing (wall)	S355	Φ25

Table 3.12 Materials about new office and industrial building

3.3.2.2 Load Quantification

A. Permanent Load

PERMENANT LOAD AND LIVE LOAD
Industrial building

ITEMS		WEIGHT [kN/m2]	LOAD FACTOR
PERMENANT LOAD	Self-weight (Roof)	0.25	n=1,35 for ULS n=1,0 for SLS
	Cladding incl. thermo-insulation (roof and walls)	0,25	
TECHNOLOGY	Additional weight (electrical wires and other device)	0.15	n=1,5 for ULS n=1,0 for SLS

Table 3.13 Permanent load and live load about industrial building

PERMENANT LOAD AND LIVE LOAD
Office building

	ITEMS	WEIGHT [kN/m2]	LOAD FACTOR
PERMENANT LOAD	Cladding incl. thermo-insulation (roof)	0.3	n=1,35 for ULS n=1,0 for SLS
	Cladding incl. thermo-insulation and Technological loadings(floor)	0.7	n=1,35 for ULS n=1,0 for SLS
LIVE LOAD	Live load	0.2	n=1,5 for ULS n=1,0 for SLS
QUASI-PERMANENT LOAD	partition walls on the slab	0.5	n=1,35 for ULS n=1,0 for SLS

Table 3.14 Permanent load and live load about office building

B. Snow Load

According to the "Cod De Proiectare Evaluarea Actiunii Zapezii Asupra Constructiilor CR-1-1-3/2012", the normalized load is calculated follow the formula:

Industrial building

For the persistent design situation

$s_k = \mu_i \times C_e \times C_t \times S_{0,k} = 1.6kN/m2$

Where:

$S_{0,k} = 2.0kN/m2$ Characteristic value of snow load on the ground

$C_t = 1.0$ Thermal coefficient

$C_e = 1$ The exposure coefficient (Windswept)

$\mu_i = 0.8$ Snow load shape coefficient (Angle of pitch of roof $0° \leq \alpha \leq 30°$)

Roof abutting and close to taller construction works

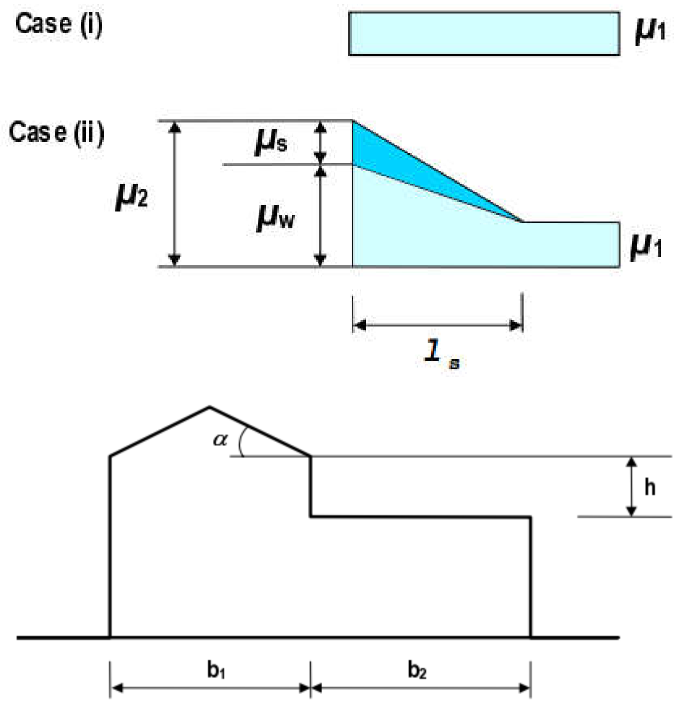


Figure 3.5 Roof abutting and close to taller construction

For agglomeration with snow, the roof of adjacent building:

$\mu_i = 1.45$ Snow load shape coefficient (Angle of pitch of roof $0° \leq \alpha \leq 15°$)

$s_k = \mu_i \times C_e \times C_t \times S_{0,k} = 2.9kN/m2$

For accidental design situations where exceptional snow drift is the accidental action

$$\mu_i = \min\left[\frac{2h}{s_k}, \frac{2b}{l_s}, 8\right] = \min[2.1, 2.85, 8] = 2.1$$

$$S = \mu_i \times S_k = 2.1 \times \frac{2kN}{m2} = 4.2kN/m2$$

office building

For the persistent design situation

$s_k = \mu_i \times C_e \times C_t \times S_{0,k} = 1.6kN/m2$

Where:

$S_{0,k} = 2.0kN/m2$ Characteristic value of snow load on the ground

$C_t = 1.0$ Thermal coefficient

$C_e = 1$ The exposure coefficient (Windswept)

$\mu_i = 0.8$ Snow load shape coefficient (Angle of pitch of roof $0° \leq \alpha \leq 30°$)

Coefficients for Ultimate limit states and Serviceability limit state of SNOW

Coefficient for ULS and SLS	
Ultimate limit states under the fundamental combinations	$\gamma_F = 1.5$
Serviceability limit state under the operation state	$\gamma_0 = 1$
Ultimate limit states under the special situation	$\gamma_e = 0.4$

Table 3.15 Coefficients for Ultimate limit states and Serviceability limit state of SNOW

C. Wind Load

The new building is an industrial factory building with an adjacent office building. That means about the wind load, the two building will be effect to each other to some extent. It depends on the height of two building, separated distance and wind direction on the pressure zone around the building.

However, according to the " *Cod de Proiectare.Bazele Proiectarii si Actiuni asupra Constructiilor.Actiunea vantului CR1-1-4/2012", or "Eurocode 1991-1-4 Actions on structures-wind actions, A.4 Neighbouring structures*". (En, 2011) if a building is more than twice as high as the average height of the neighbouring structures, then as a first approximation, the design of any of those nearby structures may be based on the peak velocity pressure at defined height. But here, the height of office building is not more than twice as high as the industrial factory building, so in this project. it is insignificant that considering the effect between two building. Just calculates the wind load separately.

Industrial building

The normalized load of wind at vertical direction above ground.

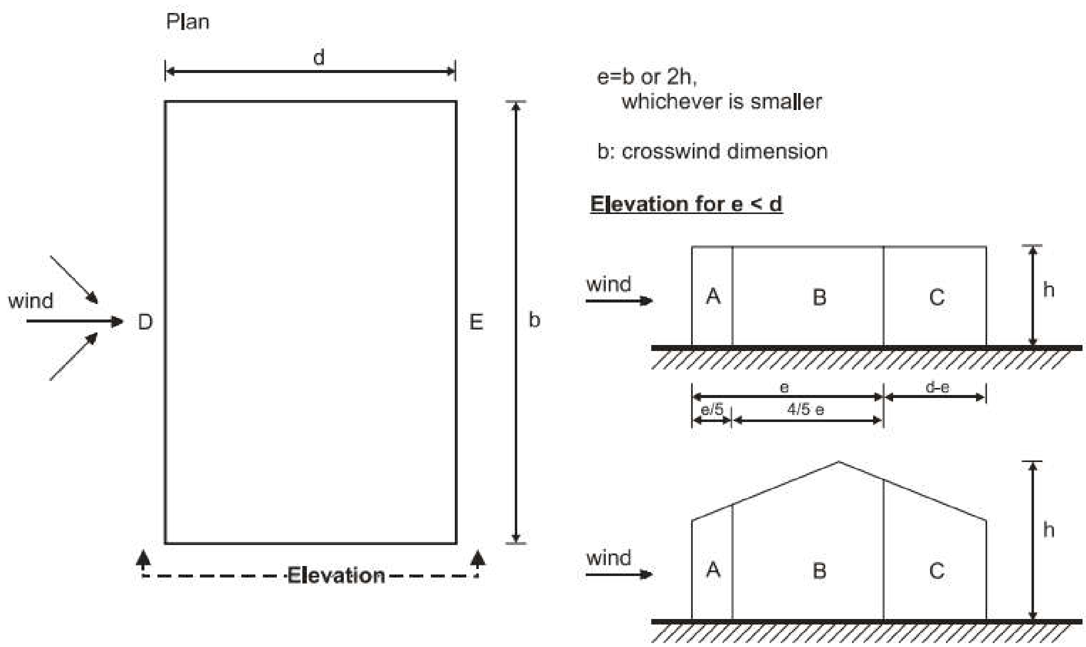
$$w(z) = q_{ref} \times c_e(z) \times C_p$$

Where:

$q_{ref} = 0.5kN/m2$ Reference wind pressure

$c_e(z) = 1.4$ Exposure factor z height above ground

Aerodynamics pressure (Depend on the size of the exposed area), according to the CR-1-1-4-2012-wind.



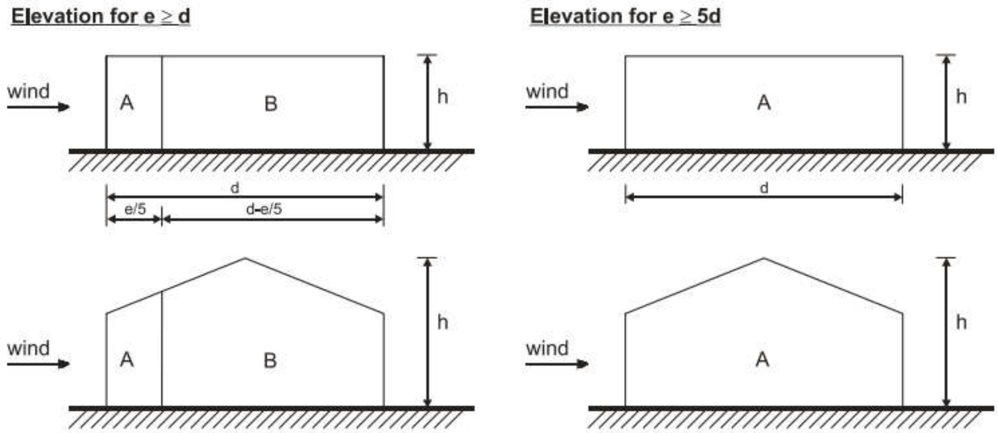
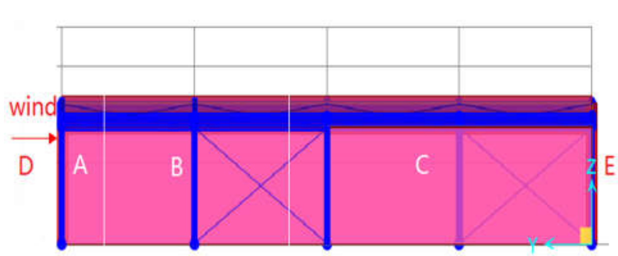
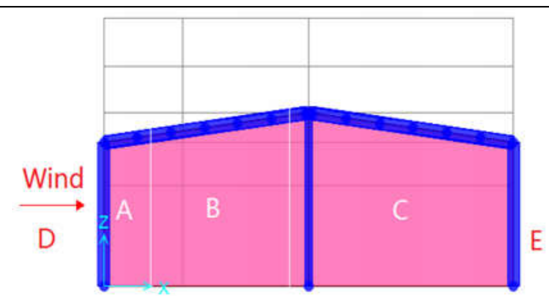


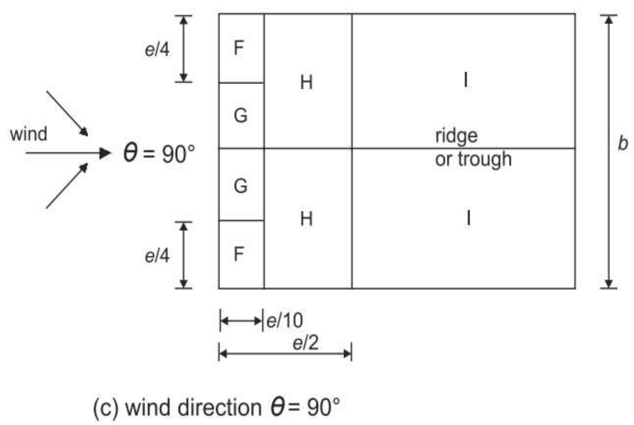
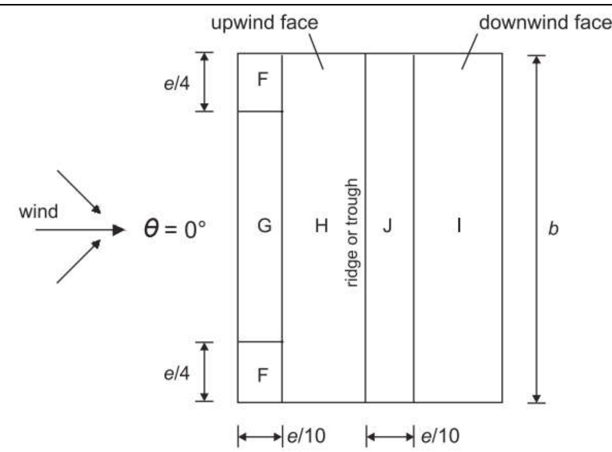
Figure 3.6 The external pressure for vertical walls

Wind Transversal	Wind Longitudinal
e=min[b,2h] =min[12m,4.7x2m] =9.4m <d=24m, so $S_A = 1.88m \times 4.7m = 8.836m2$ $S_B = 0.8 \times 9.4m \times 4.7m = 35.344m2$ $S_C = (24m \quad 9.4m) \times 4.7m = 68.62m2$ $S_D = 2 \times 12m \times (3.9m + 4.7m)/(2 \times 2) = 51.6m2$ $S_E = S_D = 51.6m2$	e=min[b,2h] =min[24m,2x4.7m] =9.4m <d=12m, so $S_A = 1.88m \times (3.9m + 4.7m)/2 = 7.56m2$ $S_B = \frac{(4.14 + 4.7) \times (6 \quad 1.88)}{2} + \frac{(4.247 + 4.7) \times 3.4}{2} = 33.4m2$ $S_C = (4.247m + 3.9m) \times 2.6m/2 = 10.59m2$ $S_D = 4.7m \times 24m \times 0.8 = 90.24m2$ $S_E = S_D = 90.24m2$
	

DRAG COEFFICIENT (TRANSVERSAL)			**DRAG COEFFICIENT (LONGITUDINAL)**		
COEEFICIENT	VALUE	NORMAL PRESSURE ON THE SURFACE (kN/m2)	COEEFICIENT	VALUE	NORMAL PRESSURE ON THE SURFACE (kN/m2)
CpA	-1.00	-0.70	CpA	-1.00	-0.70
CpB	-0.80	-0.56	CpB	-0.80	-0.56
CpC	-0.50	-0.35	CpC	-0.50	-0.35
CpD	0.60	0.42	CpD	0.80	0.56
CpE	-0.30	-0.21	CpE	-0.30	-0.21

Table 3.16 Process about calculation of Normal pressure on different surface at vertical direction (Industrial building)

The normalized load of wind at duo pitch roofs.

<table>
<tr><th>Wind Transversal</th><th>Wind Longitudinal</th></tr>
<tr><td>
</td><td>
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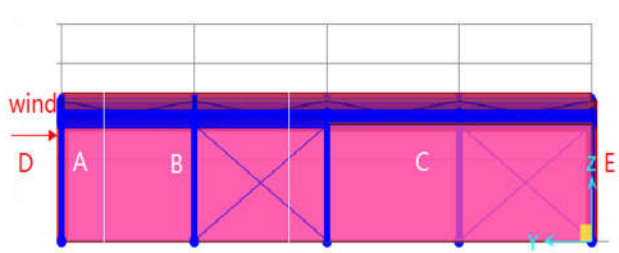
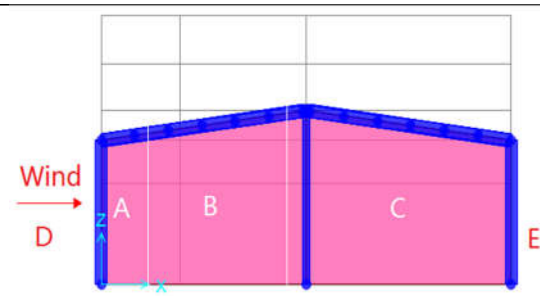
<tr><td>
</td><td>
</td></tr>
</table>

DRAG COEFFICIENT (TRANSVERSAL)		
COEEFICIENT	VALUE	NORMAL PRESSURE ON THE SURFACE (kN/m2)
CpF	-1.51	-1.06
CpG	-1.3	-0.91
CpH	-0.67	-0.47
CpI	-0.57	-0.40

DRAG COEFFICIENT (LONGITUDINAL)		
COEEFICIENT	VALUE	NORMAL PRESSURE ON THE SURFACE （kN/m2)
CpF	-1.46	-1.02
CpG	-1.08	-0.76
CpH	-0.51	-0.36
CpI	-0.54	-0.38
CpJ	-0.16	-0.11

Table 3.17 Process about calculation of Normal pressure on different surface at roof (Industrial building)

Office building

The normalized load of wind at vertical direction above ground.

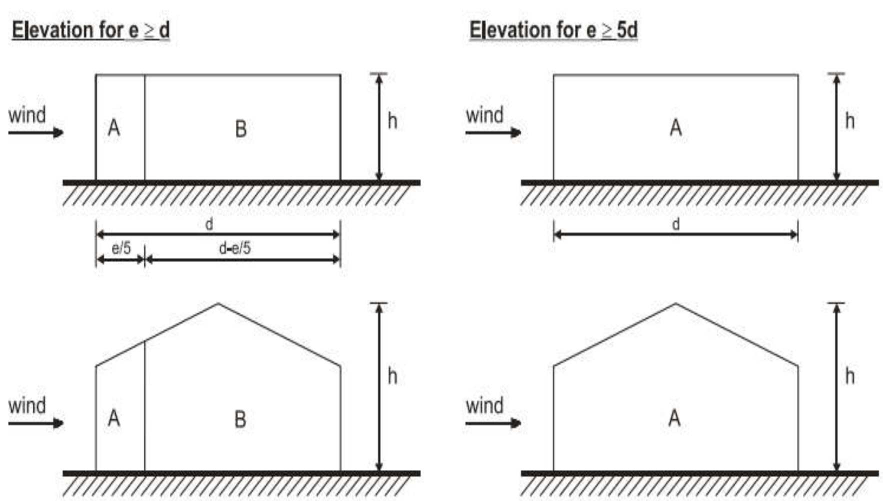
$$w(z) = q_{ref} \times c_e(z) \times C_p$$

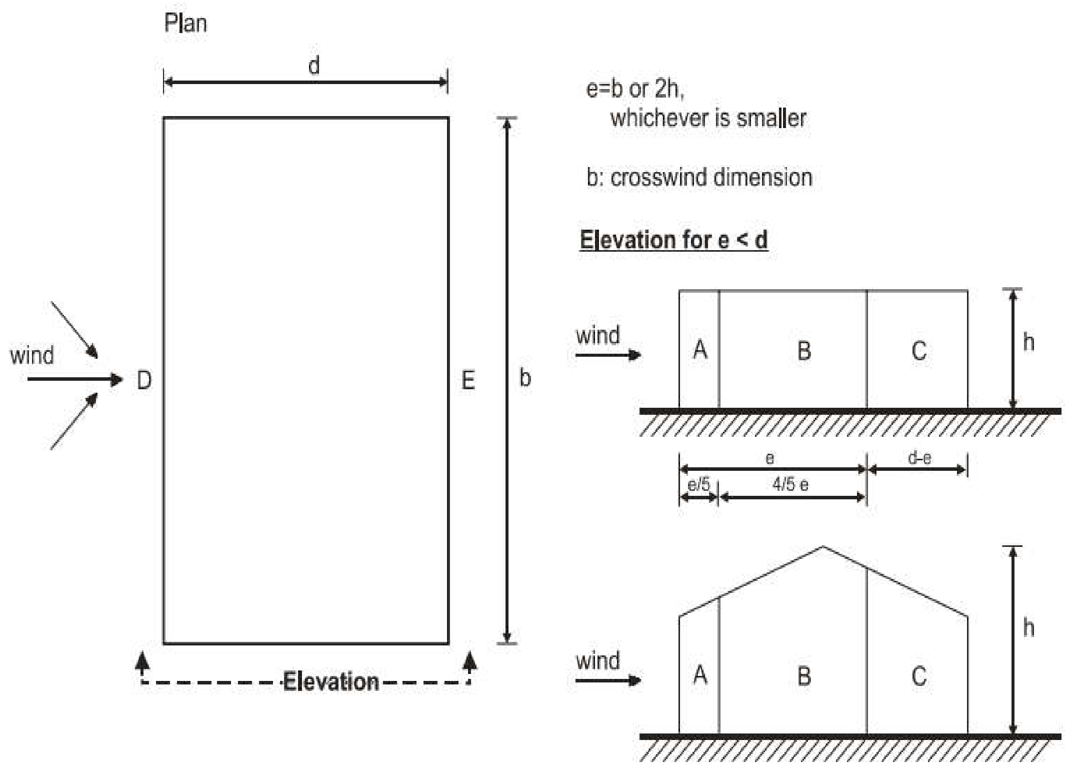
Where:

$q_{ref} = 0.5kN/m2$ Reference wind pressure

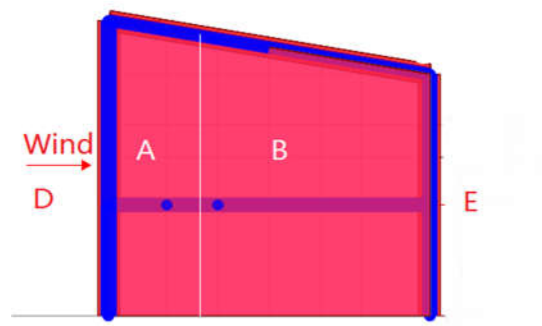
$c_e(z) = 1.65$ Exposure factor z height above ground

Aerodynamics pressure (Depend on the size of the exposed area), according to the CR-1-1-4-2012-wind.



