Module team Building Engineering

Brochure 2022-2023

Module CIEM5250 Building Engineering

Raffles City Hangzhou China
Architecture: UN Studio
Structural Engineering: ARUP

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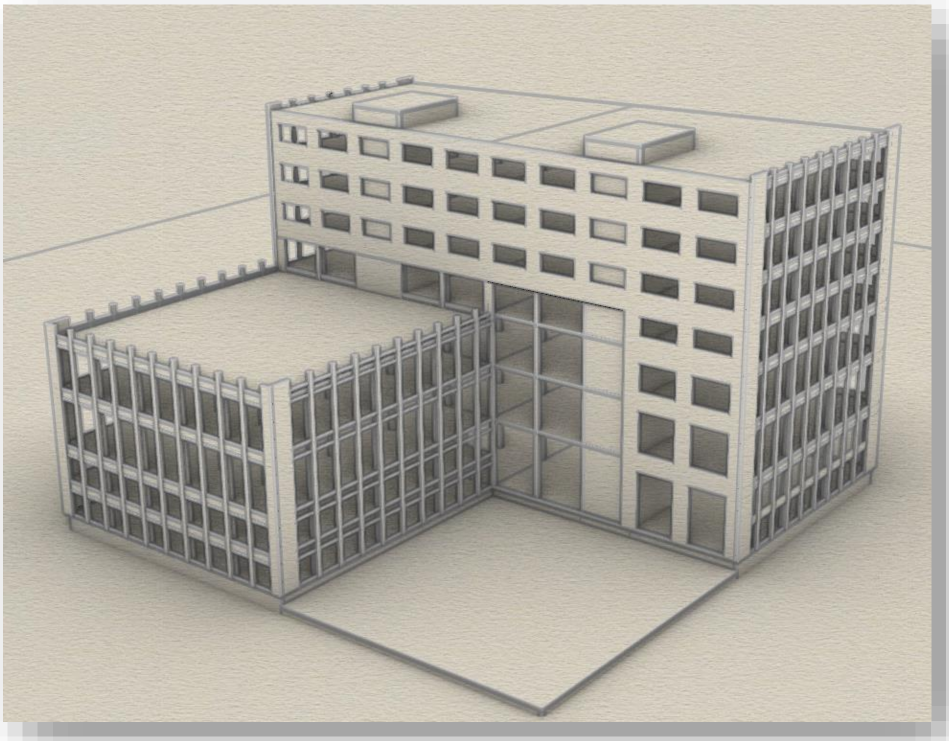
By

Module team Building Engineering



Version 26 April 2023

Contents

1 Description of module

1.1 Course contents (from TU Delft Study Guide)

The module CIEM5250 Building Engineering is an elective part of the MSc track Structural Engineering, taught in the fourth quarter of the first year of the MSc Civil Engineering. It will focus on the engineering of buildings as complex systems in which many facets need to be aligned in an integrated interdisciplinary design process. From an economy point of view, a share of about 70% of construction industry is involved with buildings, which makes this module very relevant for future civil engineers. The module content is grouped in three learning units:

LEARNING UNIT 1 (LU1, Architecture, Building Physics and Façades, 4 EC) will provide you with the specific building-related background knowledge that is not directly structural engineering:

- contemporary and 19th century architectural styles
- façade design/detailing
- building physics (heat transport, energy efficiency, acoustic insulation, daylight, thermal and wind comfort)
- building services (heating, ventilation, air-conditioning, vertical transport, water).

LEARNING UNIT 2 (LU2, Building Structures, Construction Methods and Foundations, 6 EC) is about the flow of forces in regular building structures and stability in various typologies of buildings (office, commercial, industrial, residential, etc.). Unit 2 is grouped around the following three themes:

Theme 1 (Building Structures):

- advanced knowledge on the flow of forces in building structures
- stability and lateral resistance and known solutions for various typologies of buildings according to their function (office, commercial, industrial, residential)
- use and reuse of various building materials, to give you a clear understanding on which options are available and which solutions are appropriate for every part of the new or existing building structure
- complexity of the design process and responsibilities of different partners in the design and construction chain

Theme 2 (Foundations):

- interaction with the subsoil via the foundation is an important part of the building design, and you will learn how to develop a good foundation in cooperation with the geotechnical advisor.
- attention will also be paid to deep excavations, that are often required for foundation and parking garages or other underground spaces under a building.

Theme 3 (Construction methods):

- The design of the building is depending on available construction methods, and by studying these, you will get a clear understanding of the limitations and options each of these methods offer.
- Impact on surroundings and urban context will be addressed, as well as safety of construction, economy and material efficiency (zero-waste) on the construction site.

LEARNING UNIT 3 (LU3, Design of Spatial Structures, 5 EC) is an advanced unit about special and spatial building structures such as shell, membrane and truss structures. For these structures form and flow of forces are complementary. Often resulting in beautiful shapes, but making the structural design process challenging. Unit 3 focusses on the following themes:

Theme 1 (Structural typology)

- the typology of spatial structure is guiding for the required design steps. You will learn about these typologies and must choose one typology and design structure of your own. As for regular buildings, the strength, stiffness and stability must guaranteed in the design.
- different typologies follow different steps in the design. You will learn which steps are typical for different typologies and must list the task for your own design. Spatial buildings must fulfil the same basic criteria as regular buildings. They must be safe, practical and stable. And for spatial structure achieving high efficiency is a natural addition.
- define the basic structural requirements and design criteria as any building should fulfil. Put the main focus on safety and structural efficiency of the design. Which, for educational reasons, is a different from the regular building in unit 2.
- form and force relation. The overall shape of the structure can be designed with a high degree of freedom, yet the detailed shape must be “found” by considering the interaction between flow of forces and the shape of the structure.
- materialization of the structure. Special and spatial structures are meant to transfer loads efficiently. Therefore materials must be chosen that are typically well performing for specific type of loading such as tension and compression. Form, forces and materials are complementary and must be designed simultaneous.

Theme 2 (Computational design)

- spatial structures required special design methods. Varying from manual (physical) to computation (automated) modelling. Computational design enables efficient design and analysis. You will learn how to design using computational modelling and use it for your own design.
- strength of computational modelling follows from the possibility to generated results based on logic again and again. Defining this logic can be challenging. On one hand it enables to create results that would manually (practically) be impossible, for example complex geometry. On the other hand logic can only be defined within the available features of the modelling software. Defining the logic can be seen as a creative or design process in itself. Examples of computational modelling techniques are: parametric modelling, numerical analysis, 3D measurements and develop such models in self-written code.
- form finding is essential to the design of an efficient structure. Each typology has it’s own form finding method. But all are based on finding equilibrium.
- modelling and analysis of spatial structures requires various techniques with are often performed in different software packages. Computational modelling enables that different software packages can be linked or interact.

Theme 3 (Detailing and dimensions of structural components)

- detailing of the essential structural components is required for modelling and analysis of the structure. Often the details can be define conceptually or using simple (but clear) sketches. They should make clear which degrees of freedom there are or how loads are transferer between structural components.
- dimensions of structural parts must be defined. Spatial structures can often be characterised or meant for efficient use of material. Motivated by ambition or necessity. Like large span structures. Typically resulting in higher utilization of materials than regular buildings that aim for different goals. Obviously all structural requirements must still be met.

Whereas Learning Unit 2 will focus on more regular building types, Learning Unit 3 broadens the scope with an extensive introduction into complex building typologies and geometry. And how computational modelling can be utilized in the design. Apart from design and modelling skills, also academic skills will be trained during this unit. You must study a building typology and present your finding in academic methodology by writing an extended abstract and present you design.

Working on an integrating design exercise of a realistic building that connects all three learning units, you will experience the consequences (limitations, options and uncertainties) of available design and construction methods. During the exercise, you will receive feedback from professional building engineers.

Figure 1: Arcade of a mosque with traditional Arab shapes using precast concrete (Rome)

1.2 Learning Objectives (from TU Delft Study Guide)

On completion of this module, you will be able to:

1. Recognise and discuss architectural styles and construction methods of the 19th, 20th and 21st century.
2. Distinguish façade typologies and use those in design, while correctly applying the laws of building physics in the design evaluation to meet relevant criteria for climate, energy-efficiency and durability, taking into account stochastic material properties, climate data and user behaviour.
3. Discuss the relationship and integration between design of load bearing structure, façade structure and other relevant parts/aspects of the building, such as services, vertical transport, plumbing, climate, ducts.
4. Analyse whether reuse of existing structures or structural components in a project is economically and technically feasible and, where it is, reuse such existing building structures in the design of the newly developed building, correctly assessing the reliability of the existing structure or components based on measurements or probabilistic reasoning.
5. Correctly identify functional, structural and construction requirements and loads for low-rise multi-storey buildings and spatial structures with different targeted functions.
6. Explain and apply, in the context of a design, the most important typologies and stability systems of low-rise and multi-storey buildings, using different construction materials, and being able to model and simulate the behaviour of such systems both with self-written code and existing FEM software.
7. Develop, analyse and evaluate various reliable solutions for building foundations and deep basements in close cooperation with a geo-engineer, considering the close interaction between structure and foundation, recognising and limiting risks of uncertain underground soil conditions, surveying and foundation methods.
8. Explain how a building design can be constructed in an economic, safe and practical manner, acknowledging what the consequences and risks of construction methods are for the design and vice versa, and acting as a structural engineer with a professional, responsible and ethical attitude.
9. Design spatial structures, such as (grid)shells, membrane structures, space frames and cable-structures by simultaneously considering their form, internal and external forces and materialisation, resulting in a design in which these are complementary to each other. Define tasks for the overall design process that lead to a safe and efficient spatial structure.
10. Model, using manual and advanced computational methods, with the goal to design, analyse, and explain the 3-dimensional structural behaviour and performance of a spatial structure. Explain how this leads to an efficient and optimised structure. Optimise the design of a spatial structure.

Figure 2: The Shard (London)

1.3 Educational method - Design Studio

The following educational methods are used:

LU1: Lectures, weekly short exercises, discussion in class, design studio
LU2: Lectures, individual feedback sessions centred around design studio
LU3: Lectures, hands-on physical modelling workshops, discussion in teams, presentations, design studio

The **design studio** (=design assignment) will be the integrating part between the three learning units. A design studio is a teaching concept borrowed from our Faculty of Architecture. In the studio, you will collaborate with a small team of students on your building design. The studio hours are allocated as self-study, which means that not necessarily a staff member is present. You will however always have a lecture room reservation, allowing you to meet with your group. The studio will also be the place where staff members of the various design disciplines will visit you and your group to advise, provide oral feedback and answer your questions. For this, we will create a schedule to facilitate tutoring and feedback moments in the studio.

At a number of occasions, the studio hours will be used for informal or formal presentations, to share among groups the progress and receive feedback from staff members.

1.4 Assessment (from TU Delft Study Guide)

Each of the three learning units will have a separate written exam, focused on the theory (lecture notes, textbooks) and skills that can best be assessed in a written exam. Since building engineering is very much design-oriented and aiming for a cognitive level that is hard to assess in the limited time of a written exam, many formative assessment moments will be included, for example by expert feedback, discussion sessions, presentations, and peer review of designs. On overall-module level, for each academic year, a different building for a specific clients' brief will have to be designed by the students. This design assignment will function as the integrator of the module. The final grade will be determined in a single rubric based on the level of understanding displayed at the presentation (oral exam) and the quality of the final assignment reports.

The final grade is the weighted average of four parts:

- LU1: individual written exam (2.0 EC, 13%) - please enrol now via Osiris!
- LU2: individual written exam (3.5 EC, 23%) - please enrol now via Osiris!
- LU3: individual written exam (2.5 EC, 17%) - please enrol now via Osiris!
- Design assignment (7.0 EC, 47%)

The ECs of the Design Assignment are spread over the 3 learning units (approx. in a proportion 13%, 17%, 17% for LU1/2/3). The deliverables of the Design Assignment will include presentations, a poster and a paper. Each part needs to be completed with a grade of **5.8 or higher**. For the written exams, one regular exam (end of June) and one resit opportunity (mid-July) are available per academic year.