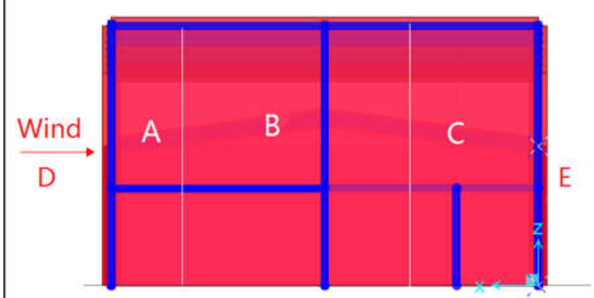


Wind Transversal	Wind Longitudinal
e=min[b,2h] =min[12m,7.4x2m] =12m >d=7.5m, and e<5d, so	e=min[b,2h] =min[7.5m,7.4x2m] =7.5m <d=12m, so
$S_A = 2.4m \times (6.856m + 7.4m)/2 = 17.1072m2$	$S_A = 1.5m \times 7.4m = 11.1m2$
	$S_B = 0.8 \times 1.5m \times 7.4m = 44.4m2$
$S_B = (5.7m + 7.4m) \times 7.5m/2 = 49.125m2$	$S_C = (12m \quad 7.5m) \times 7.4m = 33.3m2$
$S_D = 12m \times 7.4m = 88.8m2$	$S_D = 7.5m \times (7.4m + 5.7m)/2 = 49.125m2$
$S_E = 12m \times 5.7m = 68.4m2$	$S_E = S_D = 49.125m2$



DRAG COEFFICIENT (TRANSVERSAL)

COEEFICIENT	VALUE	NORMAL PRESSURE ON THE SURFACE （kN/m2)
CpA	-1	-0.7
CpB	-0.8	-0.56
CpC	-0.5	-
CpD	0.6	0.42
CpE	-0.3	-0.21



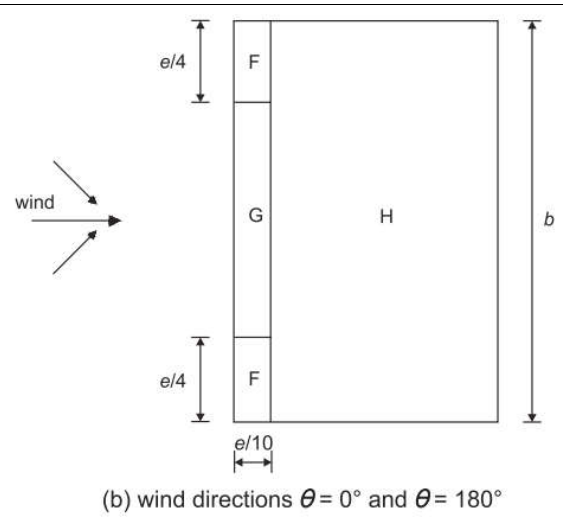
DRAG COEFFICIENT (LONGITUDINAL)

COEEFICIENT	VALUE	NORMAL PRESSURE ON THE SURFACE (kN/m2)
CpA	-1.00	-0.70
CpB	-0.80	-0.56
CpC	-0.50	-0.35
CpD	0.80	0.56
CpE	-0.30	-0.21

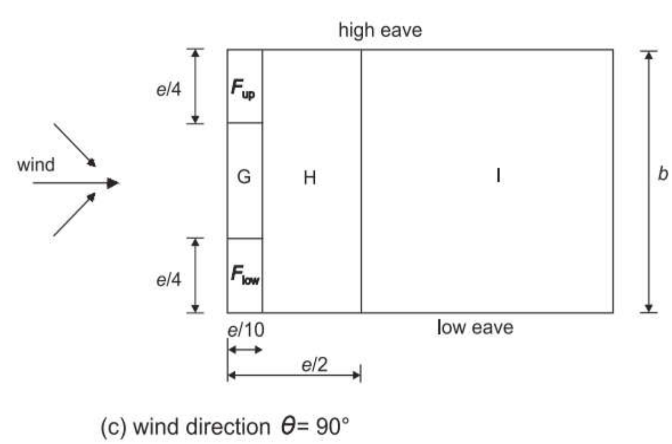
Table 3.18 Process about calculation of Normal pressure on different surface at vertical direction (office)

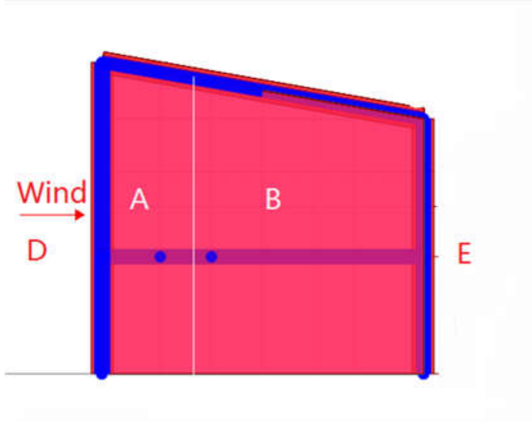
The normalized load of wind at pitch roofs.

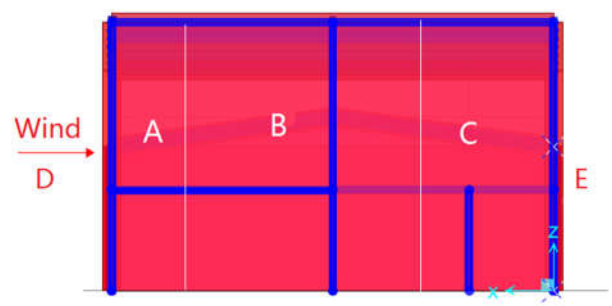
Wind Transversal



Wind Longitudinal







DRAG COEFFICIENT (TRANSVERSAL)

COEEFICIENT	VALUE	NORMAL PRESSURE ON THE SURFACE （kN/m2)
CpF (θ=0)	-1.62	-1.13
CpG (θ=0)	-1.16	-0.81
CpH (θ=0)	-0.57	-0.40
CpF (θ=180)	-2.32	-1.62
CpG (θ=180)	-1.30	-0.91
CpH (θ=180)	-0.81	-0.57

DRAG COEFFICIENT (LONGITUDINAL)

COEEFICIENT	VALUE	NORMAL PRESSURE ON THE SURFACE （kN/m2)
CpFup	-2.13	-1.49
CpFlow	-2.05	-1.44
CpG	-1.81	-1.27
CpH	-0.62	-0.43
CpI	-0.52	-0.36

Table 3.19 Process about calculation of Normal pressure on different surface at roof (office)

Coefficients for Ultimate limit states and Serviceability limit state of WIND

Coefficient for ULS and SLS	
Ultimate limit states under the fundamental combinations	$\gamma_F = \gamma_\alpha = 1.5$
Serviceability limit state	$\gamma_0 = \gamma_c = 1.0$

Table 3.20 Coefficients for Ultimate limit states and Serviceability limit state of WIND

D. Seismic

According to the "Cod De Proiectare Seismica-Preveneri De Proiectare Pentru Cladiri-P100-1-2013", the data about the seismic action is shown below:

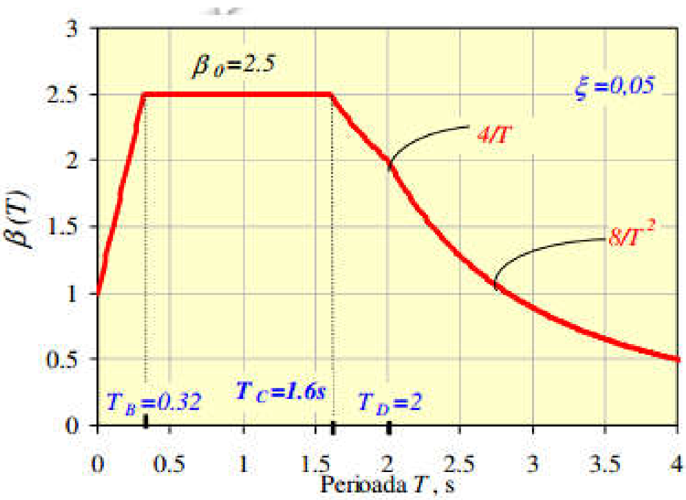


Figure 3.7 amplification coefficient

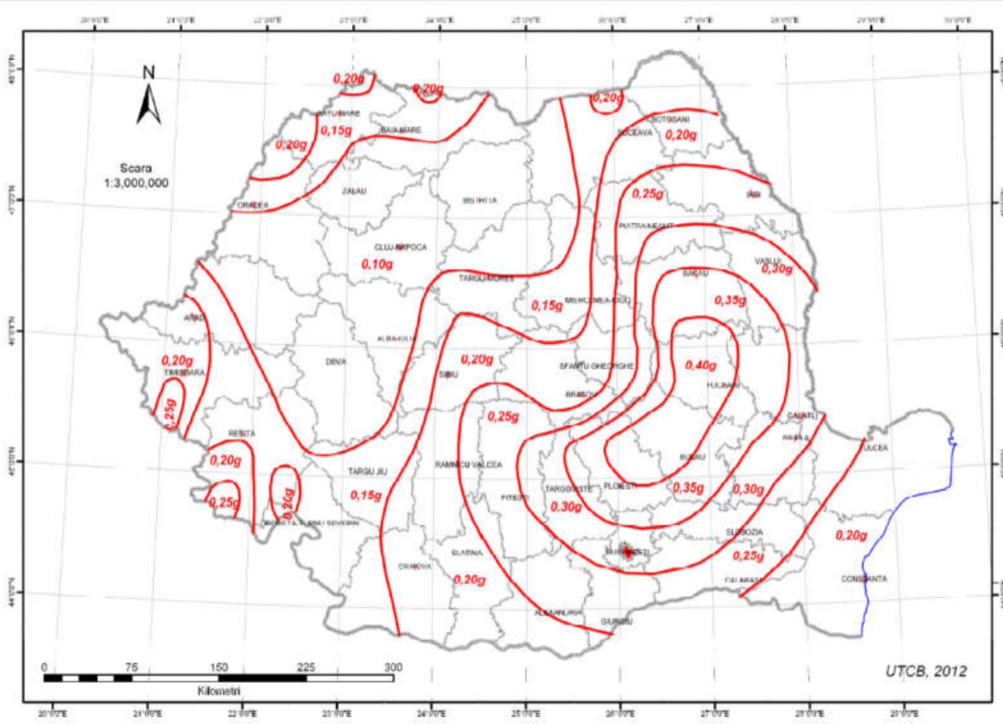


Figure 3.8 Seismic action in code P100-1/2013

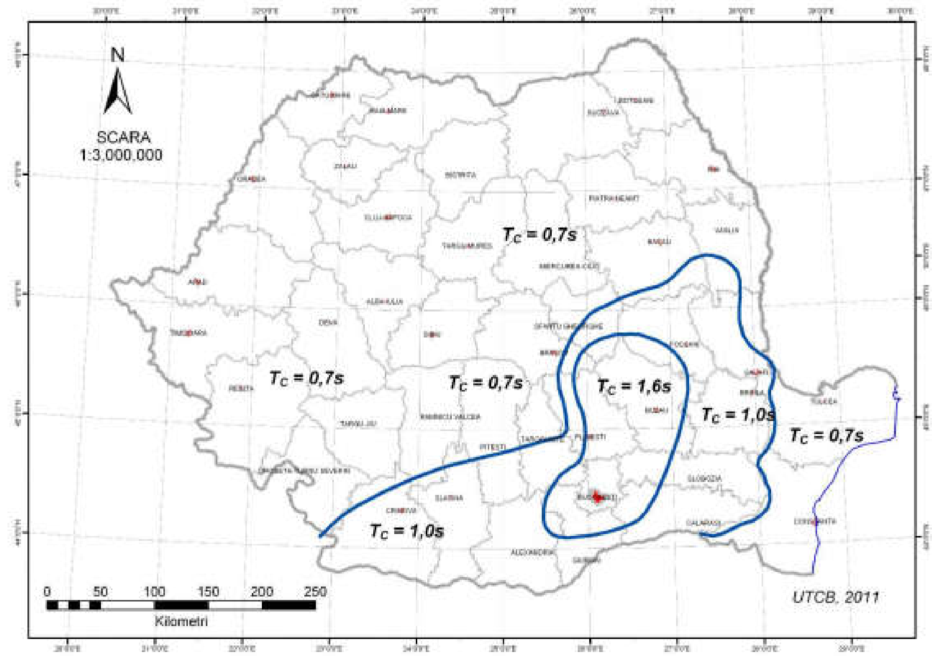


Figura 3.2 Zonarea teritoriului României în termeni de perioada de control (colț), T_C a spectrului de răspuns

Figure 3.9 Elastic response spectra

SEISMIC PARAMETERS

Design round of acceleration	ag=0.30g
Important factor	γ1=1
amplification coefficient	β0=2.5
Behaviour factor	q=1
Upper limit of the period of the constant spectral acceleration branch	Tc=1.6

Table 3.21 Parameters about seismic action

Horizontal elastic response spectrum

$0 \leq \mathrm{T} \leq T_B$ $$\beta(T) = 1 + \frac{(\beta_0 \quad 1)}{T_B} T$$

$T_B \leq \mathrm{T} \leq T_C$ $$\beta(T) = \beta_0$$

$T_C \leq \mathrm{T} \leq T_D$ $$\beta(T) = \frac{T_C}{T} \beta_0$$

$T_D \leq \mathrm{T} \leq 5\mathrm{S}$ $\qquad \beta(T) = \frac{T_C T_D}{T^2}\beta_0$

$S_e(\mathrm{T}) = a_g\beta(T)$ $\qquad$ Elastic response spectrum

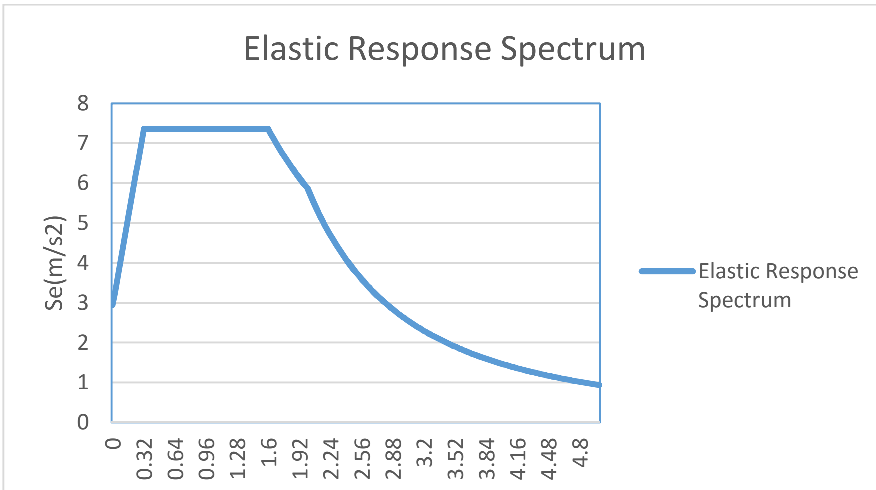


Figure 3.10 Elastic Response Spectrum

Design spectrum for elastic analysis:

$0 \leq \mathrm{T} \leq T_B$ $\qquad S_d(\mathrm{T}) = a_g(1 + \frac{(\beta_0/q \quad 1)}{T_B}T)$

$T_B \leq \mathrm{T}$ $\qquad S_d(\mathrm{T}) = a_g\beta(T)/q \geq 0.2a_g$

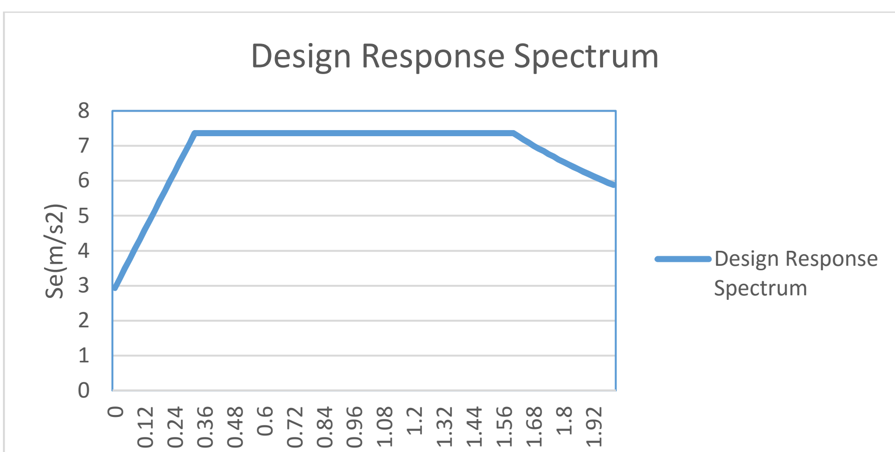


Figure 3.11 Design Response Spectrum

Seismic mass

In order to get the base shear force, it shall be considered the inertial effects of the design seismic action, which need to be evaluated by taking into account the presence of the masses associated with all gravity loads. According to the EN 1998-1 3.2.4 (2) P:

$$\Sigma G_{k,j} \text{"+"} \Sigma \psi_{E,i} \cdot Q_{k,i}$$

(2)P The combination coefficients ψ_{Ei} introduced in **3.2.4(2)P** for the calculation of the effects of the seismic actions shall be computed from the following expression:

$$\psi_{Ei} = \varphi \cdot \psi_{2i} \tag{4.2}$$

NOTE The values to be ascribed to φ for use in a country may be found in its National Annex. The recommended values for φ are listed in Table 4.2.

Table 4.2: Values of φ for calculating ψ_{Ei}

Type of variable action	Storey	φ
Categories A-C*	Roof	1,0
	Storeys with correlated occupancies	0,8
	Independently occupied storeys	0,5
Categories D-F* and Archives		1,0

* Categories as defined in EN 1991-1-1:2002.

Industrial building

GRAVITY LOAD

NO.	Items	Gk(kN/m2)	Qk(kN/m2)
①	Roof	0.25	-
②	Thermo-insulating	0.25	-
③	Additional weight	0.15	-
④	Snow	-	1.5

Roof		
Gk(kN/m2)	①+②+③	0.65
Qk(kN/m2)	④	1.5

Table 3.22 Gravity Load (Industrial building)

SEISMIIC MASS AND WEIGHT

Storey	Area(m2)	Gk(kN)	Qk(kN)	Seismic weight (kN)	Seismic mass (ton)
Roof	288	187.2	432	316.8	32.33

Table 3.23 Seismic Mass and Weight (Industrial building)

Base shear force

According to the “P100-1-2006”, The seismic base shear force is for each horizontal direction, the formula is shown below:

$F_b = \gamma_{I,e} S_d(T_1) m\lambda = 1 \times 6.65 m/s2 \times 32.33 ton \times 0.85 = 182.75 kN$

Where:

$S_d(T_1) = 6.65 m/s2$ — The ordinate of the design spectrum at period T_1

$T_1 = C_t H^{3/4} = 0.27$ — The fundamental period of vibration of the building for lateral motion in the direction considered.

$m = 32.33 ton$ — The total mass of the building, above the foundation or above the top of a rigid basement.

$\lambda = 0.85$ — The correction factor, the value of which is equal to : $\lambda = 0.85\ if\ T_1 \leq 2T_c$ and the building has More than two stories, or $\lambda = 1.0$ otherwise.

$C_t = 0.085$ — For moment resistant space steel frames.

$H = 4.7 m$ — Height of the building, from the foundation or from the top of a rigid basement.

γ1=1 — Important factor

it is necessary to transfer the base shear force to planar modes. The industrial factory building has two spans on x-direction, and four spans on y-direction.

$F_{bx,center} = \frac{F_b}{4\times2} = 22.84kN$ $F_{bx,edge} = \frac{F_b}{4\times2\times2} = 11.42kN$

$F_{by,center} = \frac{F_b}{4\times2} = 22.84kN$ $F_{by,edge} = \frac{F_b}{4\times2\times2} = 11.42kN$

Design inter-story drift

$d_r = q \times d_e = 1 \times 0.0055m = 0.0055m$

Office building

GRAVITY LOAD

NO.	Items	Gk(kN/m2)	Qk(kN/m2)
①	Roof	0.3	-
②	Floor	0.7	-
③	partition walls	0.5	-
④	Snow	-	1.6
⑤	Live load	-	2.00

Roof			Storey		
Gk(kN/m2)	①	0.3	Gk(kN/m2)	②+③	1.2
Qk(kN/m2)	④	1.6	Qk(kN/m2)	⑤	2.00

Table 3.24 Gravity Load (Office Building)

SEISMIIC MASS AND WEIGHT

Storey	Area(m2)	Gk(kN)	Qk(kN)	Seismic weight (kN)	Seismic mass (ton)
Roof	90	27	144	70.2	7.16
Storey	90	108	180	135	13.78
Total				205.2	20.94

Table 3.25 Seismic Mass and Weight (Office Building)

Base shear force

According to the "P100-1-2006", The seismic base shear force is for each horizontal direction, the formula is shown below:

$F_b = \gamma_{I,e} S_d(T_1) m\lambda = 1 \times 7.35m/s2 \times 20.94ton \times 0.85 = 130.82kN$

Where:

$S_d(T_1) = 7.35m/s2$	The ordinate of the design spectrum at period T_1
$T_1 = C_t H^{3/4} = 0.358$	The fundamental period of vibration of the building for lateral motion in the direction considered.
$m = 20.94ton$	The total mass of the building, above the foundation or above the top of a rigid basement.
$\lambda = 0.85$	The correction factor, the value of which is equal to : $\lambda = 0.85\ if\ T_1 \leq 2T_c$ and the building has More than two stories, or $\lambda = 1.0$ otherwise.
$C_t = 0.085$	For moment resistant space steel frames.
$H = 6.8m$	Height of the building, from the foundation or from the top of a rigid basement.
γ1=1	Important factor

It is necessary to transfer the base shear force to planar modes. The office building has only one span on both direction, that means the planar is 2, it can be ignored the slope roof, just consider the shape of building is like cuboid, so every planar is the same.

$F_{bx,center} = 130.82kN/4 = 32.71kN$

$F_{bx,edge} = 130.82kN/8 = 16.35kN$

$F_{by,center} = 130.82kN/4 = 32.71kN$

$F_{by,edge} = 130.82kN/8 = 16.35kN$

Distribution of horizontal and vertical seismic forces and loads

storey	Fi(kN)	Vi(kN)	zi(m)	mi(kNs2/m)	zi*mi	zi*mi/∑zj*mj	Fbxt(kN)
2(storey)	14.60405	14.60405	6.55	7.16	46.898	0.557619138	26.19
1(storey)	11.58595	26.19	2.7	13.78	37.206	0.442380862	26.19

Design inter-story drift and Second-order effects

$d_r = q \times d_e = 1 \times (0.0024 + 0.0013)m = 0.0037m$

storey	Ptot(kN)	dr(mm)	Vtot(kN)	h(m)	$\theta = \frac{P_{tot} \cdot d_r}{V_{tot} \cdot h}$
2(storey)	70.2	3.7	3.7	3.85	0.018233766
1(storey)	135	1.3	5	2.7	0.013

The $\theta < 0.1$, so the second-order effects could be neglected

About the calculation of seismic load**, it is noticed that here just to compare the two different codes due to in different time. In this thesis, it will apply software (SAP2000) for seismic analysis by putting data from response spectrum.**

3.3.2.3 Combination of Action (Static analysis)

Industrial building

Loading Assumption

P=Permanent

T=Technology

S=Snow

WT=Wind Transverse

WL=Wind Longitudinal

ET=Earthquake Transverse

EL= Earthquake Longitudinal

Ultimate limit state

THE FUNDAMENTAL COMBINATION (ULS)	
1	$1.35(P+T)$
2	$1.35(P+T)+1.5S$
3	$1.35(P+T)+1.5WT$
4	$1.35(P+T)+1.5WL$
5	$1.35(P+T)+1.05S+1.05WL$
6	$1.35(P+T)+1.05S+1.05WT$
7	$1.35P+1.5S+1.05T+1.05WL$
8	$1.35P+1.5S+1.05T+1.05WT$
9	$1.35P+1.5WT+1.05T+1.05S$
10	$1.35P+1.5WL+1.05T+1.05S$

Table 3.26 The fundamental combination (ULS) (Industrial Building)

Serviceability limit state

THE FUNDAMENTAL COMBINATION (SLS)	
1	$1P+1T$
2	$1P+1S$
3	$1P+1WT$
4	$1P+1WL$
5	$1P+1T+0.7S+0.7WL$
6	$1P+1T+0.7S+0.7WT$
7	$1P+1S+0.7T+0.7WL$
8	$1P+1S+0.7T+0.7WT$
9	$1P+1WT+0.7T+0.7S$
10	$1P+1WL+0.7T+0.7S$

Table 3.27 The fundamental combination (SLS) (Industrial Building)

THE SPECIAL SITUATION (ULS)	
1	$1P + 1T + 0.4S + ET + 0.3EL$
2	$1P + 1T + 0.4S + 0.3ET + EL$

Table 3.28 The special situation (ULS) (Industrial Building)

Office building

Loading Assumption

Per=Permanent

Pay=Live load

Qua=Quasi-permanent

S=Snow

WT=Wind Transverse

WL=Wind Longitudinal

ET=Earthquake Transverse

EL= Earthquake Longitudinal

Ultimate limit state

THE FUNDAMENTAL COMBINATION (ULS)	
1	$1.35Per + 1.35Qua + 1.5Pay$
2	$1.35Per + 1.35Qua + 1.5S$
3	$1.35Per + 1.35Qua + 1.5WT$
4	$1.35Per + 1.35Qua + 1.5WL$
5	$1.35Per + 1.35Qua + 1.5Pay + 1.05S + 1.05WL$
6	$1.35Per + 1.35Qua + 1.5Pay + 1.05S + 1.05WT$
7	$1.35Per + 1.35Qua + 1.5S + 1.05Pay + 1.05WL$
8	$1.35Per + 1.35Qua + 1.5S + 1.05Pay + 1.05WT$
9	$1.35Per + 1.35Qua + 1.5WT + 1.05Pay + 1.05S$
10	$1.35Per + 1.35Qua + 1.5WL + 1.05Pay + 1.05S$

Table 3.29 The fundamental combination (ULS) (Office Building)

Serviceability limit state

THE FUNDAMENTAL COMBINATION (SLS)	
1	$1Per + 1Qua + 1Pay$
2	$1Per + 1Qua + 1S$
3	$1Per + 1Qua + 1WT$
4	$1Per + 1Qua + 1WL$
5	$1Per + 1Qua + 1Pay + 0.7S + 0.7WL$
6	$1Per + 1Qua + 1Pay + 0.7S + 0.7WT$
7	$1Per + 1Qua + 1S + 0.7Pay + 0.7WL$
8	$1Per + 1Qua + 1S + 0.7Pay + 0.7WT$
9	$1Per + 1Qua + 1WT + 0.7Pay + 0.7S$
10	$1Per + 1Qua + 1WL + 0.7Pay + 0.7S$

Table 3.30 The fundamental combination (SLS) (Office Building)

THE SPECIAL SITUATION (ULS)	
1	$1Per + 1Qua + 1Pay + 0.4S + ET + 0.3EL$
2	$1Per + 1Qua + 1Pay + 0.4S + 0.3ET + EL$

Table 3.31 The special situation (ULS) (Office Building)

3.4 Structure Design and Verification (Model A and B of New Project)

In this part, the structure verification just **focuses on the new building, including the reused design and standard design, based on the Eurocode**. About the difference between the two designing purpose, it has been illustrated on the first chapter.

3.4.1 Industrial Building

3.4.1.1 Column

1. Classification of Cross-section — EN 1993-1-1, 5.6

2. Verification of Cross-section Resistance — EN 1993-1-1, 6

   a. Compression — EN 1993-1-1, 6.2.4

b. Flexural buckling-uniform members in compression EN 1993-1-1, 6.3

c. Combined bending and axial compression buckling

$$\frac{N_{Ed}}{N_{Rd}} + \frac{M_{y,Ed}}{M_{y,Rd}} \leq 1{,}0$$

3. Verification of the stability of the member EN 1993-1-1, 6.3.3

$$\frac{N_{Ed}}{\chi_y N_{Rd}} + k_{yy}\frac{M_{y,Ed}}{\chi_{LT} M_{y,Rd}} \leq 1{,}0$$

4. Verification of Serviceability EN 1998-1, 4.4.3.2

$$d_r \mathrm{V} \ \leq 0.005$$

COLUMN	
NO.	8
Length	3.9m
Combo	F-ULS-P/Q/S/P/WT+NL
Steel Grade	S355
GEOMETRIC PROPERTIES	
h	350mm
b	250mm
tw	6mm
tf	14mm
A	8932mm2
fy	355N/mm2
MyEd	354.8322kNm
Ned	234.771kN
Ved	90.406kN
CLASSIFICATION OF CROSS-SECTION	
Flange	Class 2
Web	Class 4
RESULT	
Compression	$\frac{N_{Ed}}{N_{cRd}} = 0.074 < 1$
Bending Moment	$\frac{M_{y,Ed}}{M_{y,Rd}} = 0.82 < 1$
Bending and Axial	$\frac{N_{Ed}}{N_{cRd}} + \frac{M_{y,Ed}}{M_{y,Rd}} = 0.89 < 1$

Lateral-torsional Buckling	$\frac{N_{Ed}}{N_{bRd}} + \frac{M_{y,Ed}}{M_{by,Rd}} = 0.96 < 1$
SLS	$d_{r,a}^{SLS} = 0.005 \quad = 0.0235m \quad > 0.0055m$

Table 3.32 Calculation process about Column of Industrial Building

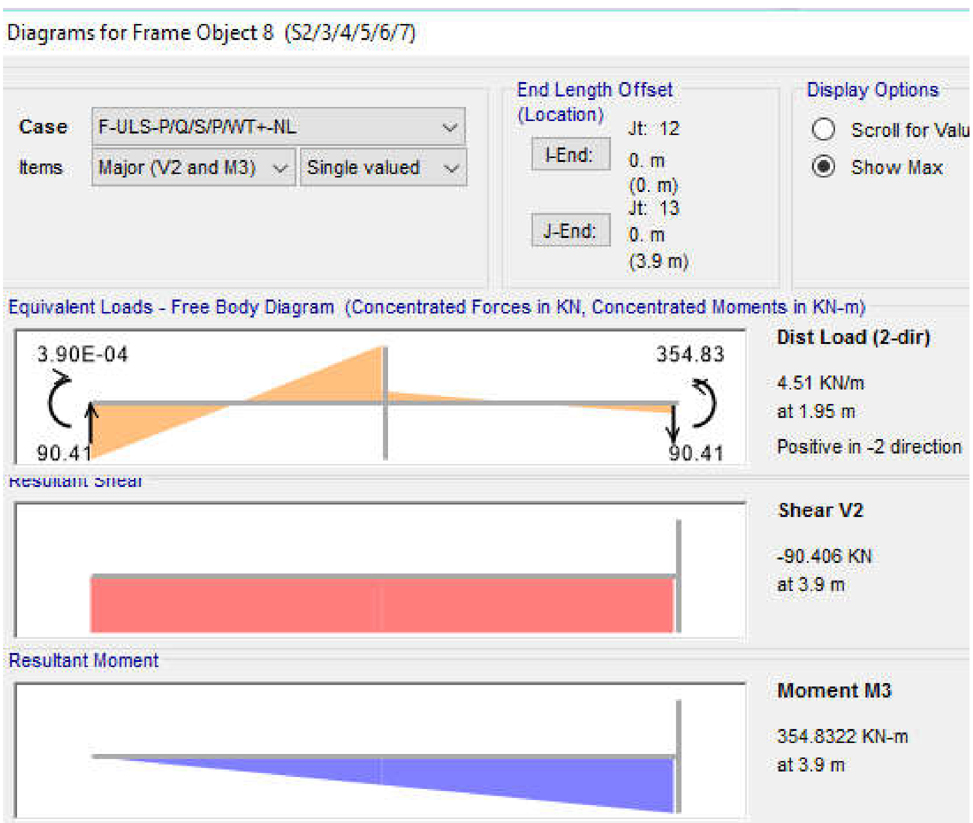


Figure 3.12 Result from SAP2000 about Column 8

3.4.1.2 Main Beam

1. Classification of Cross-section — EN 1993-1-1, 5.6

2. Verification of Cross-section Resistance — EN 1993-1-1, 6

a. Bending moment — EN 1993-1-1, 6.2.5

b. Shear EN 1993-1-1, 6.2.6

c. Bending and Shear EN 1993-1-1, 6.2.8

3. Verification of Serviceability EN 1993-1-1, 6.3.3

$$\delta_{max} = \frac{L}{360}$$

Figure 3.13 Result from SAP2000 about Beam 28

RAFTER	
NO.	28
Length	6.0m
Combo	F-ULS-P/Q/S/P/WT+NL
Steel Grade	S355
GEOMETRIC PROPERTIES	

h	350mm
b	200mm
tw	6mm
tf	14mm
A	7532mm2
fy	355N/mm2
MyEd	354.8329kNm
Ned	141.043kN
Ved	204.773kN
CLASSIFICATION OF CROSS-SECTION	
Flange	Class 1
Web	Class 1
RESULT	
Shear	$\frac{V_{Ed}}{V_{plRd}} = 0.52 < 1$
Bending Moment	$\frac{M_{y,Ed}}{M_{cy,Rd}} = 0.99 < 1$
SLS	$\delta_{max} = \frac{L}{360} = 16.81mm > 6.13mm$

Table 3.33 Calculation process about Beam of Industrial Building

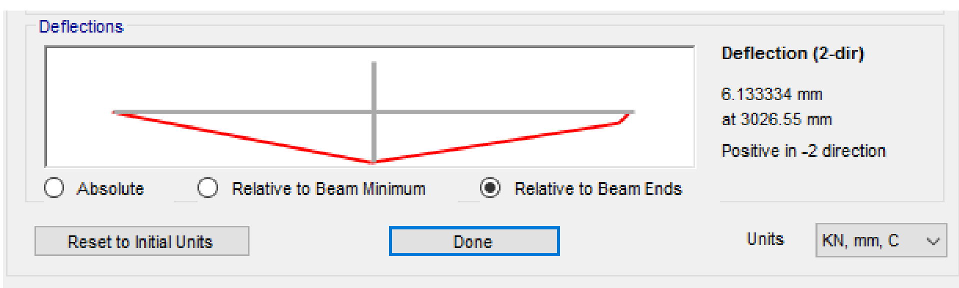


Table 3.34 Result of Deflection from SAP2000 about Beam 28

3.4.1.3 Bracing (Wall)

1. Classification of Cross-section — EN 1993-1-1, 5.6

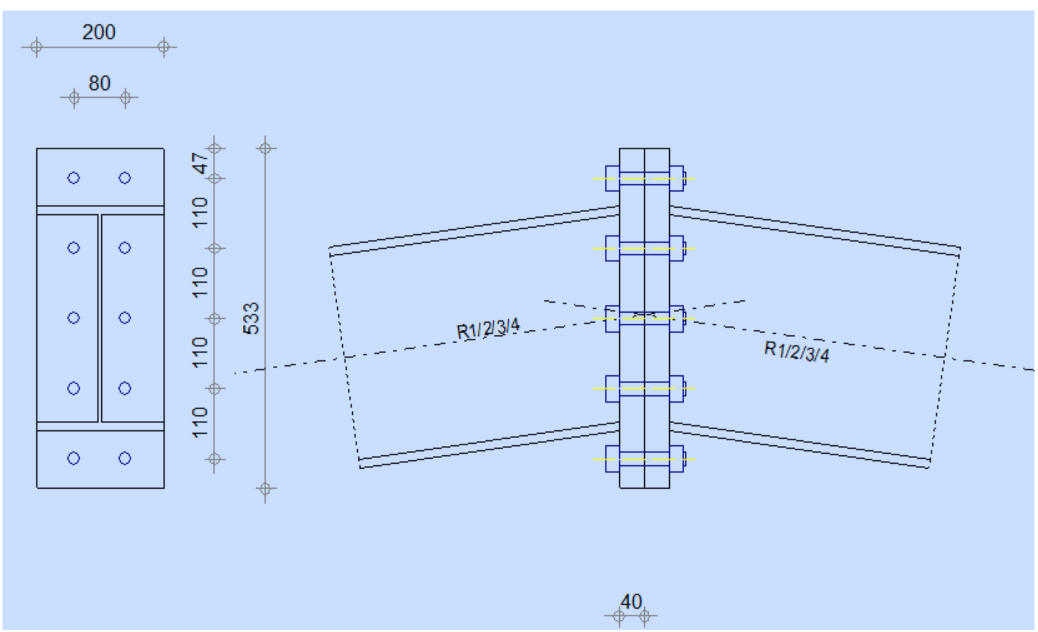
2. Verification of Cross-section Resistance — EN 1993-1-1, 6

   a. Tension — EN 1993-1-1, 6.2.5

BRACING	
TYPE	66
Length	7.156m
Combo	F-ULS-P/WT-
Steel Grade	S355
GEOMETRIC PROPERTIES	
D	27mm
A	573mm2
fy	355N/mm2
Iy	26087mm4
Iz	26087mm4
Wply	3280mm3
Wplz	3280mm3
Ned	6.636kN
RESULT	
Tension	$\frac{N_{Ed}}{N_{cRd}} = 0.033 < 1$