The design assignment is a **team exercise**. Since groups are formed only once per year, only one opportunity per academic year is available to fulfil this part of the module. In case of an **insufficient result (< 5.8)**, a repair opportunity with feedback will be provided to the group, but only if a serious attempt was taken to complete the assignment in the first round. The repair action shall be completed by the group before the start of the second MSc year (approx. 1 September).

1.5 Exam preparation

To help you prepare for the written exams, we will share example exams for each of the three learning units during the period. These example exams are representative for the type of questions you can expect during the actual exams. Answers are provided. During the lectures, also hints will be given as to what information might be asked during a written exam.

Written exam unit 1

- Architecture: neither the books for architecture nor the lecture slides can be used during the exam.
- Building Physics: the book “Building Physics”, the booklet with tables and the printed lecture slides can be used during the written exam.
- Façades: neither the books for façades nor the printed lecture slides can be used during the exam.

Written exam unit 2

The first hour of the written exam is a closed-book exam, during which you are not allowed to use any reference material. After handing in the answers of your first part, you are allowed to proceed with the second part. For this part, you are allowed to use all course material and books. Details will follow.

Written exam unit 3

The Quick Reference can be used during the written exam of unit 2. Other material is not allowed.

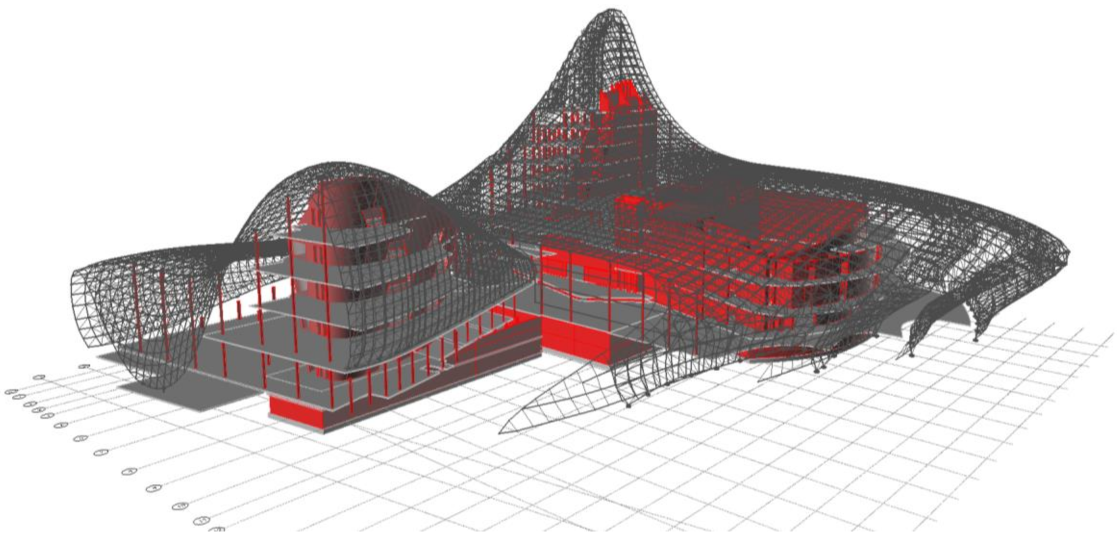


Figure 3: Space frame of roof structure of Heydar Aliyev Cultural Centre (Baku, Zaha Hadid Architects)

1.6 Assessment Design Assignment

The Design Assignments consists of contributions of multiple persons and for multiple learning objectives / units. To determine a balanced grade the following criteria are used for the group mark (percentages are related to their weight in the final grade for CIEM5250):

Unit	Learning Objectives (see page 7)	(Approximate) weight
LU1 Architecture, Building Physics and Façades	1-2-3-4	13%
LU2 Building Structures, Construction Methods and Foundations	4-5-6-7-8	17%
LU3 Design of Spatial Structures	5-8-9-10	17%
Total		**47%**

Group composition

Groups will be formed during the first week of the module, depending on attendance and enrolment. Each group consists of preferably 3 (or incidentally 4) students, depending on the total number of participants to the module. Groups of 4 will be asked to do proportionally more work. As much as feasible, we will try to mix domestic and international students. While considering this mix, group composition will be further done by lot. All students in the group are expected to point out their individual contribution to the final product. In principle, the group mark is equal for all group members, unless it becomes apparent that a group member has carried out significantly less/more work or work of a significantly poorer/better quality, such to the judgement of the lecturers.

Rubric

Below, the criteria used for the final grade of the group assignment are shown. The grade is based on the information conveyed during the final presentation as well as on the design documents that are handed in by the group. The following scales are used:

Insufficient = 5.0 Sufficient = 6.5 Good = 8.0 Very good = 9.5

For exceptionally high-quality submissions, a learning objective can also be marked with 10. The final grade for the design assignment will be awarded only **after the June exams**, since also the design documents that are submitted by each group need to be studied and marked.

CIEM5250 - Building Engineering - Rubric for Design Challenge					05/Apr/23
Group: #1					
Student 1					
Student 2					
Student 3					
Student 4					
Group grade:	**7.6**	insufficient	sufficient	good	very good
Learning objective 1	architecture			x	
Learning objective 2	façades / building physics			x	
Learning objective 3	building services integration		x		
Learning objective 4	reuse, design for disassembly, circularity		x	x	
Learning objective 5	functional requirements are identified and met by the design			x	
Learning objective 6	load-bearing structure and stability are clear, well-designed and underpinned			x	
Learning objective 7	foundations and basements are well-designed			x	
Learning objective 8	construction methods are realistic, economic and safe		x		
Learning objective 9	spatial structure is safe, elegant, well-designed and material-efficient			x	
Learning objective 10	3D-analysis of spatial structure is well-done			x	
Feedback with group grade (unit 1):					
written feedback					
Feedback with group grade (unit 2):					
written feedback					
Feedback with group grade (unit 3):					
written feedback					

Figure 4: Rubrics for design assignment

1.7 Prior knowledge required

The module can only successfully be completed with sufficient prior knowledge in the following subjects:

- general understanding of optimisation methods and numerical methods (from MUDE - necessary for LU3)
- reliability and statistics (from MUDE and BSc - necessary for understanding safety of building structures/materials, stochastic loads and soil/foundations)
- fluid flows (from CE Programme Base and BSc - recommended for wind-flow related topics)
- energy flow through solids (from CE Programme Base, necessary for building physics)
- basic and advanced structural mechanics (from BSc and SE Track Base)
- advanced knowledge on loads on structures (from BSc and SE Track Base)
- advanced knowledge of reinforced concrete members and basic knowledge of prestressed concrete and joints/connections (from BSc and SE Track Base)
- advanced knowledge of steel members and basic knowledge of joints/connections (from BSc and SE Track Base)
- Basic knowledge of timber members and basic knowledge of joints/connections (from BSc and SE Track Base)
- basic knowledge of circularity and sustainability (from BSc and SE Track Base)
- basic skills in CAD, teamwork, report writing, framework software, hand sketching, information literacy (from BSc)
- theory of ethics (from BSc and CE Programme CE Base)

where the blue lines are slightly less central to the module than the black lines. Since the choice between A-modules in the Structural Engineering track is free, we do not expect you to have attended a particular A-module. We anticipate on a mix of students from all three A-modules, leading to some diversity of prior knowledge over the student teams. In case of doublures with material taught earlier in the A-modules, you should see CIEM5250 as a design-driven module and an opportunity to further strengthen your design skills and deepen your understanding of the various construction materials and methods.

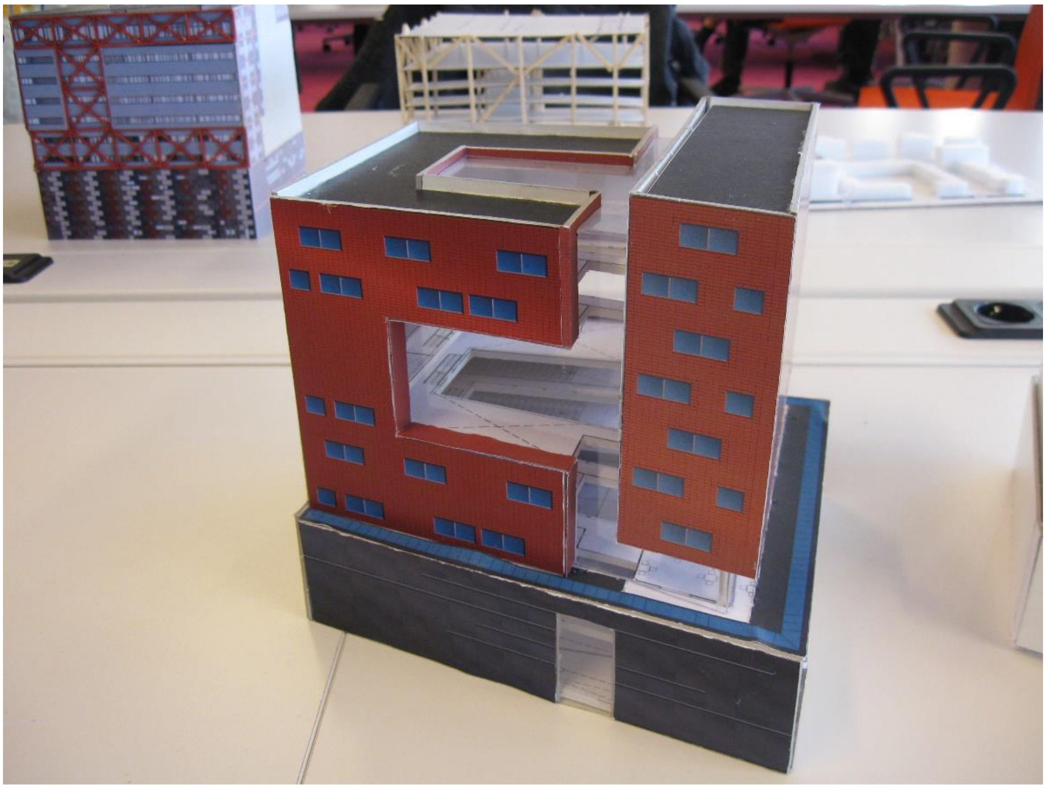


Figure 5: Scale model made during an earlier course on Building Design

1.8 Spreading B5 over multiple exam periods / academic years

Although it is recommended to see the module and its learning units as one fully-integrated course, it is possible to spread the workload for the written exams over the regular exam period (week 4.9 and 4.10, end of June) and the resit period (week 5.3, mid-July). This would allow you to spend some time on possible leftover exams of the Track Base Q3 or A-module Q3.

It is unfortunately not possible to take the design assignment as a group project outside of the regular Q4 period, due to its organisation in studios and tutoring, so it is recommended to participate in this design assignment if at least you meet the prior-knowledge requirements discussed above in section 1.7.