Table 3.35 Calculation process about Bracing of Industrial Building

3.4.1.4 Connection (Beam to Beam)

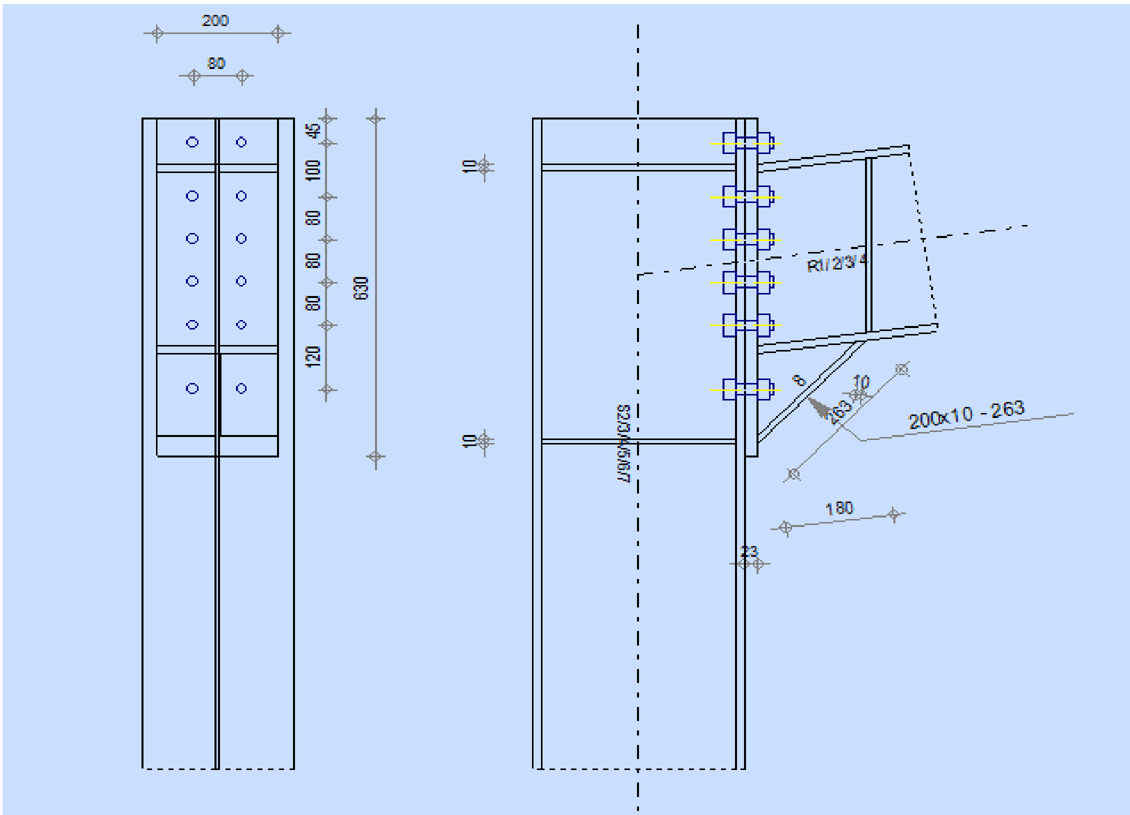


1. Beam resistances
    a. Compression — EN 1993-1-1 6.2.4
    b. Shear — EN 1993-1-1 6.2.6
    c. Bending-Plastic moment (Without Brackets) — EN 1993-1-1 6.2.5
    d. Bending on the contact surface with plate — EN 1993-1-1 6.2.5
    e. Flange and Web – Compression — EN 1993-1-1 6.2.6
2. Connection resistance for bending
    a. Column flange resistance due to bending — EN 1993-1-8 6.2.4
    b. Column web resistance due to tension — EN 1993-1-8 6.2.6
    c. Resistance of the front plate due to bending — EN 1993-1-8 6.2.5
    d. Resistance of the web in tension — EN 1993-1-8 6.2.5
    e. Resistance of the bolt — EN 1993-1-8 6.2.7
3. Connection stiffness — EN 1993-1-8 6.3.1

JOINT	
TYPE	Beam to Beam
Steel Grade(Beam)	S355
Bolts Class	10.9
RESULT	
Stiffness	1238.8
Connection resistance for bending	0.32<1
Joint classification	Rigid
Weakest component	Beam Web - Tension

Table 3.36 Calculation process about Connection (Beam to Beam) of Industrial Building

3.4.1.5 Connection (Frame knee)



1. Beam resistances

   a. Tension — EN 1993-1-1 6.2.4

   b. Shear — EN 1993-1-1 6.2.6

   c. Bending-Plastic moment (Without Brackets) — EN 1993-1-1 6.2.5

   d. Bending on the contact surface with plate — EN 1993-1-1 6.2.5

   e. Flange and Web – Compression — EN 1993-1-1 6.2.6

2. Column resistances

   a. Web panel - shear — EN 1993-1-1 6.2.6.1

   b. Web – transverse compression — EN 1993-1-1 6.2.6.2

3. Connection resistance for bending

   a. Column flange resistance due to bending — EN 1993-1-8 6.2.4

   b. Column web resistance due to tension — EN 1993-1-8 6.2.6

   c. Resistance of the front plate due to bending — EN 1993-1-8 6.2.5

   d. Resistance of the web in tension — EN 1993-1-8 6.2.5

   e. Resistance of the bolt — EN 1993-1-8 6.2.7

4. Connection stiffness — EN 1993-1-8 6.3.1

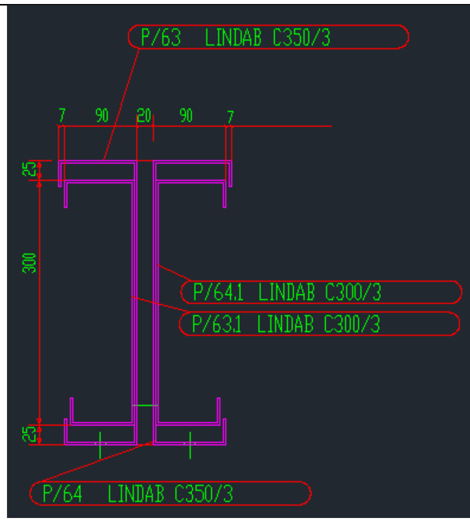
JOINT	
TYPE	Frame knee
Steel Grade(Beam)	S355
Bolts Class	10.9
RESULT	
Stiffness	532.31
Connection resistance for bending	0.57<1
Joint classification	Semi-Rigid
Weakest component	Column Web - Shear

Table 3.37 Calculation process about Connection (Frame knee) of Industrial Building

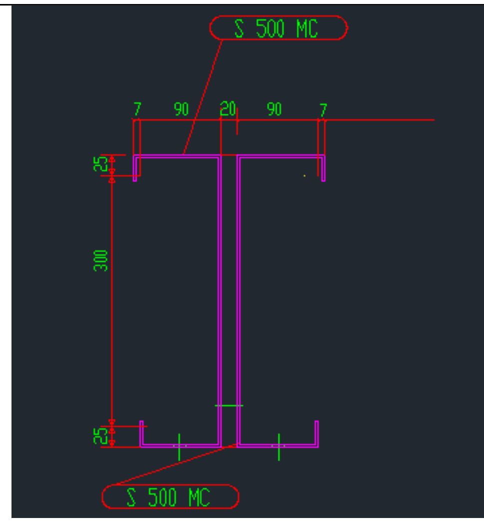
3.4.2 Office Building

About the office building in this thesis, considered from two purpose, one is the reused purpose, it means the materials are reused from the original building in Craiova. In order to satisfy the requirements of both ultimate limit state and servicing limit state, and also don't waste the component as much as possible. The cross-section is designed to compound section.

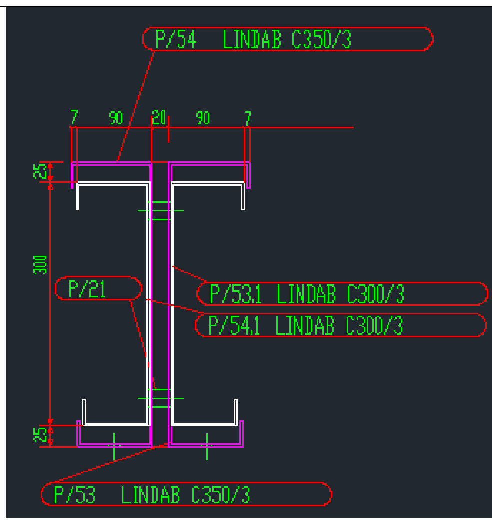
The other one is the standard design, following the general design process. The details are shown below.



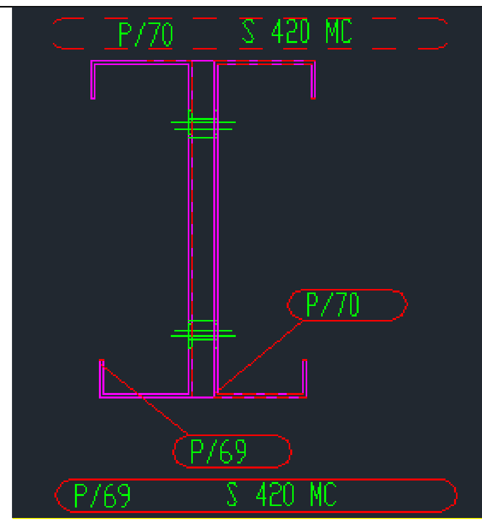
REUSED PURPOSE DESIGN (COLUMN)



STANDARD DESIGN(COLUMN)



REUSED PURPOSE DESIGN(BEAM)



STANDARD DESIGN(BEAM)

Table 3.38 Difference about Column and Beam between reused design and standard design

3.4.2.1 Reused purpose design

3.4.2.1.1 Load Capacity of Lipped-channel Column

1. Checking of geometrical proportions — EN 1993-1-3, 5.2

2. Gross cross-section properties

3. Effective cross-section for stiffener — EN 1993-1-3, 5.5.3.2

a. Obtain an initial effective cross-section for the stiffeners using effective widths of the flanges

b. Use the initial effective cross-section of the stiffener to determine the reduction factor.

c. Iterate to refine the value of the reduction factor for buckling of the stiffener. The iteration stops when the reduction factor converges.

4. Effective section properties of the web — EN 1993-1-3, 5.5.3.4.3

5. Resistance of cross-section (Compression) — EN 1993-1-1, 6.3.3

COLUMN	
NO.	6
Length	2.72m
Combo	F-ULS-P/Q/P/S/WL+
Steel Grade	S350GD+Z
RESULT	
Compression	$\frac{N_{Ed}}{N_{cRd}} = 0.116 < 1$
Bending Moment	$\frac{M_{y,Ed}}{M_{cy,Rd}} = 0.54 < 1$
Bending and Axial	$\frac{N_{Ed}}{N_{cRd}} + \frac{M_{y,Ed}}{M_{cy,Rd}} = 0.66 < 1$

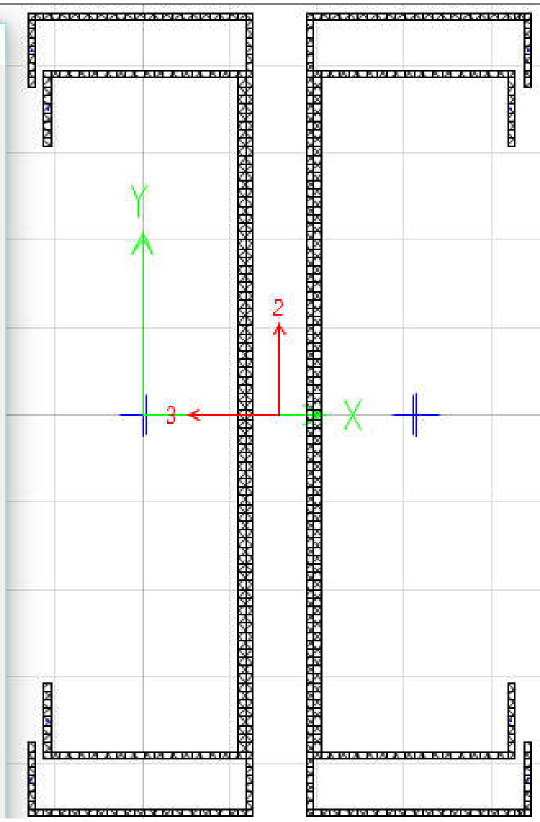
Table 3.39 Calculation process about Lipped-channel Column of Office Building (Reused Design)

PROPERTIES DATA IS FROM SAP2000

Properties

Base Material	ColdFormed
Xcg	59.9412
Ycg	0
Axis Angle	90

A	6771
J	20507
I33	1.068E+08
I22	18263423
I23	0
AS2	4085.7498
AS3	3462.2038
S33(+face)	610400
S33(-face)	610400
S22(+face)	166120
S22(-face)	165942
Z33	770935
Z22	263914
r33	125.603
r22	51.9355
d33pna	0
d22pna	11.4455

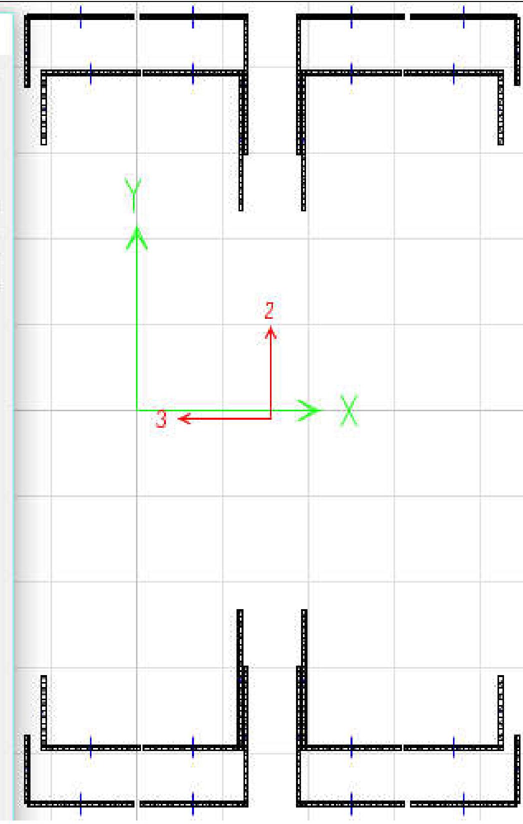


ORIGINAL CROSS-SECTION

Properties

Base Material	ColdFormed
Xcg	59.454
Ycg	-3.5702
Axis Angle	90

A	2961.7998
J	4237.8817
I33	66551958
I22	12006026
I23	-164053
AS2	2961.7998
AS3	2021.5255
S33(+face)	372277
S33(-face)	387765
S22(+face)	110245
S22(-face)	109150
Z33	431888
Z22	153254
r33	149.9003
r22	63.6681
d33pna	-94.1132
d22pna	10.168



EFFECTIVE CROSS-SECTION

Figure 3.14 Properties data about Lipped-channel Column of office building (Reused Design)

3.4.2.1.2 Load Capacity of Lipped-channel Beam

1. Checking of geometrical proportions — EN 1993-1-3, 5.2

2. Gross cross-section properties

3. Effective cross-section for stiffener — EN 1993-1-3, 5.5.3.2

   a. Obtain an initial effective cross-section for the stiffeners using effective widths of the flanges

   b. Use the initial effective cross-section of the stiffener to determine the reduction factor.

   c. Iterate to refine the value of the reduction factor for buckling of the stiffener. The iteration stops when the reduction factor converges.

4. Effective section properties of the web — EN 1993-1-3, 5.5.3.4.3

5. Resistance of cross-section (Bending) — EN 1993-1-1, 6.1.4

6. Resistance of cross-section (Shear) — EN 1993-1-1, 6.1.5

BEAM	
NO.	1
Length	7.6m
Combo	F-ULS-P/Q/P/S/WL-
Steel Grade	S350GD+Z
RESULT	
Bending Moment	$\frac{M_{y,Ed}}{M_{cy,Rd}} = 0.69 < 1$
Shear	$\frac{V_{Ed}}{V_{bRd}} = 0.43 < 1$

Table 3.40 Calculation process about Lipped-channel Beam of Office Building (Reused Design)

3.4.2.2 Standard design

3.4.2.2.1 Load Capacity of Lipped-channel Column

1. Checking of geometrical proportions — EN 1993-1-3, 5.2

2. Gross cross-section properties

3. Effective cross-section for stiffener — EN 1993-1-3, 5.5.3.2

   a. Obtain an initial effective cross-section for the stiffeners using effective widths of the flanges

   b. Use the initial effective cross-section of the stiffener to determine the reduction factor.

   c. Iterate to refine the value of the reduction factor for buckling of the stiffener. The iteration stops when the reduction factor converges.

4. Effective section properties of the web — EN 1993-1-3, 5.5.3.4.3

5. Resistance of cross-section (Compression) — EN 1993-1-1, 6.3.3

COLUMN	
NO.	6
Length	2.72m
Combo	F-ULS-P/Q/P/S/WL+
Steel Grade	S 500 MC
RESULT	
Compression	$\frac{N_{Ed}}{N_{cRd}} = 0.20 < 1$
Bending Moment	$\frac{M_{y,Ed}}{M_{cy,Rd}} = 0.78 < 1$
Bending and Axial	$\frac{N_{Ed}}{N_{cRd}} + \frac{M_{y,Ed}}{M_{cy,Rd}} = 0.98 < 1$

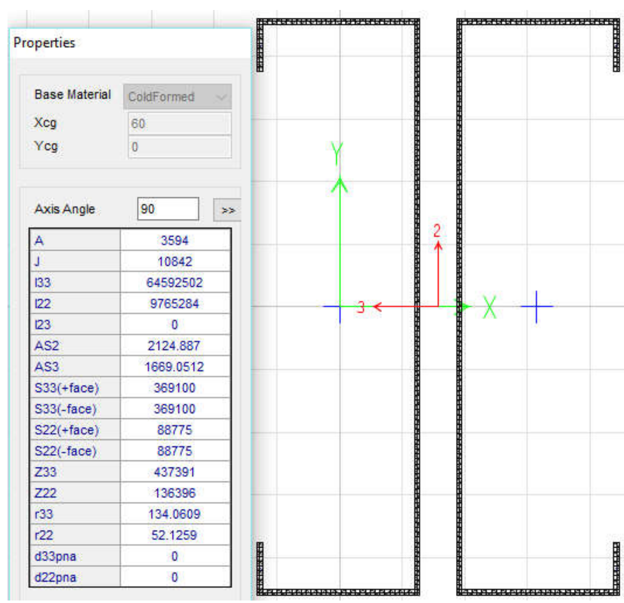


Figure 3.15 Calculation process and Properties data about Lipped-channel Column of Office Building (Standard Design)

3.4.2.2.2 Load Capacity of Lipped-channel Beam

1. Checking of geometrical proportions — EN 1993-1-3, 5.2

2. Gross cross-section properties

3. Effective cross-section for stiffener — EN 1993-1-3, 5.5.3.2

   a. Obtain an initial effective cross-section for the stiffeners using effective widths of the flanges

   b. Use the initial effective cross-section of the stiffener to determine the reduction factor.

   c. Iterate to refine the value of the reduction factor for buckling of the stiffener. The iteration stops when the reduction factor converges.