1.9 Study materials

1.9.1 LU1 Architecture, Building Physics and Façades

Architecture

- **The Great Builders**, Kenneth Powell (Ed.), London: Thames & Hudson, 2021; the following chapters:
  Karl Friedrich Schinkel (pp. 57-61),
  Augustus Welby Northmore Pugin (pp. 81-84),
  Eugène-Emmanuel Viollet-le-Duc (pp. 85-89),
  Giuseppe Mengoni (pp. 97-100),
  Louis H. Sullivan (pp. 121-127)
  Frank Lloyd Wright (pp. 128-133)
  Auguste Perret (pp. 134-137)
  Le Corbusier (pp. 141-146)
  Pier Luigi Nervi (pp. 151-154)
  R. Buckminster Fuller (pp. 157-163)
  Ove Arup (pp. 164-167)
  Jean Prouvé (pp. 173-176)
  Norman Foster (pp. 200-205)
  Kengo Kuma (pp. 212-216)
  Reading the entire book is highly recommended (link)

Building Physics

- **Basics of Building Physics**, A. Zeegers and A.C. van der Linden, I.M. Kuijpers-Van Gaalen, 2022 (link), the following chapters:
  1 Basics Heat and moisture transfer – thermal insulation (link)
  2 Basics Lighting – basics – daylight – artificial lighting (link)
  3 Basics Thermal Comfort – Ventilation – Solar Control (link)
  4 Basics Energy – Sustainability (link)
  5 Basics Acoustics (link)
  Building Physics – Tables and Formulas (link)

Building Services

Not available yet, to be announced during the lecture.

Façades

- **Exterior Building Enclosures** : Design Process and Composition for Innovative Facades, Keith Boswell and C Keith Boswell, 2006 (link), the following chapters:
  Chapter 1 Basics (53 pages)
  Chapter 2 Participants (33 pages)
  Chapter 3 Design Process (48 pages)
  Chapter 4 Construction (15 pages)

Chapter 5 Brick Masonry (17 pages theory – not the cases)
Chapter 6 Natural Stone Masonry (23 pages theory, not the cases)
Chapter 7 Architectural Concrete (17 pages theory, not the cases)
Chapter 8 Metal Framing and Glass (21 pages)
Chapter 9 All-Glass Enclosures (20 pages theory, not the cases)
Chapter 10 Realization (17 pages)
The chapters 2, 3, 4, and 10 *in italics* and the case studies are for information only and are not part of the exam.

- **Facades: Principles of Construction**, Ulrich Knaack, Tillman Klein, Marcel Bilow, and Thomas Auer, 2007 (link) – this book is for information only, not part of the exam.

- **Modern Construction Envelopes**, Andrew Watts, 2014 (link) – this book is for information only, not part of the exam. However: **Chapter 6 (Timber Walls, pp 262-283; 22 pages) is compulsory study material**.

1.9.2 LU2 Building Structures, Construction Methods and Foundations

- Reader Building Structures 1, 2018 ed. K.C. Terwel
- Reader Building Structures 2 - R. Abspoel 2013
- Concrete Building Structures 2016 (verbeterslag t.o.v. versie Paul Lagendijk)
- Structural calculations of High Rise Structures, update 2022
- Quick Reference 2014

1.9.3 LU3 Design of Spatial Structures

Lecture slides and notes, plus additional material handed out during lectures. The tested content is everything discussed in the lectures. Also check section 1.4 and section 1.5 on assessment and exam preparation.

Handouts during workshops can be found on the Brightspace course page. To enroll on this separate Brightspace page go to Catalog and search for *Structural Mechanics – BK*. After enrolling the course page will be available here: link.

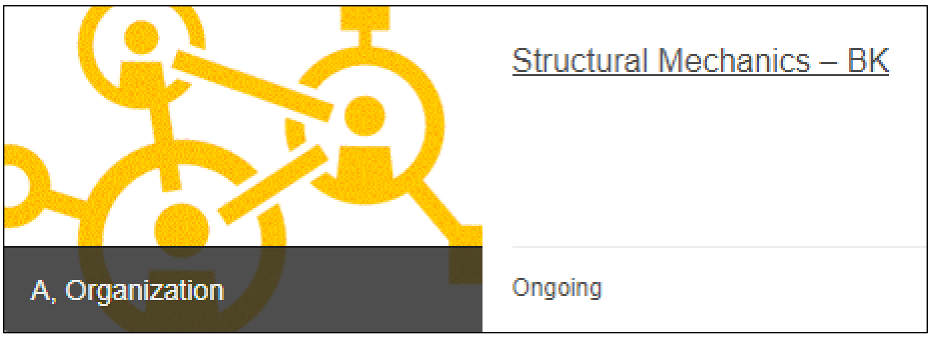


Figure 6 Structural Mechanics - BK course in Brightspace Catalog

1.9.4 All learning units

Slides or notes on the blackboard / smart screen presented during the lecture hours (including guest lectures) are part of the material to be studied for written exam. Slides will be posted on Brightspace as PDF if available.

Figure 7: Timber roof under construction (Green Planet)

1.10 Module team CIEM5250 Building Engineering

In alphabetical order, the following team members are contributing to this module:

name	unit / discipline / role	email
Ir. H. (Hoessein) **Alkisaei**	LU2 structural design, circularity	H.Alkisaei@tudelft.nl
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Prof.dr.ir. A.C. (Atze) **Boerstra**	LU1 building services	A.C.Boerstra@tudelft.nl
Ir. A. (Andrew) **Borgart**	LU3 structural design **leader unit 3**	A.Borgart@tudelft.nl
Dr. E. (Eleonora) **Brembilla**	LU1 daylight	E.Brembilla@tudelft.nl
Ir. P. (Peter) **Eigenraam**	LU3 structural design	P.Eigenraam@tudelft.nl
Ir. M.P. (Maria) **Felicita**	LU2 timber structures	M.P.Felicita@tudelft.nl
Ir. E.R. (Eric) **van den Ham**	LU1 building physics	E.R.vandenHam@tudelft.nl
Prof.dr.ing. C.M. (Carola) **Hein**	LU1 architecture	C.M.Hein@tudelft.nl
Ir. C.J. (Christien) **Janssen**	LU1 building physics	C.J.Janssen@tudelft.nl
Dr. F. (Florentia) **Kavoura**	LU2 steel structures	F.Kavoura@tudelft.nl
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Ir. S. (Sander) **Pasterkamp**	LU2 structural design, **leader unit 2**	S.Pasterkamp@tudelft.nl
Ir. J.P.G. (Hans) **Ramler**	LU2 construction methods and foundations	J.P.G.Ramler@tudelft.nl
Dr.ir. G.J.P. (Geert) **Ravenshorst**	LU2 timber structures	G.J.P.Ravenshorst@tudelft.nl
Dr.ir. H.R. (Roel) **Schipper**	LU1 façades, **responsible lecturer, leader unit 1**	H.R.Schipper@tudelft.nl
Ir. A.C.B. (Marco) **Schuurman**	LU2, structural design, design **leader design assignment**	A.C.B.Schuurman@tudelft.nl
Module CIEM5250 general mail address	**preferably send your questions to (or put in CC):**	**ciem5250-3md@tudelft.nl** (Mail address read by Amber and Roel)

1.11 Guest lectures 2023

This year there will be a total of 5 guest lectures, which are all addressing different aspects of building engineering. Below a list of this year's speakers, dates and the various projects they will be presenting.

Date	Location	Speaker(s) [company affiliation]	Project/ topic
May 8th	Bouwcampus hall 1	Steven **van Eck** [Pieters Bouwtechniek] & Robert **Schippers** [Geobest]	Post Rotterdam
May 22th	Bouwcampus hall 1	Paul **Bleijenberg** [Dura Vermeer]	Construction methods: Deep excavations and foundations - Parking Garage Lammermarkt
May 23rd	Bouwcampus hall 1	Leonie **van Ginkel** [Frontwise Façades]	Circular Façade Design & Construction
May 30th	Bouwcampus hall 1	Han **Krijgsman** [ABT]	Seismic action and earthquake resistance – Forum Groningen
June 14th	Room 1.95	Mark **Spanenburg** & Freek **Schaap** [BAM Advies en Engineering]	Construction methods of tall buildings – Zalmhaventoren
June 14th	Room 0.95 (provisional)	Tim **van der Waart van Gulik** [Efectis]	Fire Safety

Attending the lectures delivered by **guest speakers** is **strongly recommended**, for reasons of politeness towards our guest speakers and for the valuable content of the guest lectures. The written exams may contain questions about the guest lectures.

1.12 Collegerama – lecture recordings

We have requested recordings of all **lectures** by Collegerama, to allow you to review these for your written exam or in case of illness. However, we encourage you strongly to actively attend all lectures in person, for reason of group dynamics, interactivity, and engagement in the lecture hours. ~~For this reason, the recordings will only be released for online review with a two-week delay after the original lecture.~~
Studio hours and **workshops** will not be recorded.

2 Design Assignment 2023

2.1 Design assignment - introduction

For this year's edition, we will ask you to design a **multi-storey educational building** (approx. 14000 m^2) connected to a **multifunctional spatial structure** (approx. 1400 m^2) on the TU Delft campus, on the greenfield near the intersection Mekelweg-Heertjeslaan, just behind the new faculty building of Applied Sciences. The grey building block in the image below is the multistorey-building, and this part is pretty well-defined to provide you with an architectural starting point. For this multistorey building, you will design the main load-bearing structure, stability system, basement, foundations, façades, indoor climate aspects and building services, all based on the provided architectural design, with a certain freedom of suggesting improvements.

The yellow circle only indicates the approximate position and order-of-magnitude of the spatial structure. This building will house a multifunctional exposition hall, possibly including other functions such as exposition hall and/or a restaurant. The geometry of that building part, however, is undefined yet, and will be completely designed by you.