4. Effective section properties of the web — EN 1993-1-3, 5.5.3.4.3

5. Resistance of cross-section (Bending) — EN 1993-1-1, 6.1.4

6. Resistance of cross-section (Shear) — EN 1993-1-1, 6.1.5

BEAM	
NO.	1
Length	7.6m
Combo	F-ULS-P/Q/P/S/WL-
Steel Grade	S420 MC
RESULT	
Bending Moment	$\frac{M_{y,Ed}}{M_{cy,Rd}} = 0.60 < 1$
Shear	$\frac{V_{Ed}}{V_{bRd}} = 0.39 < 1$

Table 3.41 Calculation process about Lipped-channel Beam of Office Building (Standard Design)

3.5 Conclusion

3.5.1 Comparison about Load between previous code and new code.

After review the precious code and new code, the comparison of loading will be shown below.

OLD LOADING-Industrial Factory-Craiova 2004

Load (Design code)	Characteristic Value		Safety Coefficient (STAS 10101/0A-85)		
			ULS-Fundamental	SLS-Fundamental	ULS-Accidental
Permanent load (STAS 10101-1/78)	Self-weight	provided by the software	1.100	1.000	1.000
	Cladding incl. thermo-insulation (roof and walls)	0.25kN/m2	1.100		
	Technological loadings	0.15kN/m2	1.100		
Snow (STAS 10101/21-92 STAS 10101/0A-77)	uniform load	1.5 kN/m2	2.130	1.370	0.300
	drifted load	3.0 kN/m2	2.130	1.370	0.300
	exceptional load	5.25 kN/m2			1.000
Wind (STAS 10101/20-90)	transversal	0.704kN/m2	1.200	1.000	
	longitudinal	0.704kN/m2	1.200	1.000	
Seismic (P100-92)	Parameters				1.000
	Design ground of acceleration	ag=0.20g			
	Amplification coefficient	$\beta 0=2.5$			
	Behaviour factor	q=1			
	Upper limit of the period of the constant spectral acceleration Branch	Tc=1.5			

OLD LOADING-Office-Craiova 2004

Load	Characteristic Value		Safety Coefficient (STAS 10101/0A-85)		
			ULS-Fundamental	SLS-Fundamental	ULS-Accidental
Permanent load (STAS 10101-1/78)	Self-weight	provided by the software			
	Cladding incl. thermo-insulation (roof)	0.3kN/m2	1.100	1.000	1.000
	Cladding incl. thermo-insulation and Technological loadings(floor)	0.7kN/m2	1.100		

Quasi-Permanent (STAS 10101-1/78)	Partition walls on the slab	0.5kN/m2	1.100		
Live load (STAS 10101-1/78)	Live load	0.2kN/m3	1.200		
Snow (STAS 10101/21-92)	uniform load	1.5 kN/m2	2.130	1.370	0.300
Wind (STAS 10101/20-90)	transversal	0.704kN/m2	1.200	1.000	
	longitudinal	0.704kN/m3	1.200	1.000	
Seismic (P100-92)	Parameters				1.000
	Design round of acceleration	ag=0.20g			
	Amplification coefficient	β0=2.5			
	Behaviour factor	q=1			
	Upper limit of the period of the constant spectral acceleration branch	Tc=1.5			

NEW LOADING-Industrial Factory-Bucharest (2012). The calculations have been confirmed for 2016 too.

Load (Design code)	Characteristic Value		Safety Coefficient (CR 0-2012)		
			ULS-Fundamental	SLS-Fundamental	ULS-Accidental
Permanent load (SR EN 1991-1-1)	Self-weight	provided by the software	1.350	1.000	1.000
	Cladding incl. thermo-insulation (roof and walls)	0.25kN/m2	1.350		
	Technological loadings	0.15kN/m2	1.350		
Snow (CR 1-1-3/2012)	uniform load	1.6 kN/m2	1.500	1.000	0.400
	drifted load	2.9 kN/m2	1.500	1.000	0.400
	exceptional load	4.2 kN/m2			1.000
Wind (CR1-1-4/2012)	transversal	0.42 kN/m2	1.500	1.000	
	longitudinal	0.56 kN/m2	1.500	1.000	
Seismic (P100-2013)	Parameters				1.000
	Design round of acceleration	ag=0.30g			
	Amplification coefficient	β0=2.5			
	Behaviour factor	q=1			
	Upper limit of the period of the constant spectral acceleration branch	Tc=1.6			

NEW LOADING-Office-Bucharest (2012). The calculations have been confirmed for 2016 too.

Load	Characteristic Value		Safety Coefficient (CR 0-2012) ULS-Fundamental	SLS-Fundamental	ULS-Accidental
Permanent load (SR EN 1991-1-1)	Self-weight	provided by the software	1.350	1.000	
	Cladding incl. thermo-insulation (roof)	0.3kN/m2	1.350	1.000	
	Cladding incl. thermo-insulation and Technological loadings(floor)	0.7kN/m2	1.350	1.000	1.000
Quasi-Permanent (SR EN 1991-1-1)	Partition walls on the slab	0.5kN/m2	1.350	1.000	
Live load (SR EN 1991-1-1)	Live load	0.2kN/m3	1.500	1.000	
Snow (CR 1-1-3/2012)	uniform load	1.6 kN/m2	1.500	1.000	0.400
Wind (CR1-1-4/2012)	transversal	0.42 kN/m2	1.500	1.000	
	longitudinal	0.56 kN/m2	1.500	1.000	
Seismic (P100-2013)	Parameters				1.000
	Design round of acceleration	ag=0.30g			
	Amplification coefficient	β0=2.5			
	Behaviour factor	q=1			
	Upper limit of the period of the constant spectral acceleration branch	Tc=1.6			

Comparison of Loading-Industrial factory

Load (Design code)	Characteristic Value	OLD	NEW	OLD ULS-Fundamental	NEW ULS-Fundamental	RATE	OLD SLS-Fundamental	NEW SLS-Fundamental	RATE	OLD ULS-Accidental	NEW ULS-Accidental	RATE
Permanent load (STAS 10101-1/78)	Cladding incl. thermo-insulation (roof and walls)	0.25kN/m2	0.25kN/m2	0.275	0.338	18.5%	0.250	0.250	0.0%	0.250	0.250	0.0%
	Technological loadings	0.15kN/m2	0.15kN/m2	0.165	0.203	18.5%	0.150	0.150	0.0%	0.150	0.150	0.0%
Snow (STAS 10101/21-92 STAS 10101/0A-77)	uniform load	1.5 kN/m2	1.6 kN/m2	3.195	2.400	-33.1%	2.055	1.600	-28.4%	0.450	0.640	29.7%
	drifted load	3.0 kN/m2	2.9 kN/m2	6.390	4.350	-46.9%	4.110	2.900	-41.7%	0.900	1.160	22.4%
	exceptional load	5.25 kN/m2	4.2 kN/m2							5.250	4.200	-25.0%
Wind (STAS 10101/20-90)	transversal	0.704kN/m2	0.42 kN/m2	0.845	0.630	-34.1%	0.704	0.420	-67.6%			
	longitudinal	0.704kN/m2	0.56 kN/m2	0.845	0.840	-0.6%	0.704	0.560	-25.7%			

Comparison of Loading-Office

Load (Design code)	Characteristic Value	OLD	NEW	OLD ULS-Fundamental	NEW ULS-Fundamental	RATE	OLD SLS-Fundamental	NEW SLS-Fundamental	RATE	OLD ULS-Accidental	NEW ULS-Accidental	RATE
Permanent load (SR EN 1991-1-1)	Cladding incl. thermo-insulation (roof)	0.3kN/m2	0.3kN/m2	0.330	0.405	18.5%	0.300	0.300	0.0%	0.300	0.300	0.0%
	Cladding incl. thermo-insulation and Technological loadings(floor)	0.7kN/m2	0.7kN/m2	0.770	0.945	18.5%	0.700	0.700	0.0%	0.700	0.700	0.0%
Quasi-Permanent (SR EN 1991-1-1)	Partition walls on the slab	0.5kN/m2	0.5kN/m2	0.550	0.675	18.5%	0.500	0.500	0.0%	0.500	0.500	0.0%
Live load (SR EN 1991-1-1)	Live load	0.2kN/m3	0.2kN/m3	0.240	0.300	20.0%	0.200	0.200	0.0%	0.200	0.200	0.0%
Snow (CR 1-1-3/2012)	uniform load	1.5 kN/m2	1.6 kN/m2	3.195	2.400	-33.1%	2.055	1.600	-28.4%	0.450	0.640	29.7%
Wind (CR1-1-4/2012)	transversal	0.704kN/m2	0.42 kN/m2	0.845	0.630	-34.1%	0.704	0.420	-67.6%			
	longitudinal	0.704kN/m3	0.56 kN/m2	0.845	0.840	-0.6%	0.704	0.560	-25.7%			

Comparison of Seismic loading between old and new code

	Parameters	OLD (P100-92)	NEW (P100-2013)	RATE
Seismic	Design round of acceleration	ag=0.20g	ag=0.30g	50.0%
	Amplification coefficient	$\beta_0=2.5$	$\beta_0=2.5$	0.0%
	Behavior factor	q=1	q=1	0.0%
	Upper limit of the period of the constant spectral acceleration branch	Tc=1.5	Tc=1.6	-

From the comparison, there are some results need to be paid attention. in ULS, the load factor of permanent load, new code is larger than previous one, almost 18.5%, because in the previous load factor is 1.1, but in new code is 1.35. Then about the snow load and wind load. In new code, the load factor about snow is 1.5 but in previous is 2.13, increased almost to 50%. About wind, there are two main points need to be considered, the first is the load factor about wind decreased by 15% from the previous code to new code, and the other is that calculation method is changed, for example, the drag coefficient, in old code, the transversal direction, the drag coefficient is 0.8, but in new code, is 0.6, decreased by 33%. In SLS, the load factor of s+++now load is changed from 1.37 in previous code to 1 in new code.

3.5.2 Structure improvement of New project

Compared to old project, there are some structure members need to be added or improved on new project.

1. Industrial building: The number of the bays change to four from three on original building, and in new building, the roof is not diaphragm as previous building, it changed to bracing for supporting.
2. Office building: The shape about the office building is same, but the section of the primary members need to be changed (About the changed members, shown in Figure 2.2), because the design code had already updated as time goes on, and the location is also different, based on the new code, about the constant spectral acceleration, Bucharest is higher than in Craiova. So, the cross-section of new building need to be strengthened. Model A is designed by reused purpose, it means the elements of the new building will be as much as possible reused from the old building. But in Model B, the new building will be designed under the standard process. That means we do not need to consider about the reused members, any member can be made from the steel making factory. So about the cross-section shown in graph in Model B column, it is not necessary C350/3, but in the Model A column, it should be C350/3, same as the previous building, and because the cross-section in new building need to be strengthened, in the Model A, the only one choice

is adding the C300/3 inside C-channel. But in the Model B, after calculation and verification, S 500MC can be satisfied.

3.5.3 Properties degradation about structure materials

After checking the loading resistance of elements both reused purpose design and standard design. The steel parts meet requirements. However, it still needs to consider the mechanical properties degradation about reused steel. In this project, because the environment is proper, after checking the element from the old building, steel is not corroded too much. In most situation, it should be taken into account about the properties degradation. The problem is that, in practical, it was not possible to perform material testing about how much reducing of the reused steel, it is suggestion that about further research of the degradation of the reused steel bearing element.

4. SUSTAINABILITY ANALYSIS (MODEL A and B of New Project)

The Roman architect, Vitruvius, once defined the purposes of architecture as creating commodity, firmness, and delight—roughly translated as usefulness, stability, and beauty. To that list, we now must add a fourth purpose, harmony, by which I mean the fit between buildings and the built environment broadly with the ecologies of particular places.(Charles J. Kibert, 2013)

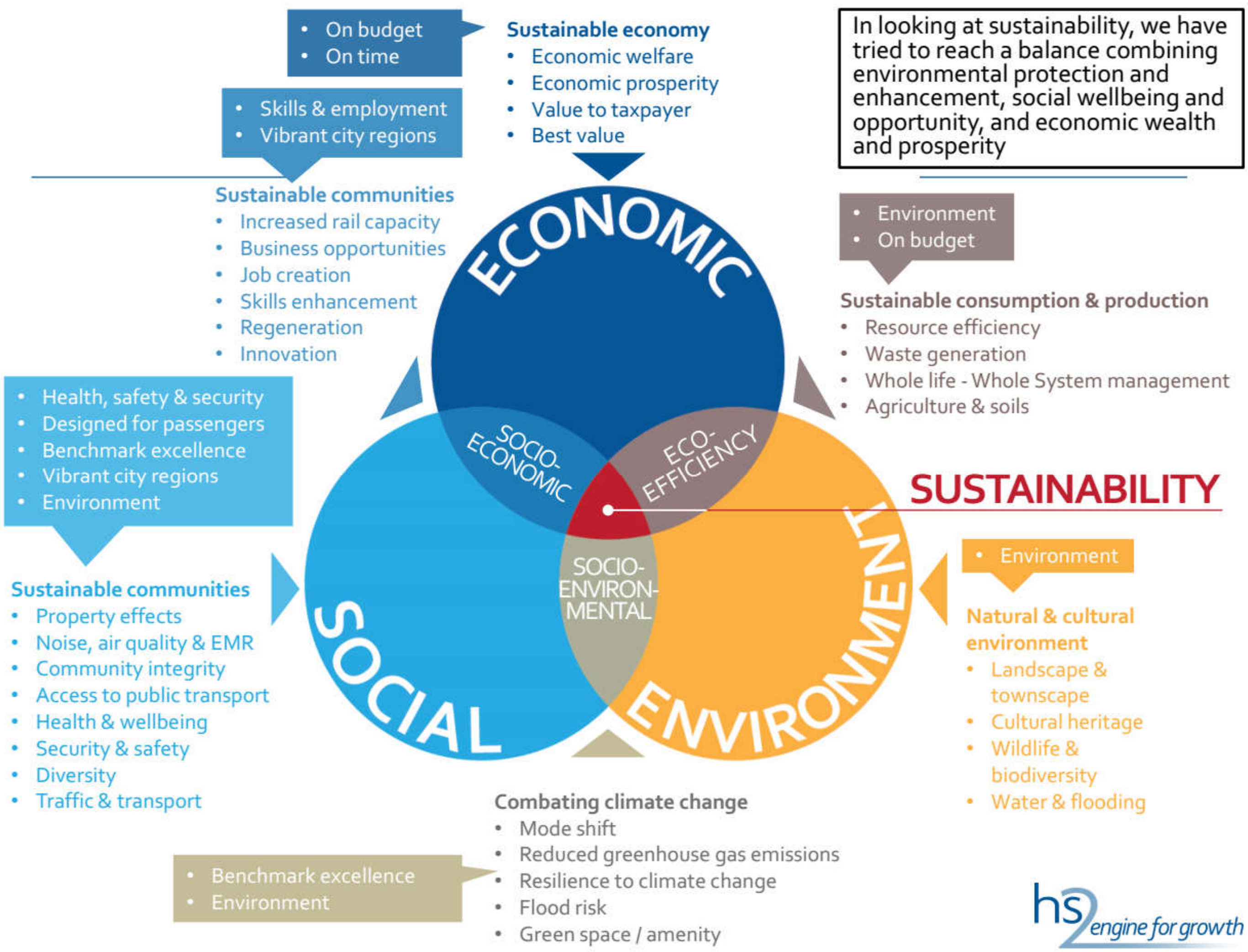


Table 4.1(Smart, Sustainable Construction)

4.1 Overview

In this chapter, it will focus on the Model A and Model B, to analyse and compare the two design processes about the material saving, economic and environmental concerns.

It should be underlined the fact here that even though it is a real project, the previous structure was constructed in more than 10 years ago and new building is still 5 years ago. Some data and information is difficult to get. **So without influence the analysis, 1. part information will be searched from internet or reference book. For example, the insulation of the wall and floor, and the price about the steel. 2.The models in SimaPro will be simplified to avoid inputting uncertain data. It will explain later 3. The elements for reuse here are considered as potential resources. The net impacts are the totally impact includes reusing process which substitutes primary production, minus the impacts producing substituted primary product.**

4.2 Prerequisite of the reused structure

The prerequisite of reused building is rather crucial. The first thing is the previous structure should be easy to dismantle and then keep the members in good condition. In this real case study. The old industrial building in Craiova turned out to satisfy all requirements. The elements were demolished and then transport to Bucharest, almost 250km away. New building is similar with the old building, consist of two separate part. One is office building with the cold-form members and the other is steel industrial factory.

In general, in order to get the reused section under good condition from the old building, it should dismantle the structure in damage-free way. Sometimes, cutting or torch cutting the steel is more economical. Fortunately, in this project, almost every member is the same dimension, so just uninstalling the joint is enough.

The next important part is storage and transportation. Usually, structural elements will be placed on the ground and then transport to the warehouse. But considering secondary damage of the reused members due to further sandblasting, it is better to adopt the protective measures such as painting operation. About transportation, truck is an ideal choice. If transported by train, it will still be transfer again by truck from rail station to the construction site, and this process will need more man power, furthermore, in Romania, expense of train is not that cheaper than highway transportation. Hence, truck is cheaper and more convenient.

4.3 Material List of Previous Building VS New Building

About the material saving, superficially, it is a positive result because every member from the previous building is reused again. In reality, the design should be different if not consider the reuse-purpose, and the elements from the old structure still can be recycled or reused to another thing, not only to structure. So, it is difficult to compare which way is more material-saving.

In this thesis, in order to account, even to an approximate result, considering two models. **One is designing new structure in new elements (standard design). The other way presents the reused structure (reused purpose).** Next steps will show the details about the volume of material saving and environmental impact.

Comparison of Materials about Model A and Model B

Item	Previous building		Model A: reused purpose design						Model B: New standard design			
			Old elements from previous building		New elements from steel making factory		Totally consumption		New elements from steel making factory		Totally consumption	
Industrial	8799.67	kg	8799.67	kg	2762.03	kg	11561.7	kg	11561.7	kg	11561.7	kg
office	6436.3	kg	6436.3	kg	529.28	kg	6965.58	kg	6441	kg	6441	kg
Total	15235.97	kg	15235.97	kg	3291.31	kg	18527.28	kg	18002.7	kg	18002.7	kg

Table 4.2 Comparison of Materials about Model A and Model B

It is noted that **here is just illustrating the total weight from the design drawing**. In general, it should consider **the damage ratio of steel**. There is a fixed ratio to use based on much experience from the industry statistical data. And, about the reused way, the reused member need to be dismantled and if it is possible, some capacity losing members will be filtered out by verifying from responding institute. However, here it is difficult to get the rate, so just got the approximate result.

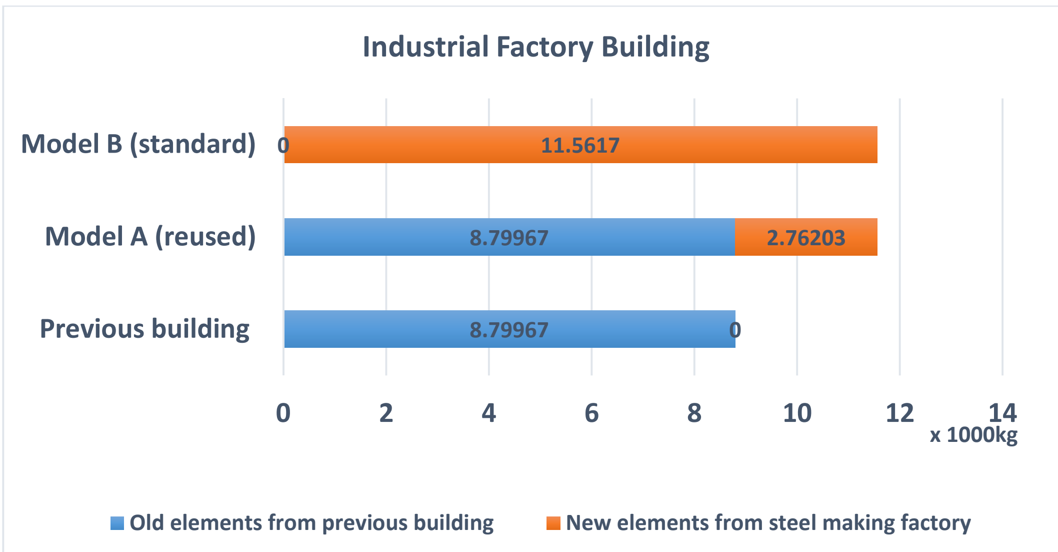


Figure 4.1 Materials of Previous building and New building in Model A and Model B (Industrial factory building)

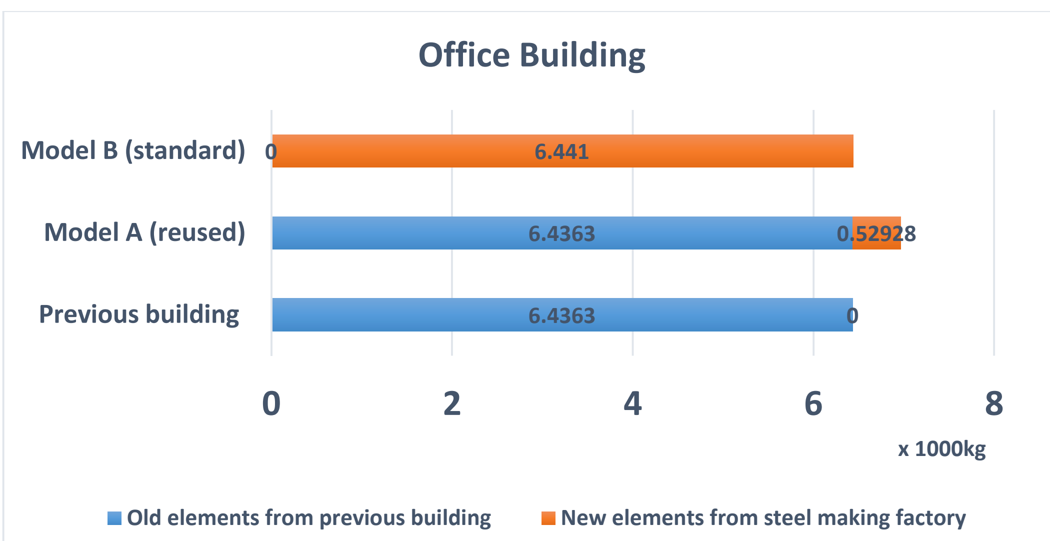


Figure 4.2 Figure 4.3 Materials of Previous building and New building in Model A and Model B (Office building)

From the graph, in simple comparison, the total consumption in Model B is nearly double of Model A, because in Model B, the all previous members are not reused and waste, and the materials of new building are produced by steel making factory, it is a large amount. And in Model A, considering saving materials as much as possible, the consumption is not that much.

4.4 Boundaries about Economic and Environmental concerns

The main factors affecting to economic and environmental issues here are: material production, construction and transportation.

In the Model B (a standard design process), steel making process should be considered, but in the Model A (reused design), most of elements are used from the existing building, so it will decrease much spending and greenhouse gas to produce steel members. However, from another aspect, if the elements are produced in local place, compared the reused members transported from another city (in this case study, almost 250km), it still can cut the cost and reduce the CO2 emission due to transportation. Furthermore, although in the model B, all members are bought from the steel factory, it still does not necessary to throw away all the previous members, they can be recycled in other ways. In this chapter, it will show the details later of expense and Life cycle assessment considering the factors above.

Next, such processes related to demolition is not easy to evaluate because of uncertainty of data, for instance different facilities of dismantling, it depends on the company. So here the energy consumption related to the dismantling and re-fabrication process will generally be ignored. At the same time, about the foundation, because the soil quality in different two places and other related factors are not clear. In this thesis, it will not be considered. The table will show about which impact will be considered.

ECONOMIC IMPACT

		Considered
Structure	Structure elements	
	Foundation	
	Non-structure materials	
Transport	Truck	
Construction	Dismantling	
	Installation	
Others	Electricity	
	Labour	

ENVIRONMENTAL IMPACT

		Considered
Structure	Structure elements	
	Foundation	
	Non-structure materials	
Transport	Truck	
Construction	Dismantling	
	Installation	
Others	Electricity	
	Labour	

Table 4.3 Aspect need to be considered about economic and environmental impact

4.5 Economic concerns

Model A					
New elements from steel making factory			**Price**		
			Material	**Transportation/10km**	**SUM**
Industrial	2762	kg	3,380.72 €	350.00 €	3,730.72 €
office	529.28	kg	647.84 €	85.00 €	732.84 €
Old elements from previous building			**Price**		
			Material	**Transportation/250km**	**SUM**
Industrial	8799.7	kg	0.00 €	2,870.00 €	2,870.00 €
office	6436.3	kg	0.00 €	760.00 €	760.00 €
Total (New and Old)	18527	kg	4,028.56 €	4,065.00 €	8,093.56 €

Table 4.4 Total expense about the Model A (Reused Design)

Model B					
New elements from steel making factory			**Price**		
			Material	**Transportation/10km**	**SUM**
Industrial	11,561.70 €	kg	14,151.52 €	350.00 €	14,501.52 €
office	6,441.00 €	kg	7,883.78 €	85.00 €	7,968.78 €
Total	18,002.70 €	kg	22,035.30 €	435.00 €	22,470.30 €

Table 4.5 Total expense about the Model B (Standard Design)

After the calculation, it is easy to know if just consider the economic impact, the Model A (Reused Design) can save more money, almost 14000 euro. Because of neglecting the old steel elements production. Even though need to plus the 250km transportation, the expense of transportation is not that much influence than steel production.

4.6 Environmental concerns (LCA)

4.6.1 Scope and definition

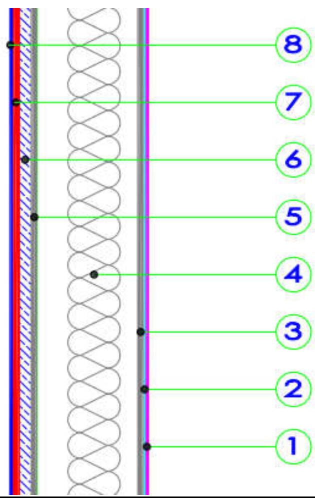
As said before in literature review, it will employ the SimaPro software and Ecoinvent database to analyse the LCA, the input materials here based on the constructive elements:

1. Exterior walls;
2. Interior was;
3. Flooring system;
4. Roof system;

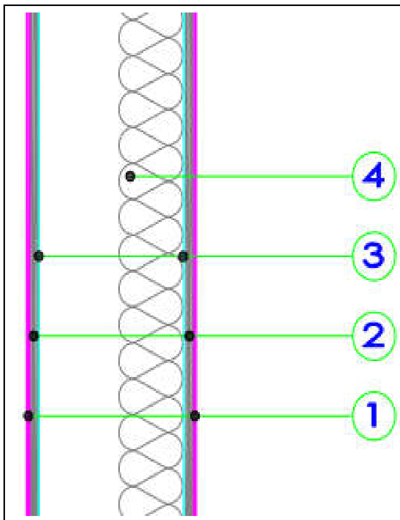
Foundation-infrastructure here will not be considered because the soil texture and condition in two projects (previous building in Craiova and new building in Bucharest) is different. The foundation design here will not be same and it will influence the results of comparison.

Table below presents the quantities of materials for the construction stage. Note that the value was from the internet and some factory product book. The result includes the generic weight as the materials are gathered all-together.

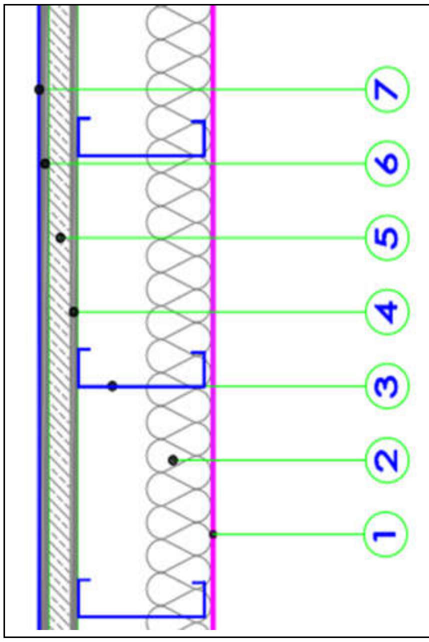
INFORMATION ABOUT THE MATERIALS (OFFICE)



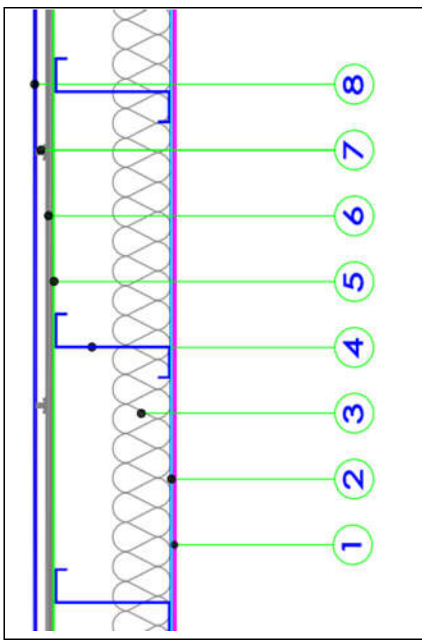
External Wall		
Constitutive materials	Thickness	Use(kg/sqm)
1.Gypsum plaster board	12.5cm	9.15
2. Vapour barrier (foil)	2mm	0.1
3. Internal oriented strand board (OSB)	12mm	7.7
4. Mineral wool	100mm	4.5
5. Oriented strand board(External wall)	1.5cm	7.7
6. Thermo-insulation (polystyrene extruded) 20mm	2cm	0.7
7. Polyester wire lattice (glass fibre)		0.16
8.Exterior plastering (Silicone Baumit)	1.5cm	4.2



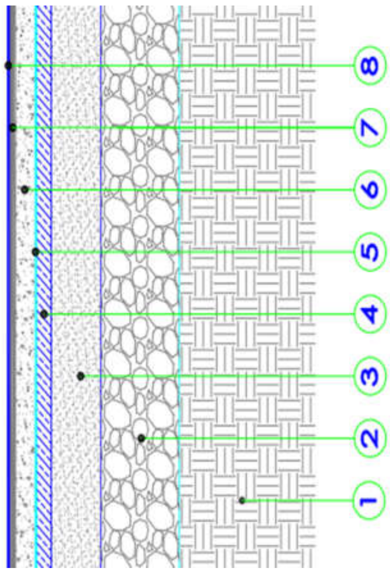
Internal Wall		
Constitutive materials	Thickness	Use(kg/sqm)
1. Gypsum plaster board, at plant/CH S (Internal and external wall)	12.5cmx2	18.3
2. Oriented strand board, at plant/RER S defined per mass (Internal and external wall)	2x1.5cm of OSB	15.36
3. Ethylvinylacetate (foil), vapour barrier	2cmx2	0.2
4. Mineral wool ETH S	5cm	2.25



FLOOR		
Constitutive materials	Thickness	Use(kg/sqm)
1. Interior gypsum plaster board	12.5cm	9.15
2. Thermo-insulation, mineral wool 50mm	5cm	2.25
3. TWCF profile		
4. Oriented strand board	1.2cm	7.68
5. Phono-insulation foil	3mm	0.1
6. Oriented strand board (OSB)	12mm	9.6
7. Finishing		



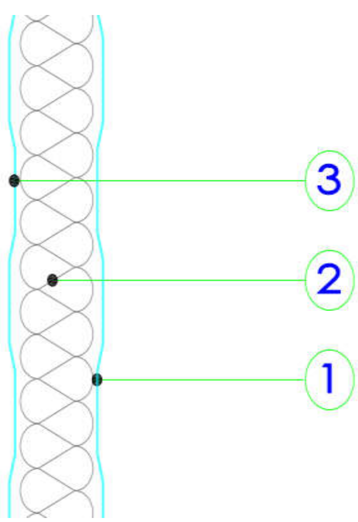
ROOF		
Constitutive materials	Thickness	Use(kg/sqm)
1. Interior gypsum plaster board	12.5cm	9.15
2. Vapour barrier (foil), anti-condense barrier	2mm	0.235
3. Mineral wool ETH S	18cm	8.1
4. TWCF profile		
5. Aluminium anti-reflex foil	3mm	0.1
6. Oriented strand board	1.5cm	9.6
7. Timber framing (sawn timber)		5.16
8. Steel tiled sheet (coated steel)		5



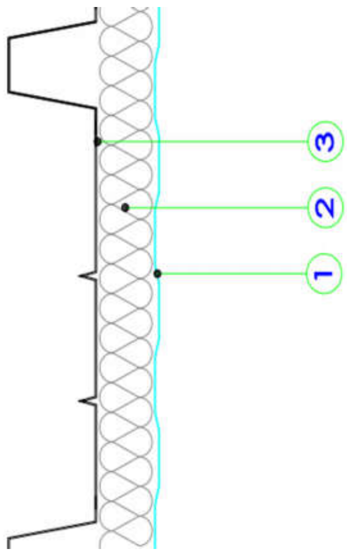
GROUND FLOOR		
Constitutive materials	Thickness	Use(kg/sqm)
1. Foundation soil		
2. Compacted soil	40cm	
3. Ballast	10cm	320
4. Thermo-insulation (polystyrene extruded)	5cm	1.75
5. Vapour barrier (foil)	2mm	
6. Concrete slab	10cm	1078
7. Concrete flooring (cement mortar)	3cm	
8. Finishing		

Table 4.6 Table 4.7 Layers used for structural components (Office)

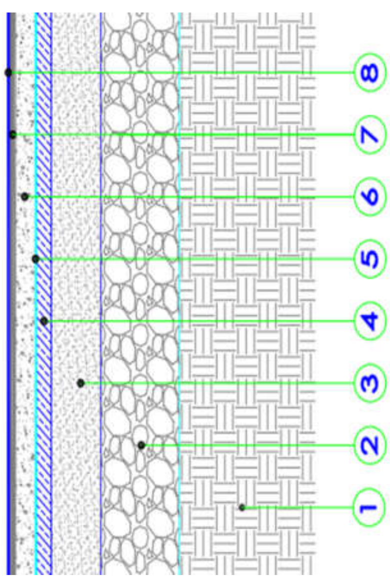
INFORMATION ABOUT THE MATERIALS (INDUSTRIAL FACTORY)



EXTERIAL WALL		
Constitutive materials	Thickness	Use(kg/sqm)
1. Rolled steel sections galvanized and pre-painted by the Coil Coating		
2. polyurethane		
3. Rolled steel sections galvanized and pre-painted by the Coil Coating		



ROOF		
Constitutive materials	Thickness	Use(kg/sqm)
1. Rolled steel sections galvanized and pre-painted by the Coil Coating		
2. polyurethane		
3. Rolled steel sections galvanized and pre-painted by the Coil Coating		



GROUND FLOOR		
Constitutive materials	Thickness	Use(kg/sqm)
1. Foundation soil		
2. Compacted soil	40cm	
3. Ballast	10cm	320
4. Thermo-insulation (polystyrene extruded)	5cm	1.75
5. Vapour barrier (foil)	2mm	
6. Concrete slab	10cm	1078
7. Concrete flooring (cement mortar)	3cm	
8. Finishing		

Table 4.8 Layers used for structural components (Industrial building)

SURFACE AREA (OFFICE)

Constructive element	Area(m2)
Exterior walls	249.99
Interior walls	281.74
Second Floor	81.89
Roof system	86.74
Ground floor	81.89

SURFACE AREA (INDUSTRIAL)

Constructive element	Area(m2)
Exterior walls	242.64
Interior walls	0
Second Floor	0
Roof system	218.16
Ground floor	216

Table 4.9 Computed surface for different constructive elements (sqm)

4.6.2 Boundary conditions

The main idea in this thesis is comparing the environmental impacts between two design processes, so in order to simplify the model and save time, about the boundary condition, some aspects which are similar in both solutions will be not integrated. The details here are:

1. All identical components and materials, including finishing but electrical or heating systems are left out of comparison
2. Transportation here will be taken into account, especially for comparing the environmental impacts between two design processes.
3. The domestic use of the building (water/gas/electricity) is left out of comparison.
4. Energy used for construction purpose (such as cranes and other machinery) was not included into the comparison.