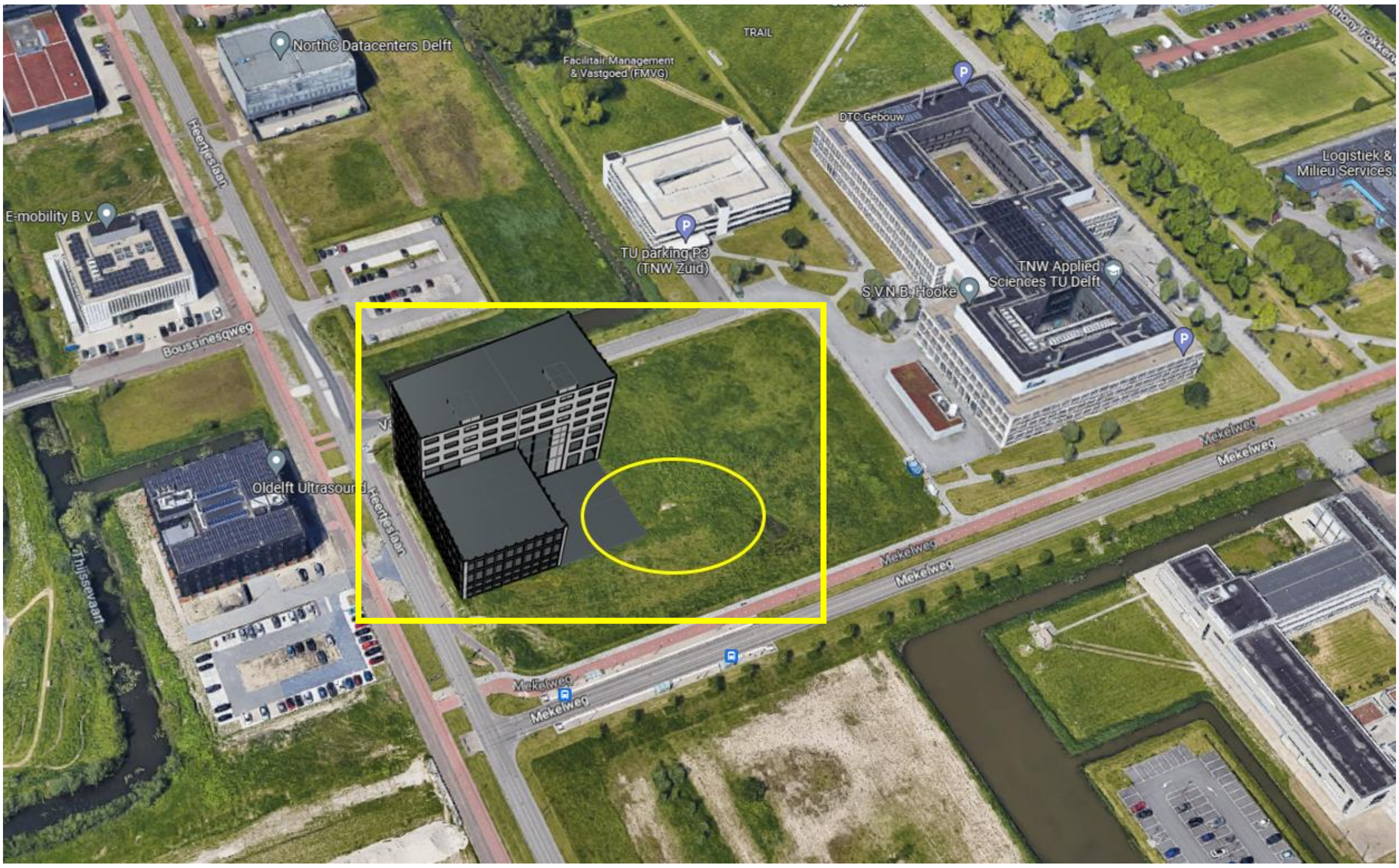


Figure 8: Overview of the site, view in approximately north-west direction

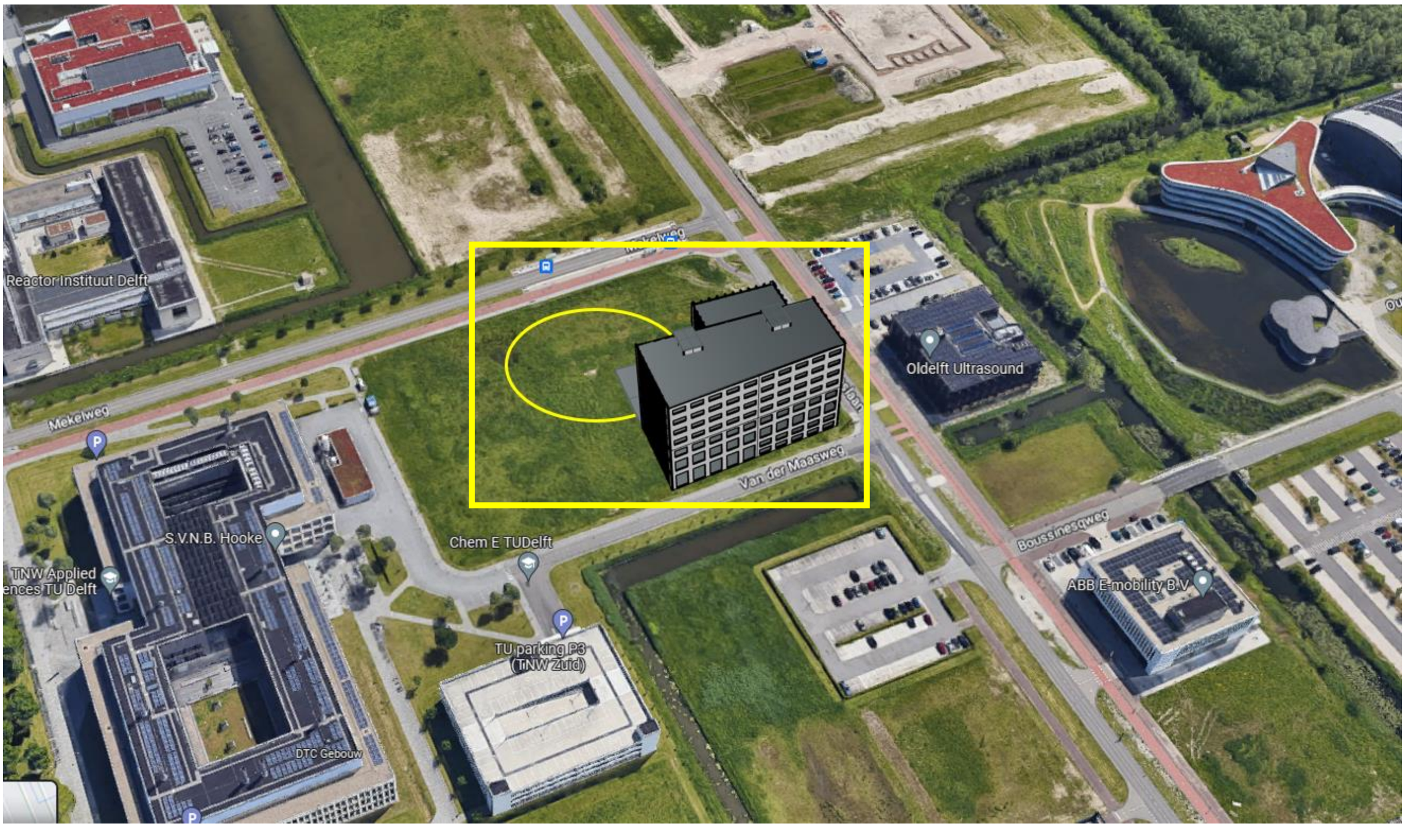


Figure 9: Overview of the site, view in approximately south-east direction

This design of the **multistorey building** will need to be documented in a number of deliverables, such as:

- Structural floor plans
- Structural cross-sections
- Foundation and basement plan
- Façade elevations and cross-sections
- Structural details and façade details
- Structural calculations
- Building physics / climate calculations
- Building services schemes

These deliverables and their targeted quality level should be more or less similar to what in an engineering firm would deliver as a final design to the client. Further below, you will find more detailed lists of deliverables per unit.

For the **spatial structure**, you can stay on a slightly more conceptual level, depending on the complexity of the structural typology chosen (e.g. shell structure, dome, grid-shell, membrane structure, …). However, we need a good underpinning of its main structure, both in drawings and in calculations.

2.2 Work load of design assignment

To allow the work to be done in a systematic way and to collaborate effectively in your group, we have prepared lists of required deliverables per unit and have made an indicative planning per week of the stage in which your design (by approximation) should be. The total volume of the design challenge is 7 ECTS, which equals 7 x 28 ≈ **200 hours per student**, **distributed over 10 weeks**. This implies that, by approximation and on average, half of your working week (~ 20 h / week) should be spent on the design challenge. Since the exam weeks will also require preparation, please consider to take a head start, in order not to get in a time conflict around the exams.

2.3 Design brief

The design brief is the document that describes what the client requires. For this assignment, it comprises of **two educational buildings** with the following functions:

- offices, instruction rooms, restaurant with roof terrace, auditorium, and
- (external) exhibition hall, which should be a spatial (= large span) structure.

An architectural design is already provided for the multistorey-building, but not for the spatial structure. Appendix 5.1 offers an idea how the functions are distributed across the buildings and about the square meters per floor. The global program is provided in Table 1 and Table 2 on the next pages.

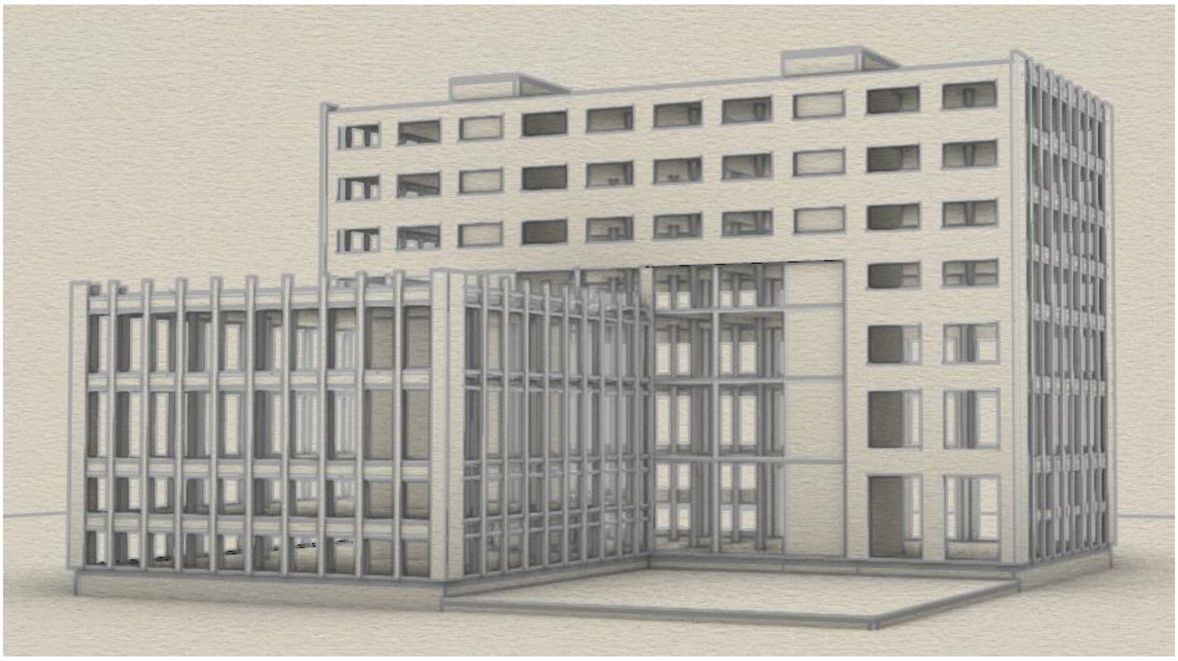


Figure 10: Architectural impression of the multistorey-building

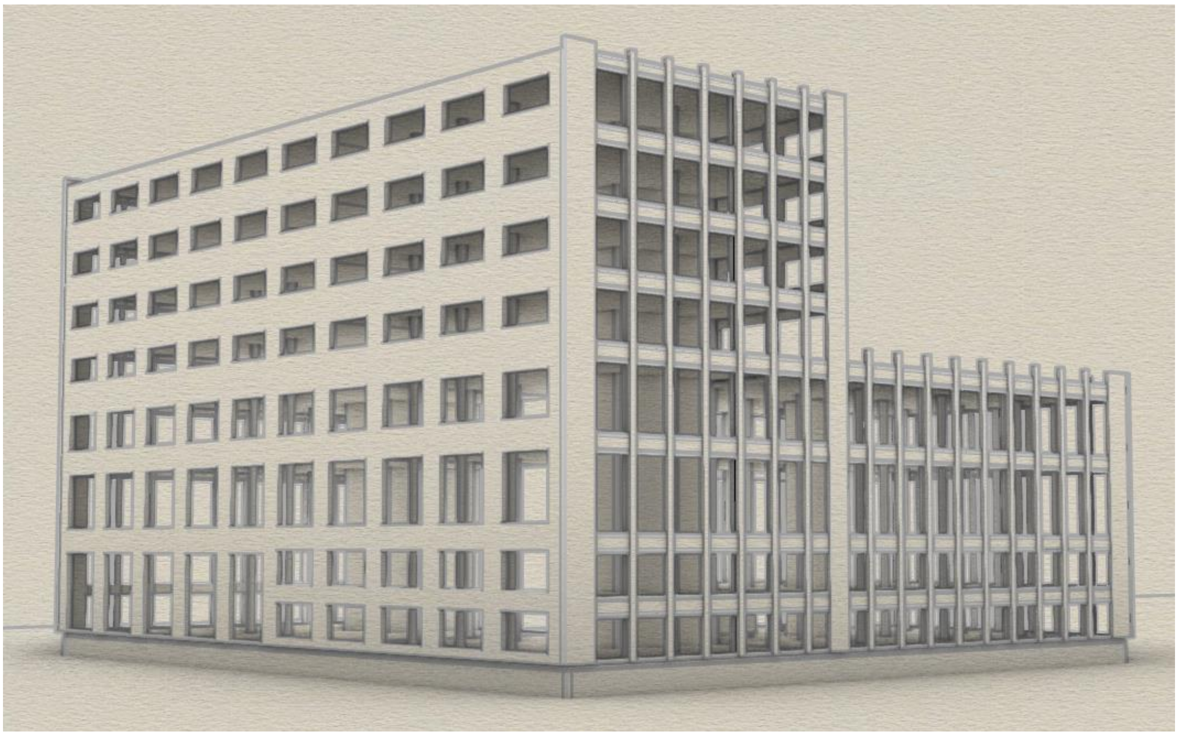


Figure 11: Architectural impression of the multistorey-building

Table 1: Main functions of both buildings

Function	**Requirements**		**Points of attention**
Education	Auditorium (Ground floor) 4x large room 4x small room	$250\ m^2$ ~ $10 \times 15\ m^2$ ~ $9 \times 10\ m^2$	Loads Headroom Free spans Column-free
Roof garden	On roof of lower part of multi-storey building	Suitable for terrace, medium-sized trees ~ $700\ m^2$	High loads due to soil layer
Restaurant	Can be placed in either of the two buildings	$600\ m^2$	Loads, ventilation, water
Meeting rooms	2 x large 2 x medium 7 x small Distributed over building	~ $6x7\ m^2$ ~ $5x6\ m^2$ ~ $4x3\ m^2$	Sound insulation
Library		$200\ m^2$	Sound absorption Climate control
Study places	Distributed over lower half of building	200 seats	
Tele-meeting cabins (1 person)	Distributed over buildings	20 seats	Sound insulation
Exhibition Hall	Needs to have a free span and flexible use of floor space (easy to adapt)	Preferably in spatial structure building Elegant structure with architectural and aesthetic quality	Loads, Foundation, Construction methods

Table 2: Support functions of both buildings

Function	**Requirements**		**Points of attention**
Parking	In the basement, 65 positions for cars / EVs, additional space for (motor) cycles	Car parking sizing according to NEN 2443 (see appendix)	
	Sloped access lane(s) to street	Slope for easy and safe access to basement	Unsupported soil retaining basement walls
	Regular grid	Column positions according to NEN2443	Alignment with superstructure
Technical rooms	In the basement	Sprinkler room 2 basins of 7500 ltr + sprinkler pump	High loads waterproofing

Function	Requirements		Points of attention
		Transformer room	High loads
		Waste handling and storage	
	Kitchenettes	Small kitchens on each floor with coffee machine, tap, sink, fridge, dishwasher, etc.	Near vertical shafts
	Toilets	5 to 10 m^2 each floor	Near vertical shafts
	Accessible by trucks	Loading dock	Near freight elevator
	On the roof	Combined units for air treatment and heat recovery 1.8 x 8 m^2 connected to vertical shafts – also servicing the spatial structure! Solar panels 1000 m^2	Medium-high loads, vibrations Possible "pergola" construction to combine with engineering
Circulation / traffic areas	Vertical building services space Corridors Entrance lobby	Sufficient shaft space for vertical services distribution Approx. 2 m^2 air inlet and 2 m^2 air outlet, plus stormwater, sewer, freshwater, electricity and data – also servicing the spatial structure! Sufficient traffic area to allow people to walk inside the building without congestion 250 m^2 outside	Fire safety, noise, vibrations Free paths during fire, compartments, doors, entrance area
	Stairs		Sufficient capacity during fire evacuation
	Elevators	2 single elevators similar to the elevators A, C, E in Civil Engineering building, optional: 1 freight elevator, similar to B and D.	

Function	Requirements		Points of attention
	Channels/pipes	Above false ceiling where possible	
Office / multifunctional spaces	Remaining part of building	Flexible use / open floorplans	Load installations Flexible separation walls

2.4 Architectural aspects

The architect has expressed the following wishes:

- Transparent entrance, clearly recognisable in the façades of both the multi-storey building as the spatial structure, facing the spatial structure (in the armpit of the L-shape), with glass façade spanning the first 12 m from ground floor upwards, tourniquet door with canopy to mark entrance
- Open and high area behind main entrance (vide, no 1^{st} floor)
- Roof garden on lower part of building, possibly connected to restaurant or other function for social interaction on that floor (4)
- Connection of transparent façade area around entrance to roof garden
- Façade facing Heertjeslaan (SSE): vertical lines and horizontal bands, curtain wall or similar, transparent to street Heertjeslaan
- Façade facing Applied Sciences (NNW): same typology as SSE-façade
- Façade facing Van der Maasweg (WSW): closed facade with massive appearance (brick, concrete) and smaller and distinct window openings that the facades mentioned above
- Clear visual interaction between main entrance and spatial structure

3 Work Planning

For each of the three units, we have made a work planning for the Design Assignment, that should help you as a group to organise your time in the module. As explained in section 2.1, the total workload for the assignment per student (including the formative building physics exercises) is approximately 20 hours per week.

3.1 Learning Unit 1: Architecture, Building physics & Facades

A suggestion for a work planning for the exercises and design assignment related to unit 1 is provided in Table 3 below. The written exam for unit 1 in week 9 is not mentioned here, so please keep this in mind.

Table 3: Work planning Building Physics Exercises and Design Assignment unit 1

	Building Physics Exercises	**Design Assignment (Facades)**
Week 1	• Calculate Rc-value and U-value for a part of the façade (Excel)	-
Week 2	calculate BENG1 for the building – verify glass percentage of 1 façade (Excel)	• Analyse requirements of and loads on all facades in relation to function and orientation (as a group) • Sketch façade cross-section 1:50 (each student 1 façade) • Identify potentially interesting details
Week 3	• Calculate heat/moisture (Excel) • Daylight calculation of a room	• Improve façade cross-section 1:50 • Sketch façade elevation 1:50
Week 4	Acoustic insulation calculation (Excel)	• Improve façade cross-section 1:50 • Improve façade elevation 1:50 • Sketch details 1:10 / 1:5 (3 per student) • Prepare midterm presentation
Week 5	Climate diagram BENG 2 + 3 calculation	• Improve details 1:10 / 1:5 (3 per student) • Prepare midterm presentation
Week 6 **Week 7** **Week 8**	Work on deliverables: • Report with rationale behind façade (requirements, functions, solutions) • Choice of materials, U-values, Rc-values, glass percentages, g-values of sunshading, daylight access • Rc/ U-value of relevant details • BENG 1-2-3 calculation • Daylight calculation • Climate diagram • Conclusions and recommendations	Work on deliverables: • Report with rationale behind façade (requirements, functions, solutions) • Choice of materials, U-values, Rc-values, glass percentages, g-values of sunshading, daylight access • 4 façade elevations 1:200 (N-E-S-W) • 4 façade cross-sections 1:200 • 3 details 1:10 or 1:5 per student of different and relevant parts of the façade (2 vertical cross-sections, 1 horizontal cross-section)
Week 9	Finishing deliverables	Finishing deliverables

	Building Physics Exercises	Design Assignment (Facades)
	Final presentation	Final presentation
Week 10	Final report	Final report + drawings

3.2 Learning Unit 2: Building Structures, Construction Methods and Foundations

In week 1of the module, students for LU2 start working on the principles for the design of the building. Several variants for the structure will be examined and compared during the first half of the module. This requires students to read up on the design, divide the tasks among themselves for the next few weeks and establish the design principles for the structure. In the first 4 weeks, the fundamentals of the design will be calculated as well as 3 different variants for the end product. In week 5 there will be an intermediate presentation, with a report review in week 6. After week 5 there will be a reduction in the work load of LU2 to make time for the increased workload of LU1 and LU3. From week 6 till 8, the calculations and drawings of the chosen variant need to be further elaborated. In week 10 there will be an end presentation with the full report.

Table 4: Work planning unit 2

Week 1	**Fundamentals**	
	Structural principles	Construction classification: ○ Design service life of the structure with the corresponding class ○ Reliability and consequence class General structural loads: ○ Permanent loads (facades, finishes, trims, etc.) ○ Decide the load classes corresponding to the different building functions ○ Variable loads vertical (incl. rain, snow) ○ Wind loads (for overall stability) ○ Load combinations (ULS and SLS) General requirements: ○ Vibrations ○ Deformations (horizontal and vertical)
	Variant study	Describe 3 variants to develop in the coming weeks, with distinct differences in: ○ Materialisation (e.g. concrete, steel, timber, glass) ○ Floor system ○ Vertical load bearing system ○ Stability system Prepare floor plan sketches (to scale, e.g. 1:200) for the variants; initial ideas on span directions of the floors, principle stability, etc.
	Quality Control	Student task division/assignment: ○ Drawing up calculations/drawings ○ Quality check of the calculations/ drawings

		Assessment framework for the variants: o Define criteria for Multicriteria Analysis (MCA)
Week 2/3	**Vertical loads & stability**	
	Variant development of support structure (3 options) Make use of the design charts, tables and rules of thumb from the Quick Reference and different readers	Constructions loads: o Determine governing elements (floor, beams, columns, walls) o Dimension the governing floors, columns, beams o Determine the governing load to the foundation o Test the normative elements with ULS and SLS Calculate as simple as possible; Design tables > 1D hand calculation (> 2D framework), depending on assessment and availability of information
	Sustainability	Determine the conditions for sustainability (global quantities of GWP (CO_2 footprint) and Environmental Cost Indicators (MPG, Milieuprestatie Gebouwen in Dutch) for materials
	Variant study stability	Determine the thrust factor, the form factor, etc. for the overall building structure
	Wind loads	Sketch/outline how the wind loads are distributed by the building stability system (façade to floor to foundation), and globally calculate/design your stability system accordingly Indicate and explain which load combinations are governing, so that these can be calculated Keep in mind/check the global horizontal stiffness of the building Prepare floor plans/mechanical diagrams for the variants; span directions of the floors, principle stability, etc. Drawings (to scale, e.g. 1:200)
	Design exploration of specials elements (1)	Construction concepts for: o Basement construction o Auditorium
Week 4	**General**	
	Elaborate principle design for the superstructure	Continue with the calculation checks for the different variants Prepare floor plans/mechanical diagrams for the variants; span directions of the floors, principle stability, etc. Floor plans and intersections 1:200

	Elaborate on the principles of the basement and foundation	How to deal with e.g. bearing capacity of piles?
	Design exploration of specials elements (2)	Construction concepts for: o Rooftop garden o Installations in the building
Week 5	**Presentation** Intermediate presentation	Prepare for the presentation Prepare interim report (for review in week 6)
Week 6-8	**Elaboration** Final definitive calculations	Calculations: o Load takedown for principal locations in the building o Stability calculations o Calculations for the main structure o Foundation and support structure
	Definitive drawings	Prepare floor plans/mechanical diagrams for the variants; span directions of the floors, principle stability, etc. Floor plans and intersections 1:200
Week 9	**Final presentation** Keep in mind: the goal of the presentation is to “sell” your project, convince the audience that you’ve designed the optimal building structure, that meets all requirements.	Presentation should touch upon / show: o Boundary conditions (e.g. loads) o Safety and reliability, also during construction where applicable o Explanation of chosen structural principles and materials o Construction method and foundation o Interaction with architecture, façade and building services o Sustainability and circularity o Main dimensions of floors, columns, beams, stability elements, foundation o Floor plans and cross-section(s) of the building For the presentation, use graphical material where possible rather than text (only).
Week 10	**Final report**	Final Report* should include: o Technical Description of the project, with all design calculations o Technical drawings of the project

** Global report structure (max. 40 pages for LU2, excluding appendices):*

1. *Basis of design (description of structure, loads, materials, options & design choices, etc.)*
2. *Load transfer & stability analysis*
3. *Primary design calculations for the structure/structural elements*

Drawings, extensive calculation output (software), etc. should be included in appendices.

3.3 Learning Unit 3: Design of Spatial Structures

A work planning for the workshops and design assignment of the spatial structure is provided below in Table 5.