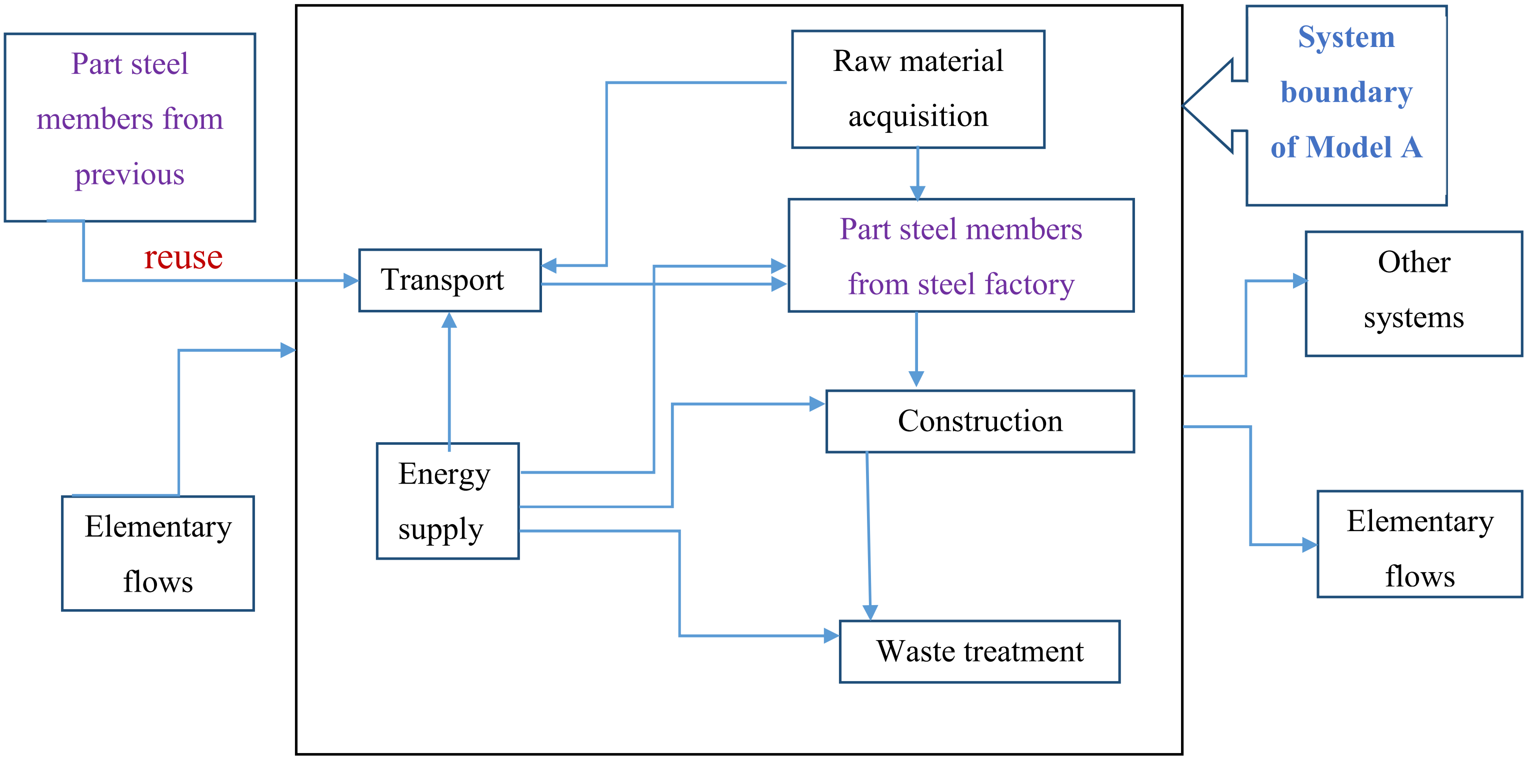


Figure 4.4 System Boundary of Model A

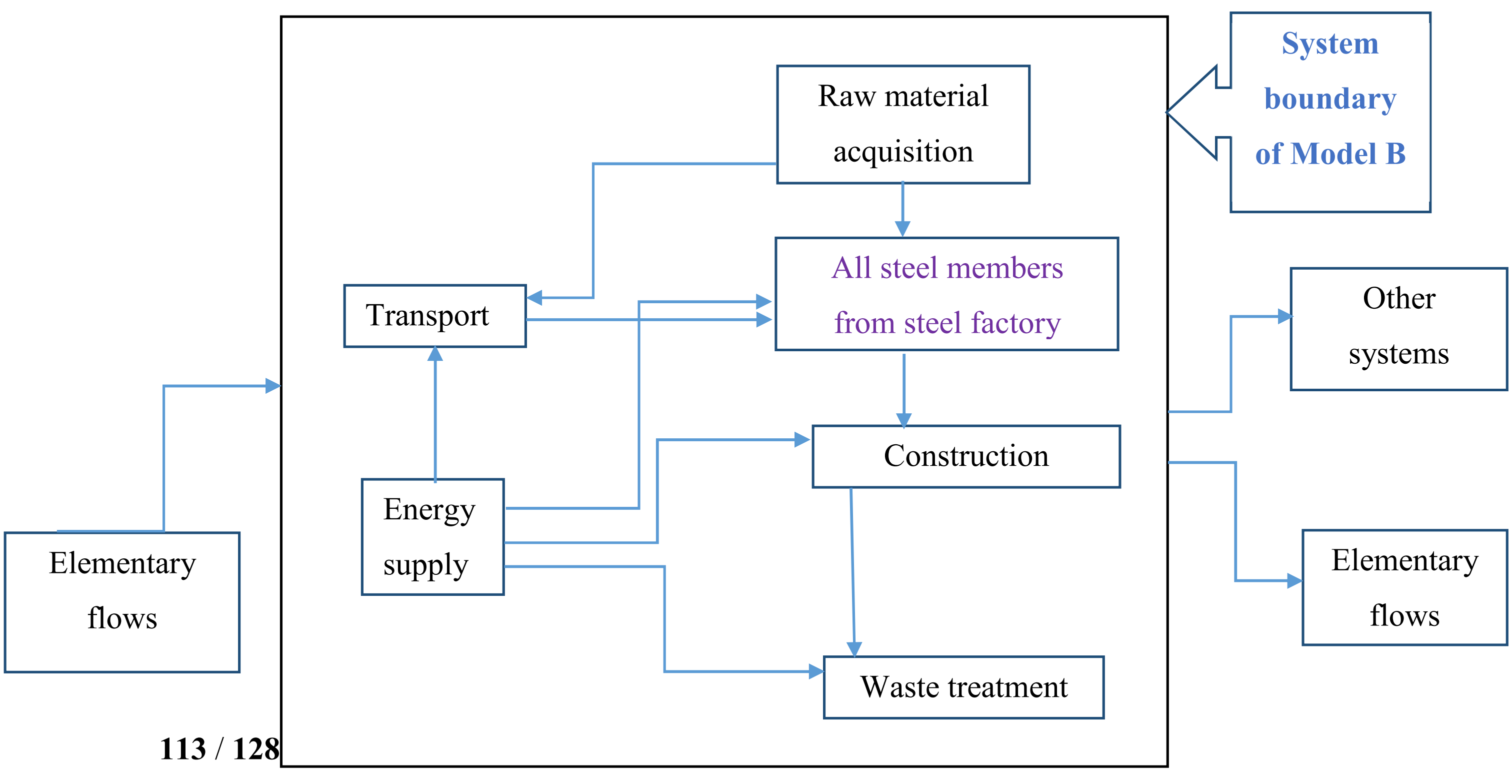


Figure 4.5 Figure 4.6 System Boundary of Model B

4.6.3 Result from SimaPro 7

In order to simplify the analysis from software, making an easier input of construction materials, and get the concise comparison of the two Models. There have been two parts for analysis, Stage 1 and Stage 2.

OPERATION PROCESS

TYPE	Stage 1		Stage 2		
MODEL A	new elements from steel making factory reused elements from previous building	transport 10km transport 250km	construction	maintenance	disposal
MODEL B	new elements from steel making factory	transport 10km	construction	maintenance	disposal

Table 4.10 Comparison of Operation Process about Model A and Model B

From the table above about the operation process, apart from the construction, maintenance and disposal (stage 1) which totally the same. The differences between the model A and B are just structure elements resources and transportation (stage 2)**. The another point here is regardless of the demolition of elements from previous members, and the reused steel production when input the data to SimaPro.** The first one is because it is difficult to get the database about the demolition, second one is because the materials are just from the previous building, it will not make the emission and waste to environment by steel making.

Hence, about analysis with SimaPro 7, it will be apart to stage 1 and stage 2.

4.6.3.1 Comparison of environment impact between MODEL A and B (Stage 1)

TYPE	Stage 1	
MODEL A	new elements from steel making factory (3t) reused elements from previous building (15t)	transport 10km transport 250km
MODEL B	new elements from steel making factory (18t)	transport 10km

Table 4.11 Operation Process about Model A

Environmental impact in every aspect

After calculation by SimaPro 7, almost every aspect of Model B is much higher than Model A. the details were shown below. It means even though in the reused design, there is a large distance from previous location to new location, the impact of transportation is not that much influence as the steel making process following the new design, in which almost 200tonnes steel production need to be taken into account about the environmental impact.

Regard to every aspect, one could realize that for both designs the major impact is for fossil fuels, because this resources are used for fabrication of building materials at all levels. Next are the eco-toxicity and respiratory inorganics. And noticed that these three impacts take the dominant among the environmental impacts.

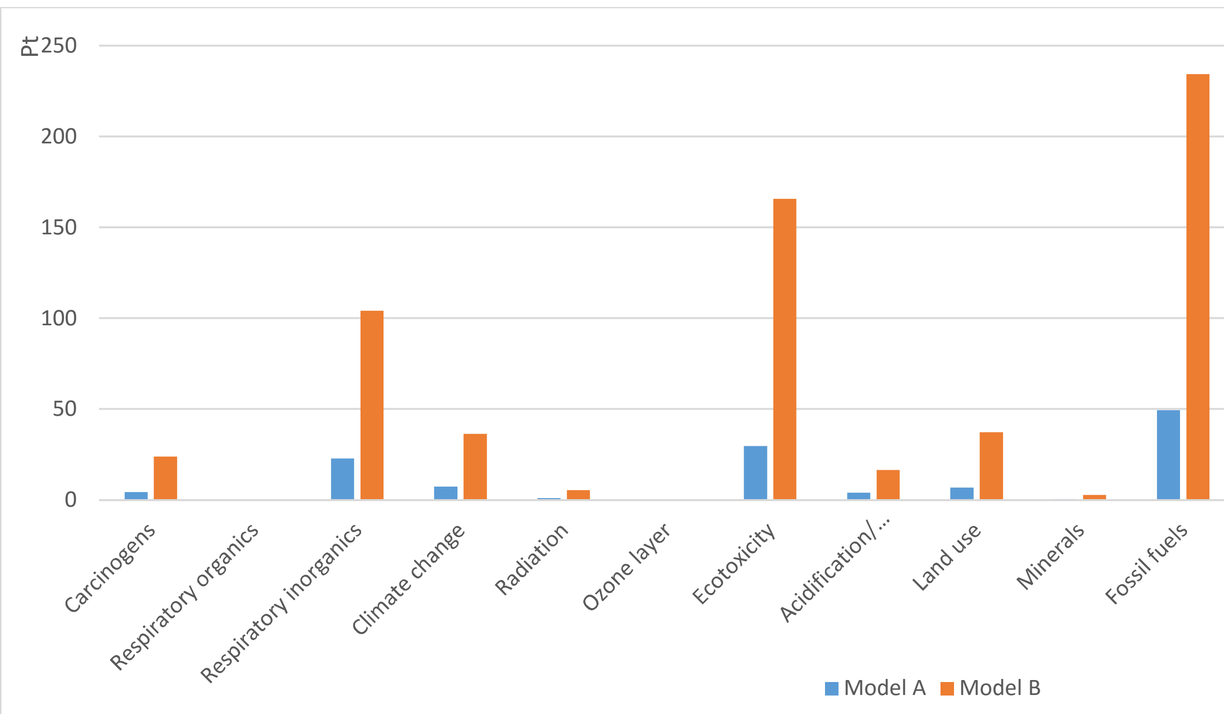


Figure 4.7 Comparison on environmental impact for reused design and standard design

Damage categories

According to the Eco-indicator 99 used by software, the damage oriented method tried to model the cause-effect chain up to endpoint, but this method sometimes is not that precise.

In order to get more objective results, some similar category endpoints can be gathered into one part. Recently, the definition study of the SETAC/UNEP life cycle initiative suggested utilizing the advantages of both approaches by grouping similar category endpoints into a structured set of damage categories. In addition, the concept also works with midpoint categories. (Jolliet et al., 2003)

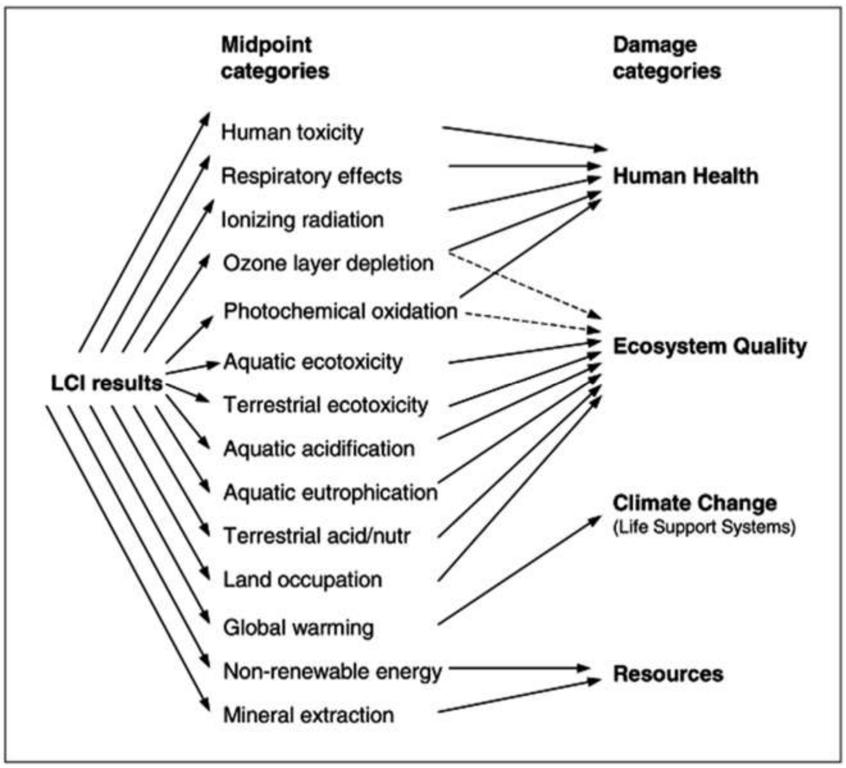


Figure 4.8 Overall scheme of the IMPACT 2002+ framework, linking LCI results via the midpoint categories to damage categories. (Jolliet et al., 2003)

No. of LCI results covered [source]	Midpoint category	Midpoint reference substance	Damage category	Damage unit
769 [a]	Human toxicity (carcinogens + non-carcinogens)	kg_{eq} chloroethylene into air	Human health	DALY
12 [b]	Respiratory (inorganics)	kg_{eq} PM2.5 into air	Human health	
25 [b]	Ionizing radiations	Bq_{eq} carbon-14 into air	Human health	
22 [b]	Ozone layer depletion	kg_{eq} CFC-11 into air	Human health	
130 [b]	Photochemical oxidation [= Respiratory (organics) for human health]	Kg_{eq} ethylene into air	Human health	
			Ecosystem quality	–
393 [a]	Aquatic ecotoxicity	kg_{eq} triethylene glycol into water	Ecosystem quality	PDF * m^2 * yr
393 [a]	Terrestrial ecotoxicity	kg_{eq} triethylene glycol into water	Ecosystem quality	
5 [b]	Terrestrial acidification/nutrification	kg_{eq} SO_2 into air	Ecosystem quality	
10 [c]	Aquatic acidification	kg_{eq} SO_2 into air	Ecosystem quality	*Under development*
10 [c]	Aquatic eutrophication	kg_{eq} PO_4^{3-} into water	Ecosystem quality	*Under development*
15 [b]	Land occupation	m^2_{eq} organic arable land·year	Ecosystem quality	PDF * m^2 * yr
38 [b]	Global warming	kg_{eq} CO_2 into air	Climate change (life support system)	(kg_{eq} CO_2 into air)
9 [d]	Non-renewable energy	MJ Total primary non-renewable or kg_{eq} crude oil (860 kg/m^3)	Resources	MJ
20 [b]	Mineral extraction	MJ additional energy or kg_{eq} iron (in ore)	Resources	

Table 4.12 Number of LCI results covered, main sources for characterization factors, reference substances, and damage units used in IMPACT 2002+ 1. (Jolliet et al., 2003)2.ecoinvent (Frischknecht et al., 2004)3.Eco-indicator 99(Goedkoop, 2001)

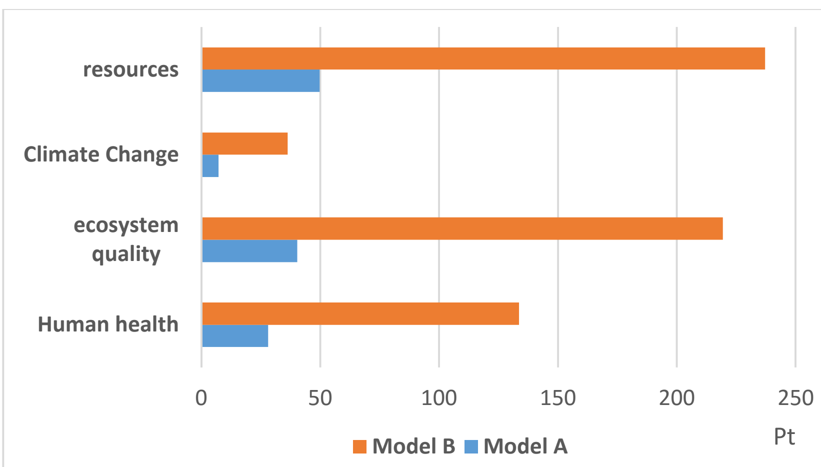


Figure 4.9 Environmental impact in damage categories

From the graph above, LCI results can be re-classified to four damage categories. And after recalculation. The impact of Model B is still much bigger than Model A, every aspect, more than four times bigger.

In this situation, considering about the environmental impact, the Model A (Reused design purpose) is much better than Model B (standard design). And the transportation is not that much influence than steel production.

4.6.3.2 Evaluation of environment impact of new building (Stage 2)

In the stage 2, because the fabrication of building is the same for both designs, so here just analysis the environment impact, not need to compare them. Then, **the construction and disposal of the building should be taken into account except the maintenance of building,** because integration of maintenance works is difficult to define in the initial stage. The predictions made before construction may not be the same with the actually happened.

TYPE	Stage 2		
MODEL A	construction	~~maintenance~~	construction
MODEL B	construction	~~maintenance~~	construction

The first two figures show the contribution flow of processes for the construction stage and disposal to the environment impact in the form of process trees for office and industrial building respectively.

Then the six figure later will show the environmental impact. it is noted that **the weight of materials was divided to the total area of constructive elements.** Because the final result represents an aggregate average per square meter of constructive element.