Table 5: Work planning workshops and design assignment spatial structure unit 3

Week 1-3	Workshops	6 workshops in which essential skills are provided for the design of Spatial Structures. Various techniques and software are explained through examples and assignments.
Week 4	Kick-off design assignment	The design assignment is started with a workshop physical modelling of special structures. During this workshop various typologies of structures are made and explored. Examples and typical design steps will be discussed. As a group you must choose a structural typology to work on in the design assignment.
	Choice for structural typology	**Spend in total approximately 6 hours on workshop and choice**
Week 5	Start of assignment Structural Design and Analysis	Based on the skills provided in the first week you will design and analyse a Spatial Structures. The first focus should be on a simple structure for which the entire process of design and analysis can be performed. Depending on your progress, the last week(s) can be used to increase complexity in your design. **Spend approximately 5 hours.**
	Concept of design	Individually finalize sketches of your version of the structural concept. Make figures of your initial simple design. Also make a list of the following: - All tasks in the process of design and specify in which week you will perform the task - The criteria of the final design and analysis. Focus mostly on safety and efficiency.
	Consults	To assist you in the design and analysis there will be consults by various teachers. It is expected you come prepared with results and questions.
	Online forum	To provide additional support and communication among yourself a forum will be available to post your question.
Week 6-8	“Simple” design and analysis	Experience in education has shown that most students over-complicate a design from the start

		and then get stuck. This can be prevented by starting off with a simple design. Finishing and presenting working models for all steps in the process of design and analysis are a minimum requirement for this course. When all steps in the process of design and analysis work it is possible to improve you model. Each student must show that all tasks are working before improving the design. Therefore, a visualization of the results in a few A4 pages which must be uploaded to Brightspace. **Spend approximately 5 hours per week.**
	“Improved” design and analysis	After finishing a simple design and analysis some aspects of the design can be improved. This must be done one-by-one. Structural concept vary in complexity. Therefore it is possible you will not have the time to deliver an improved design and analysis. Finishing and presenting working models for the improved design and analysis is not a requirement, but will affect the assessment.
Week 9	Final presentation	The final presentation of your assignment. The following topics are relevant for practically all structural concepts and should be explained in figures and text; - the structural concept (including stability and foundation); - the (structural) design, including the 3D models; - flow of forces; - results of the physical and computational form finding process; - schematisation of the structure as basis for the (computer) calculations; - analysis type (e.g. static linear / non-linear etc.); - input for the computer calculations. E.g. mesh type, materials, section properties, loads, constraints (incl. boundary conditions); - principle stresses and forces; - checks for ULS and SLS (limited to most relevant load combination. E.g. peak loading) - details of your structure in principle; - principles of constructability and fabrication; - conclusions; - consulted literature
Week 10	Paper submission	End of the week the extended abstract with the written underpinning of your spatial structure should be submitted. Use the provided template.

4 Timetable

4.1 Timetable and content of lectures

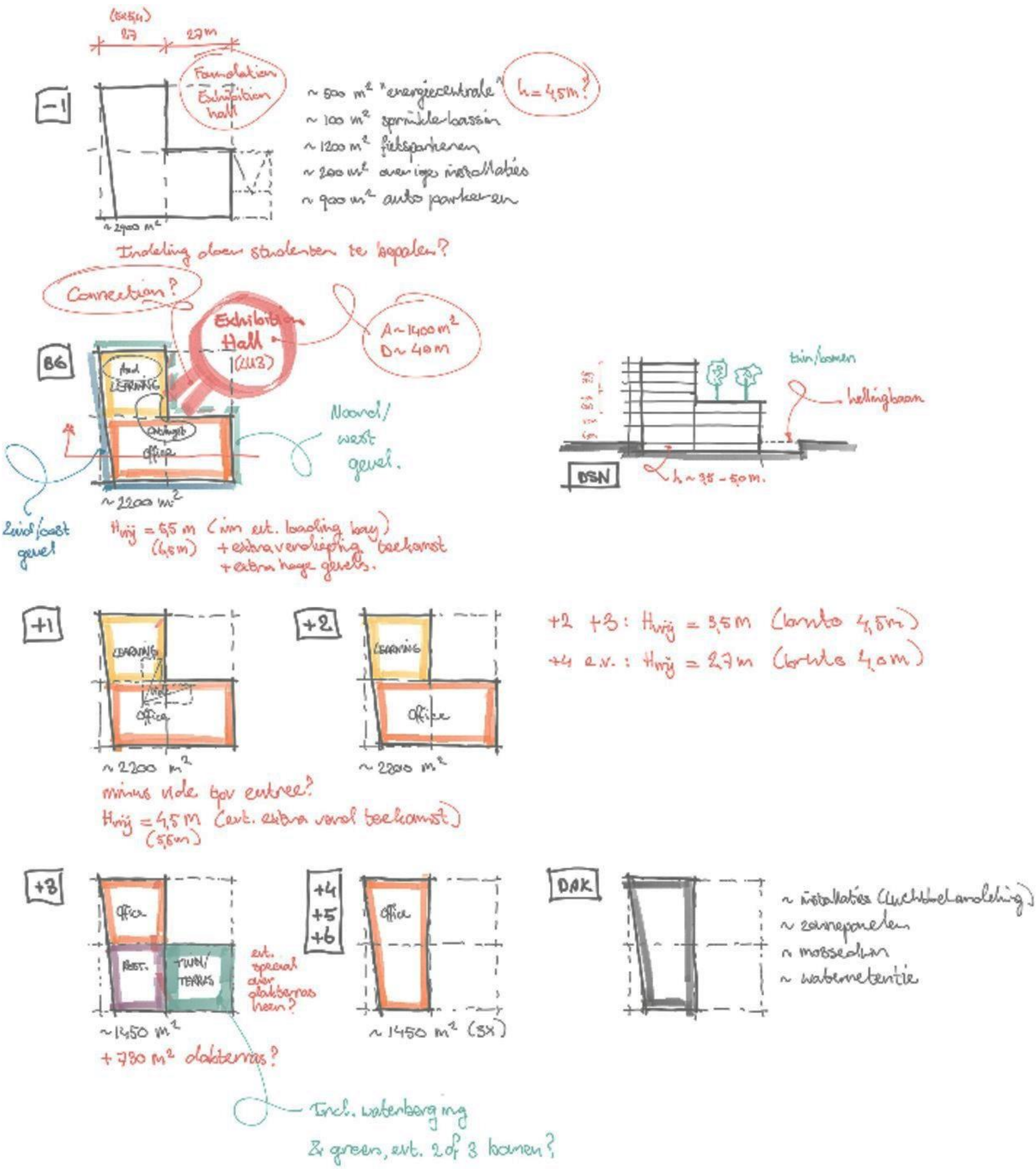
On Brightspace, you can find the detailed version of the timetable, including content of each lecture hour and the name of the lecturer. Please always check https://mytimetable.tudelft.nl for last-minute changes of locations or cancellations. We will also post announcements on Brightspace in case of changes. The most recent version of the schedule below can also be found on Brightspace.

Studio hours in general are not compulsory but are meant to help you collaborate in a group and help us to find your group for tutor sessions and answering your questions.

5 Appendices

5.1 Draft floor plans and cross-section

The sketches below from the (Dutch) architect provide an indication as to how the building could be divided over the various functions.

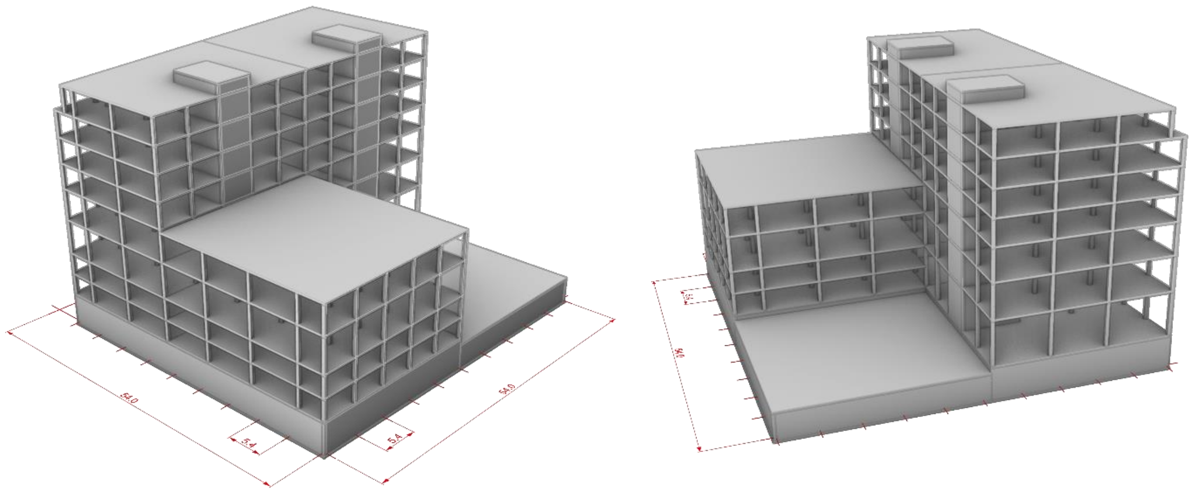


as measured in Rhino-3D file,
perimeter drawn inside façades

gross floor area (so including columns, shafts, elevators)

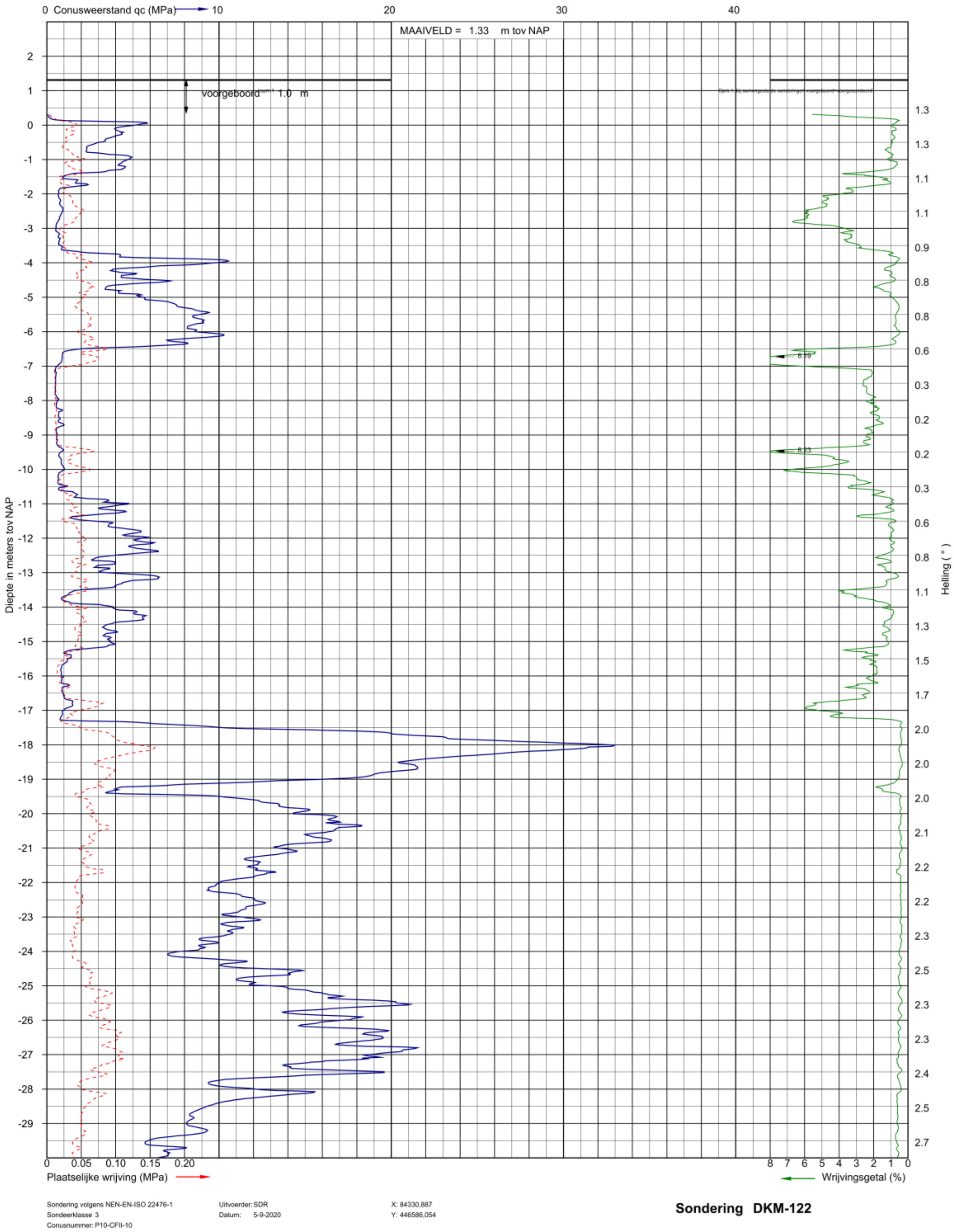
multi-storey building	basement			2000	m2
	ground floor			2000	
	+1	floor		1200	
	+1	vide	800		
	+2	floor		2000	
	+3			2000	
	+4	floor		1270	
	+4	roof garden	730		
	+5			1270	
	+6			1270	
	+7			1270	
	+8	roof	1270		
				14280	**m2**
spatial structure				**1400**	**m2**
total program				**15680**	**m2**

Initial renders of <u>a possible</u> building structure:



5.2 Soil investigation & pile foundation advise

For the design of the foundation, geotechnical output for a project in the center of Delft is used as reference, since the soil properties are similar. The results of a governing CPT test are given below:



Additional general geotechnical information on the project location:	
- Ground level	0.0m + NAP
- Ground floor level (top ground floor finish)	0.1m + NAP
- Ground water level (highest)	0.6m – NAP

For three types of foundation piles, an advise has been drafted by the geotechnical engineer. For the purpose of this design exercise, the other CPT tests are to be ignored:

Sonderingen voor opdracht: 02P015850 DPA-paal 0,410 m

diepte tov NAP	DKM-118	DKM-119	DKM-120	DKM-121	DKM-122	DKM-123	DKM-124	DKM-125
-20,00	333	212	293	71		89	263	
-20,50	431	354	358	139	67	170	340	282
-21,00	500	510	436	311	129	205	399	423
-21,50	638	559	513	245	193	243	490	459
-22,00	737	627	563	282	246	287	556	542
-22,50	771	659	632	320	240	328	623	447
-23,00	766	709	678	348	286	467	681	371
-23,50	818	769	704	569	321	506	712	415
-24,00	864	550	752	653	363	557	762	441

Sonderingen voor opdracht: 02P015850 DPA-paal 0,460 m

diepte tov NAP	DKM-118	DKM-119	DKM-120	DKM-121	DKM-122	DKM-123	DKM-124	DKM-125
-20,00	440	289	386	129		148	350	
-20,50	552	469	469	216	104	209	452	384
-21,00	631	643	561	365	190	252	516	548
-21,50	788	657	638	322	261	330	628	585
-22,00	877	762	707	370	300	376	704	678
-22,50	875	823	798	418	307	432	787	509
-23,00	943	879	850	446	367	593	832	444
-23,50	1000	946	853	719	408	643	885	504
-24,00	1049	618	927	814	453	699	941	529

Sonderingen voor opdracht: 02P015850 DPA-paal 0,510 m

diepte tov NAP	DKM-118	DKM-119	DKM-120	DKM-121	DKM-122	DKM-123	DKM-124	DKM-125
-20,00	558	375	459	195		217	443	
-20,50	688	591	575	299	158	276	565	507
-21,00	775	759	701	412	251	340	648	633
-21,50	954	783	768	405	339	430	775	724
-22,00	1033	870	866	470	338	477	869	829
-22,50	1031	980	971	520	384	537	962	571
-23,00	1130	1065	1041	557	450	742	1013	536
-23,50	1199	1142	1037	886	506	795	1076	603
-24,00	1252	731	1120	992	556	857	1138	625

In de grond gevormde grondverdringende betonpaal, middels een ingeschroefde stalen hulpbuis en verloren punt met groutinjectie, respectievelijk Ø380/450 / Ø460/560 / Ø540/670:

In de grond gevormde grondverdringende betonpaal, middels een ingeschroefde stalen hulp

diepte tov NAP	DKM-118	DKM-119	DKM-120	DKM-121	DKM-122	DKM-123	DKM-124	DKM-125
-20,00	555	406	536	277		299	489	
-20,50	663	581	611	351	228	357	583	505
-21,00	734	758	694	513	306	384	638	669
-21,50	893	766	767	445	372	455	746	695
-22,00	976	865	824	482	423	493	815	657
-22,50	973	912	908	518	402	541	892	566
-23,00	1016	861	949	537	456	704	929	502
-23,50	1063	712	939	822	488	746	973	554
-24,00	1103	654	1005	911	544	796	1021	567

In de grond gevormde grondverdringende betonpaal, middels een ingeschroefde stalen hulp

diepte tov NAP	DKM-118	DKM-119	DKM-120	DKM-121	DKM-122	DKM-123	DKM-124	DKM-125
-20,00	886	675	814	510		511	781	
-20,50	1047	950	938	646	420	556	911	861
-21,00	1142	1008	1077	639	515	646	1007	997
-21,50	1322	1125	1158	717	585	762	1162	1091
-22,00	1388	1205	1266	775	567	798	1264	822
-22,50	1391	1325	1381	822	639	859	1351	712
-23,00	1494	1073	1358	850	704	1113	1418	764
-23,50	1584	890	1437	1288	757	1176	1487	827
-24,00	1631	957	1522	1401	851	1236	1548	828

In de grond gevormde grondverdringende betonpaal, middels een ingeschroefde stalen hulp

diepte tov NAP	DKM-118	DKM-119	DKM-120	DKM-121	DKM-122	DKM-123	DKM-124	DKM-125
-20,00	1264	1004	1174	798		735	1135	
-20,50	1466	1274	1333	809	655	807	1289	1233
-21,00	1629	1404	1436	917	726	941	1394	1412
-21,50	1813	1493	1597	1038	712	1085	1617	1553
-22,00	1783	1639	1763	1114	813	1147	1781	942
-22,50	1909	1779	1799	1162	917	1277	1883	1014
-23,00	2031	1236	1895	1200	998	1579	1989	1075
-23,50	2133	1210	2004	1826	1056	1658	2077	1147
-24,00	2221	1308	2132	1981	1208	1754	2162	1131

Sonderingen voor opdracht: 02P015850 VIBRO (heiend getrokken) 0,380/0,465 m

diepte tov NAP

	DKM-118	DKM-119	DKM-120	DKM-121	DKM-122	DKM-123	DKM-124	DKM-125
-20,00	802	616	776	481		504	721	
-20,50	936	838	872	584	423	572	845	757
-21,00	1029	1050	984	744	524	622	919	957
-21,50	1221	1060	1074	703	609	715	1054	996
-22,00	1325	1185	1154	758	672	766	1144	1106
-22,50	1308	1258	1263	811	656	831	1243	832
-23,00	1396	1322	1322	841	725	1031	1293	792
-23,50	1460	1007	1317	1183	773	1088	1354	862
-24,00	1515	974	1404	1296	845	1153	1418	885

Sonderingen voor opdracht: 02P015850 VIBRO (heiend getrokken) 0,406/0,480 m

diepte tov NAP

	DKM-118	DKM-119	DKM-120	DKM-121	DKM-122	DKM-123	DKM-124	DKM-125
-20,00	852	651	816	505		529	758	
-20,50	994	885	916	615	445	598	895	802
-21,00	1092	1098	1042	769	552	658	974	998
-21,50	1295	1115	1120	737	645	758	1117	1058
-22,00	1403	1240	1224	805	710	812	1217	1175
-22,50	1384	1336	1342	861	695	881	1322	875
-23,00	1489	1409	1410	896	769	1099	1377	845
-23,50	1557	1063	1405	1261	824	1159	1443	919
-24,00	1616	1039	1497	1381	897	1229	1512	944

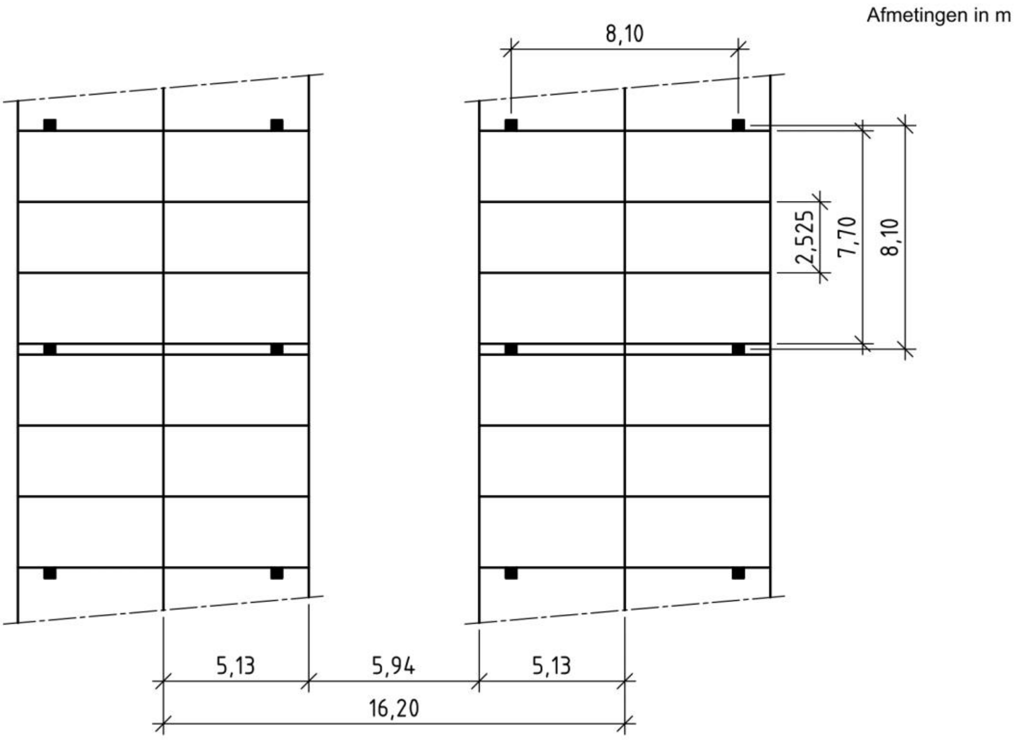
Sonderingen voor opdracht: 02P015850 VIBRO (heiend getrokken) 0,457/0,560 m