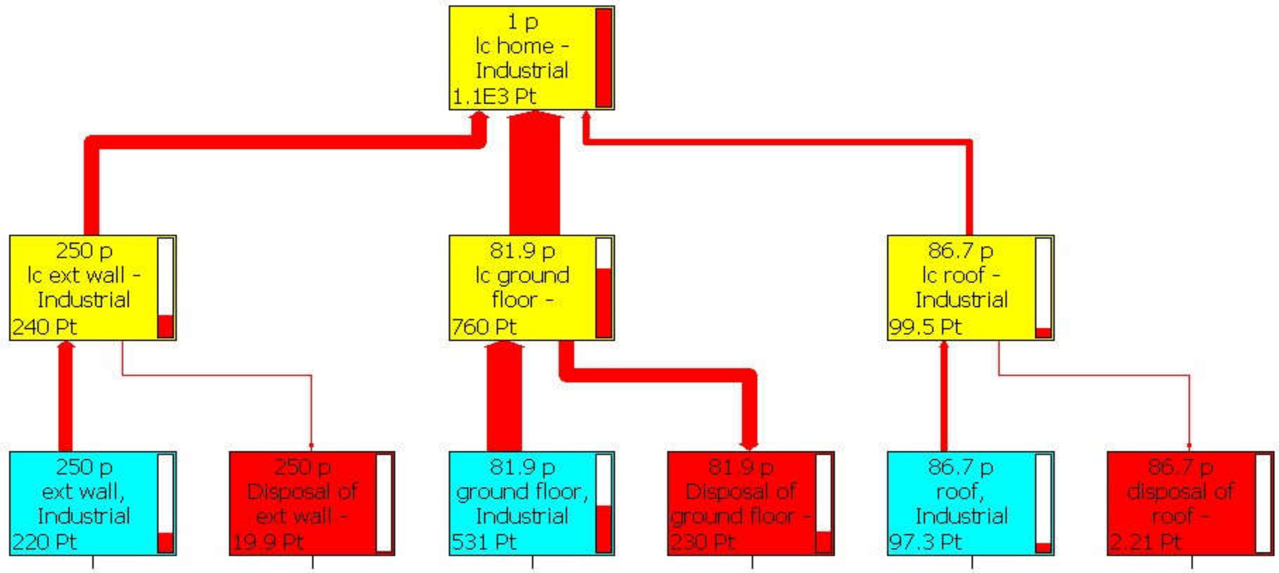


Figure 4.10 Contribution flow of process about industrial building

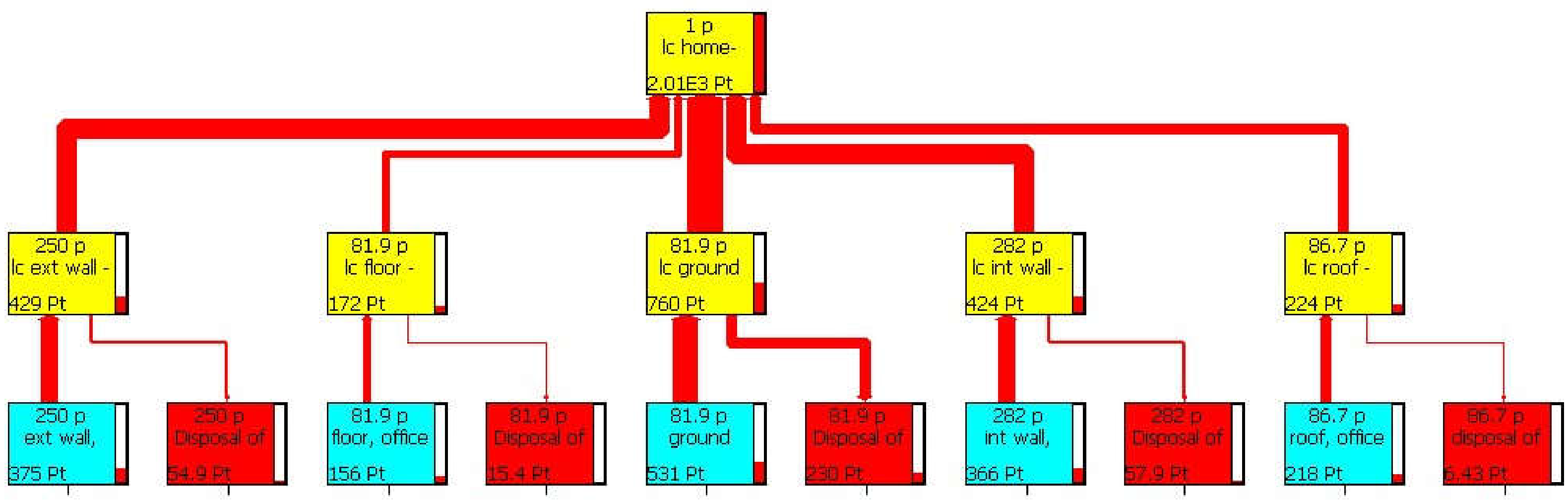


Figure 4.11 Contribution flow of process about office building

Office

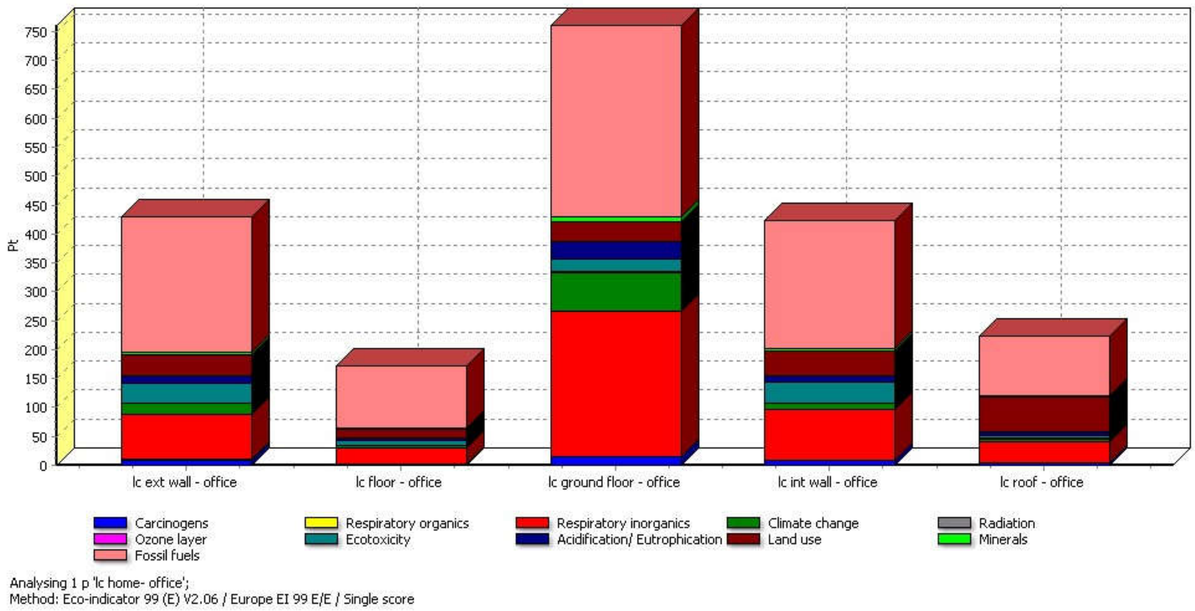


Figure 4.12 Environmental impact per constructive element about office building

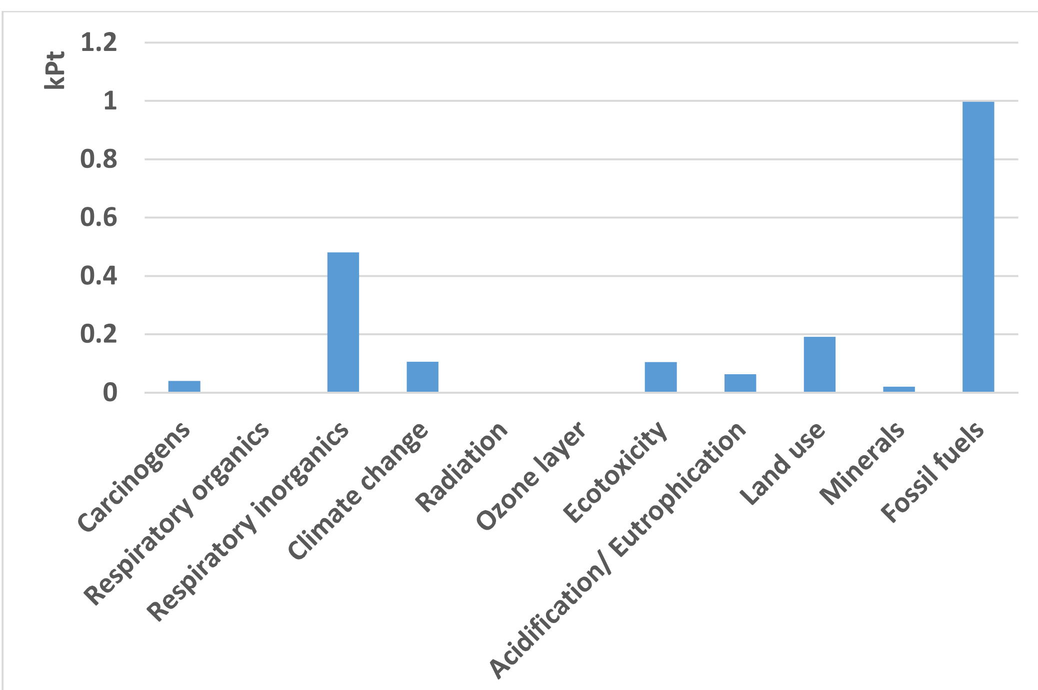


Figure 4.13 Environmental impact about office building

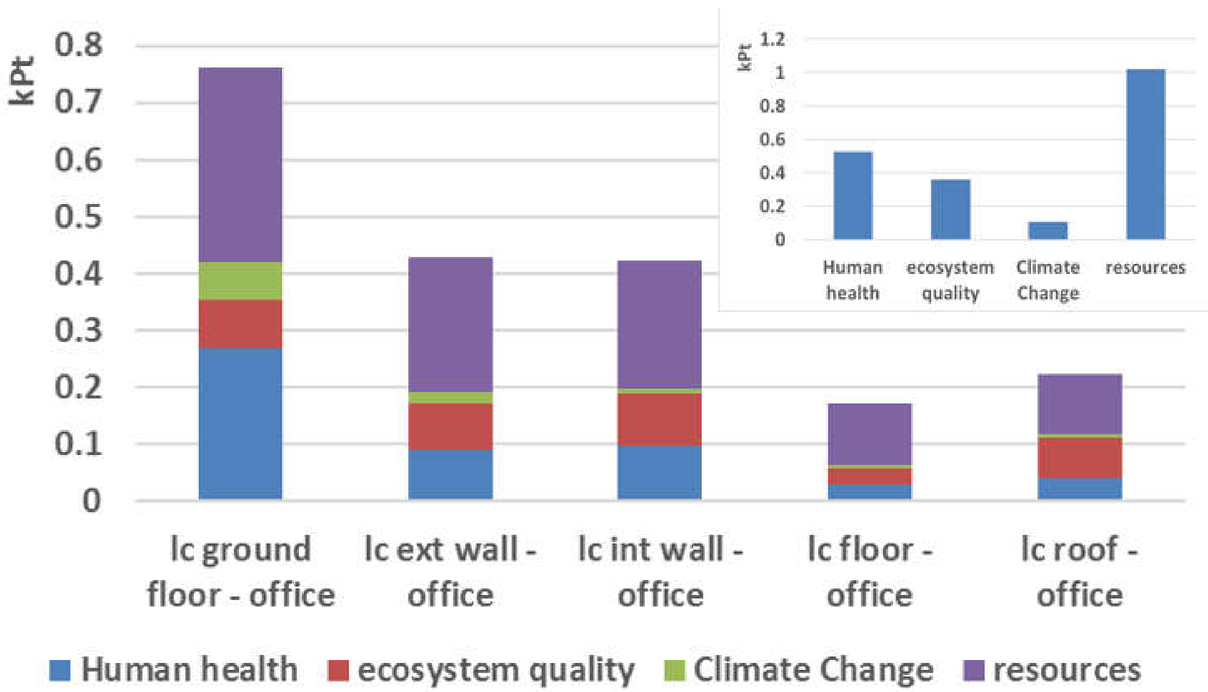


Figure 4.14 Environmental impact in damage categories per constructive element and in damage categories about office

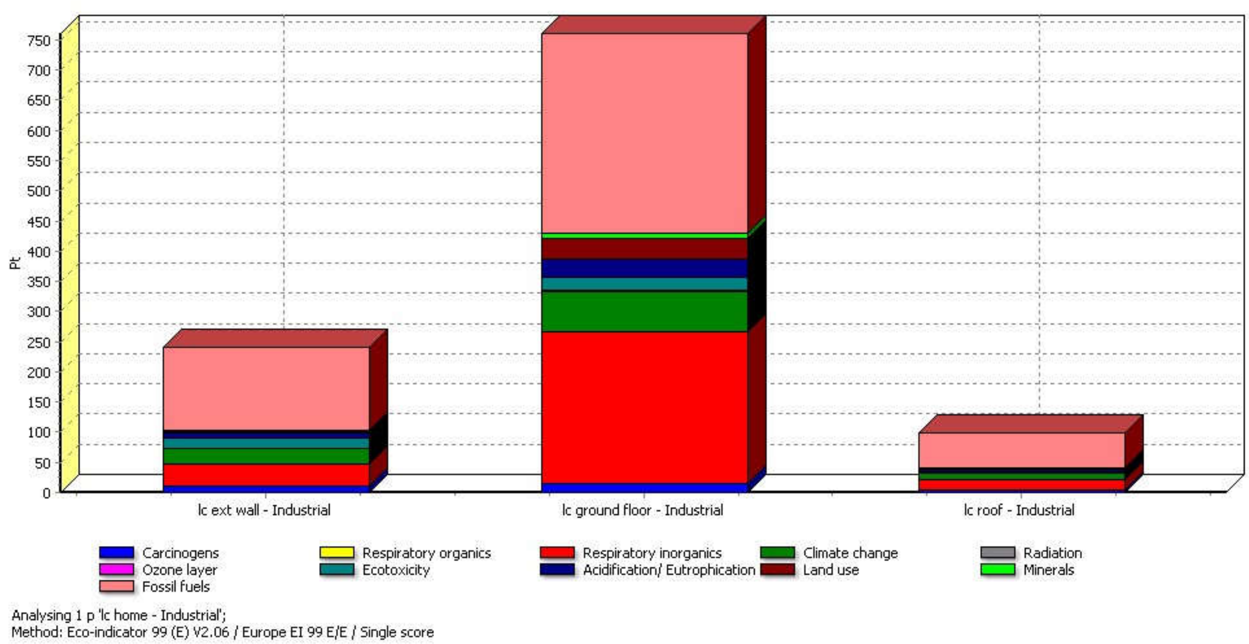


Figure 4.15 Environmental impact per constructive element about industrial building

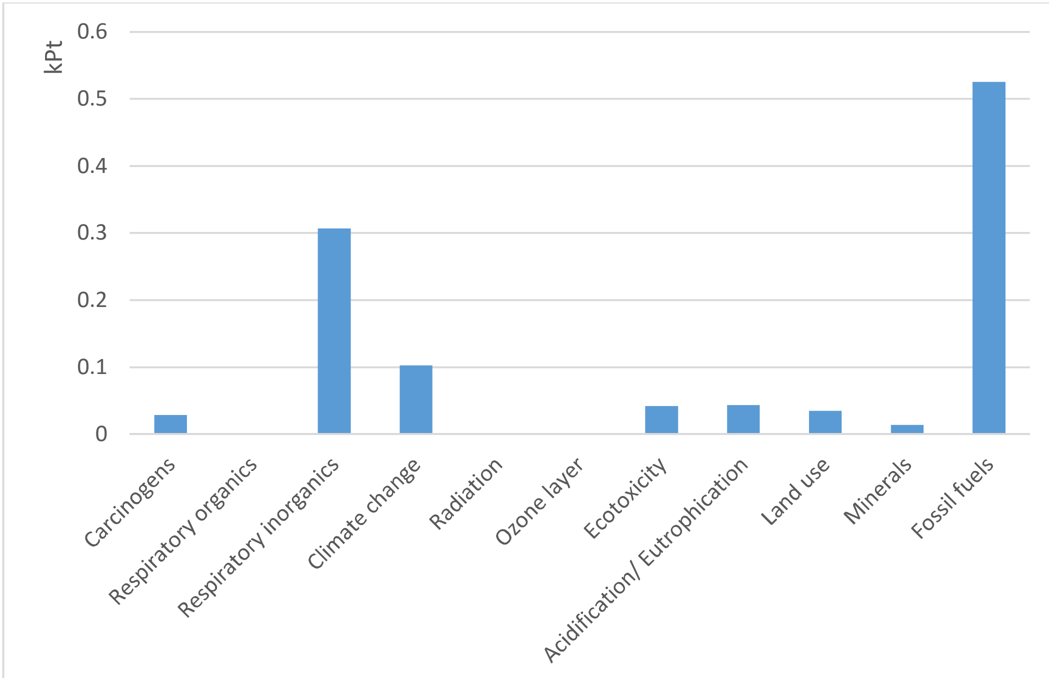


Figure 4.16 Environmental impact about industrial building

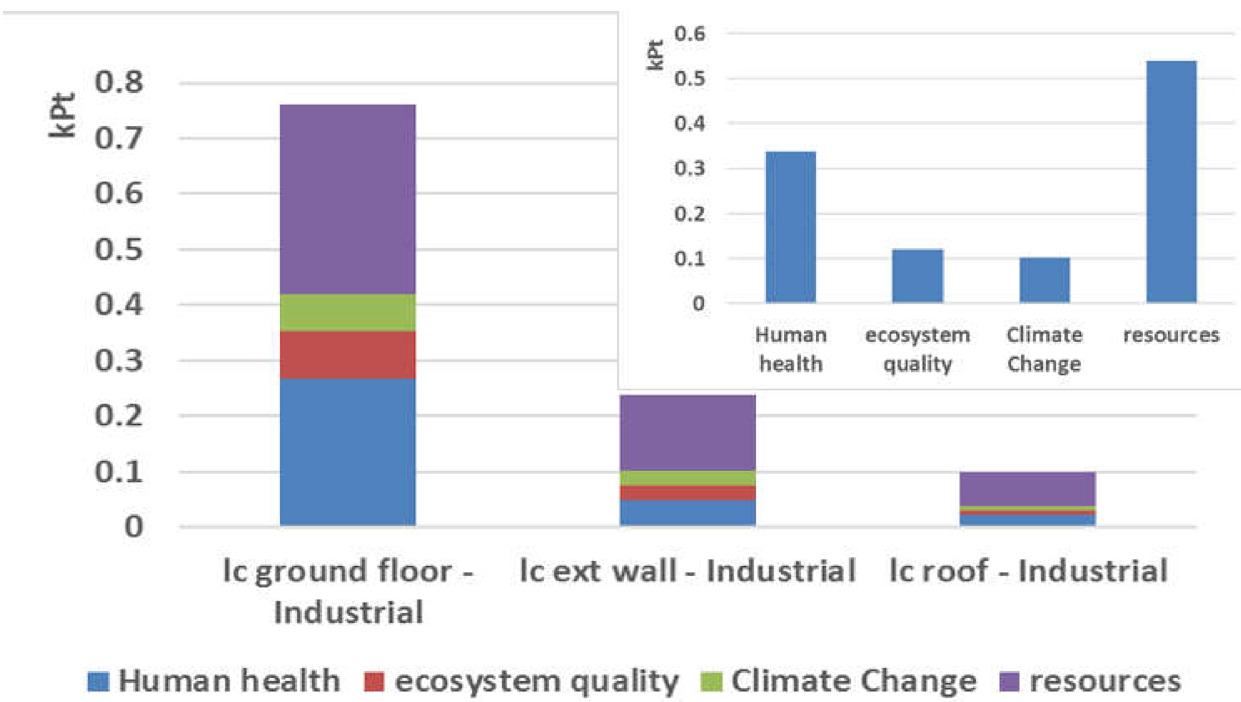


Figure 4.17 Environmental impact in damage categories per constructive element and in damage categories about industrial building

The six figures above show the environmental impact in different categories. About office, in the comparison, the ground floor plays the dominant impact (760.49 Point) in the whole building, because the ground floor consumes so much resources. And among the resources, the fossil fuel undoubtedly is the major part (997.20 Point). Then the second impact is human health (526.40 Point), further comparison inside the human health, the most part is respiratory inorganics (481.27 Point). That means during the construction, too much PM 2.5 into air according to the table 4.12.

About industrial, same as the office building, the ground floor is the most impact, almost double of all other components. Then the fossil fuel (525 Point) still the major part, respiratory inorganics (306.63 Point) is the second one.

After comparison, it is easy to get the most affected impact categories:

1. Fossil fuels (Materials, Oil etc.)
2. Respiratory inorganics (PM2.5)
3. Climate change (Climate change gas)
4. Acidification/Eutrophication (SO2/PO4)
5. Land use (Wood exploitation, ballast pits etc.)

5. Conclusion

In this thesis, the steel reuse analysis is discussed by means of a case study, in particular the structural feasibility and sustainability, considering one scenario for the reuse of existing structure.

About **the structure feasibility**, in order to confirm the codes requirements, after checking the design resistance and design buckling resistance of elements, together with the deformations at SLS it can be concluded:

1. In case of **industrial building**, the major changings are related to the number of the bays, i.e. it changes from three on original building to four in case of the new building, and secondly, in case of the new building, at the level of roof, bracings have been introduced, due to the fact the seismic action increases significantly, moreover in the case of old building the diaphragm effect was considered.
2. In case of **office building** the dimensions of the office building remain the same, but due to the fact the seismic action increases significantly, the sections of the columns in the intermediate frame members need to be reinforced/changed (see Figure 2.2).
3. Theoretically, the existing structure, before dismantling and reuse in a different location have to be evaluated, to detect the non-conformities, the mechanical properties degradation, corrosion and so on. In this project, because the main structure was subjected to indoor climate, after checking the element from the old building, it was considered that steel was not corroded and no degradations were observed.

About **the sustainability**, the comparative life-cycle analysis was done using Simapro software ("SimaPro 7," 2008) and the Ecoinvent database (Ecoinvent, 2000):

1. The impact to environment and costs of steel production is much larger than transportation. So the material savings is much important in reuse design.
2. In construction process integrating the end-of-life scenario, the impact category which takes major impact is represented by the use of fossil fuels.
3. Based on the results of this particular case, the impact of reusing the existing structure (Model A) is better than building a steel structure with the same dimensions and functionality (Model B).

Nevertheless, the above conclusions are based on many limits of the study, because the uncertainty data and by using European mean values for transportation and others components. The other parameters may change the result ratio in the comparison, but for this particular case, where the distance is relatively small, the reuse (Model A) will bring more benefits.

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