diepte tov NAP

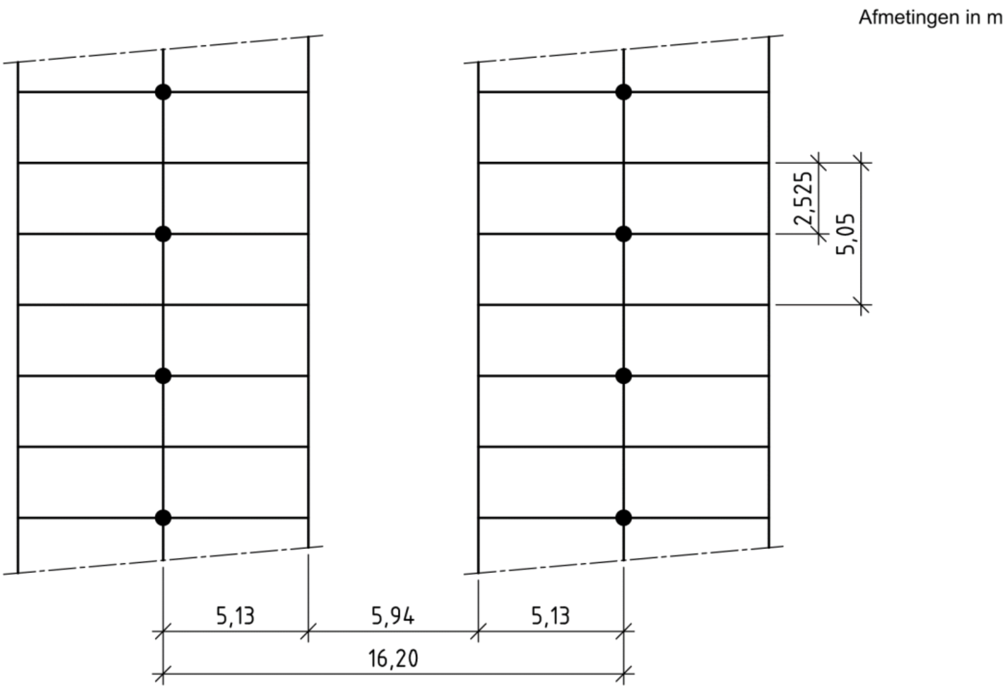
	DKM-118	DKM-119	DKM-120	DKM-121	DKM-122	DKM-123	DKM-124	DKM-125
-20,00	1132	887	1049	716		715	1014	
-20,50	1322	1204	1199	879	621	777	1170	1117
-21,00	1439	1280	1367	882	738	888	1288	1280
-21,50	1650	1421	1468	982	826	1027	1472	1396
-22,00	1736	1523	1600	1058	815	1078	1595	1532
-22,50	1752	1668	1740	1122	903	1156	1703	999
-23,00	1878	1804	1725	1164	984	1447	1788	1069
-23,50	1990	1208	1824	1658	1053	1526	1875	1150
-24,00	2055	1292	1930	1795	1157	1603	1954	1164

5.3 Parking layout examples (NEN2443 & project)

Example layouts from NEN2443:

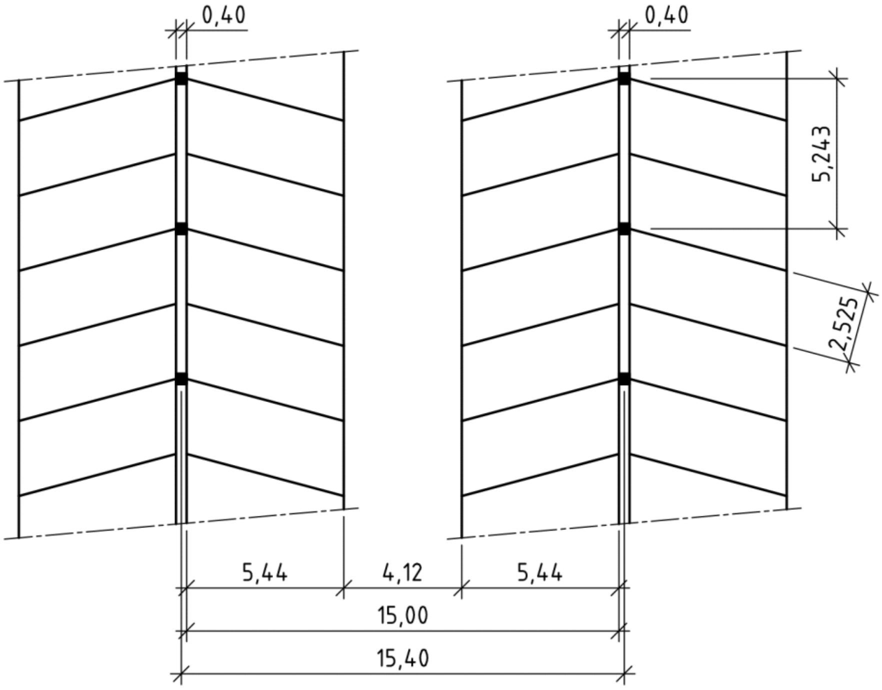


Voorbeeld I



Voorbeeld II

Afmetingen in m

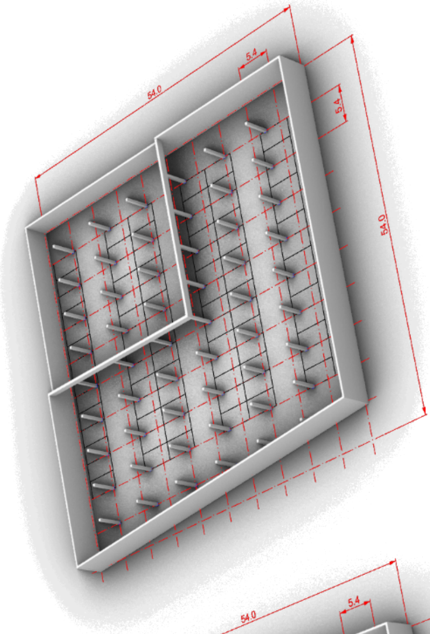


Voorbeeld III

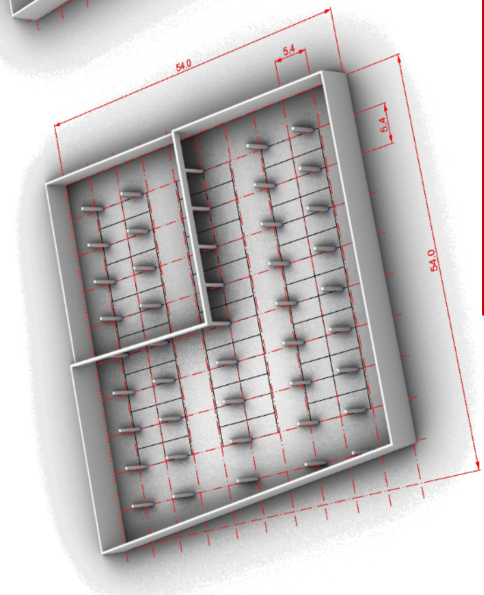
VOORBEELDEN

	I	II	III
Kolomvrij	**Nee**	**Ja** [a]	**Ja**
X-as, in m	8,10	5,05	5,24
Y-as, in m	8,10	16,20	15,40
Vloerveld, in m^2	65,61	81,80	80,70
Kolom, in m	0,40 × 0,40	*R* = 0,50	0,40 × 0,50
Parkeerhoek, in graden	90	90	74 42
Parkeervakbreedte, in m	2,525	2,525	2,525
Parkeereenheid, in m	16,20	16,20	15,00
Parkeervakdiepte, in m	5,13	5,13	5,44
Parkeerwegbreedte, in m	5,94	5,94	4,12
m^2 per parkeervak	21,87	20,45	20,17
Reductie vloeroppervlakte	0 %	6,5 %	7,8 %
Reductie op overspanning, in m	–	–8,10	–7,30
[a] Kolommen staan in het vak volgens figuur 35.			

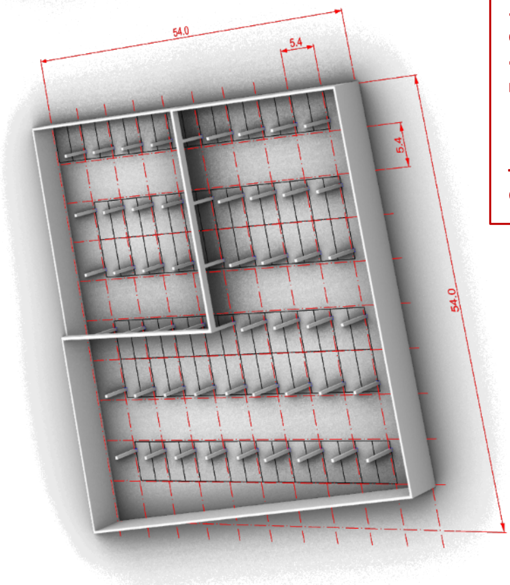
Examples of layouts for the design assignment:



Columns 5.4x8.1m (rotated)



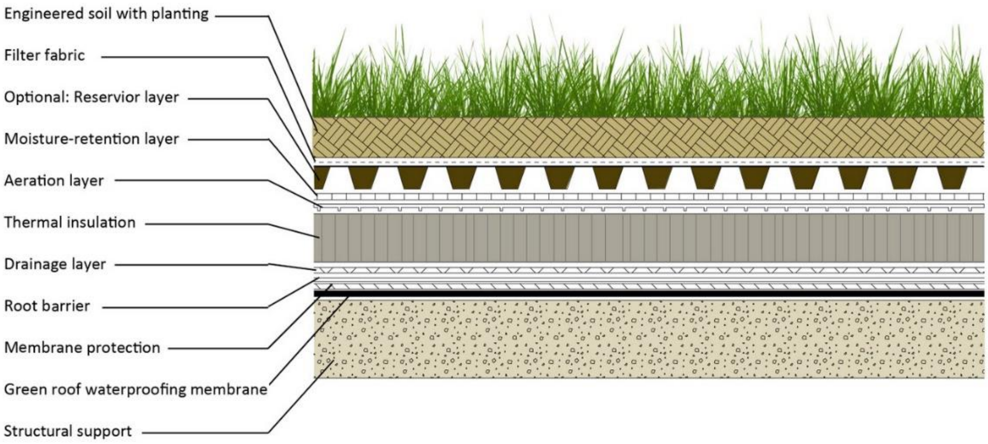
Columns 5.4x8.1/12.2m



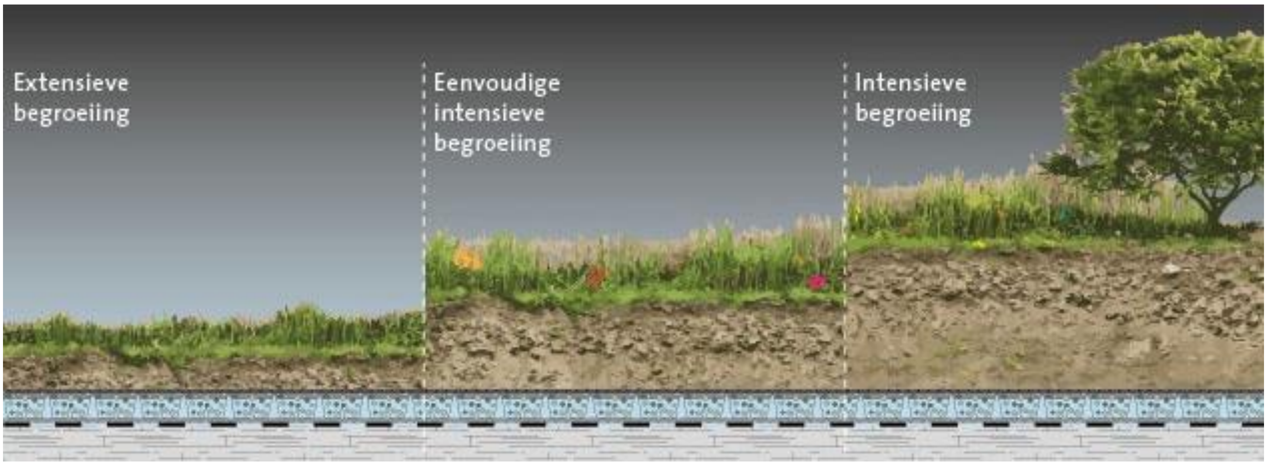
Columns 5.4x8.1m

5.4 Rooftop gardens

Standard cross section for a green roof (with water retention; source: Architizer.com):



Types of green roof (source: papagreen.org):



Load overview for different types of green roof:

beplanting	sedum	vet-plant	bloemen-tapijt	kruiden	grassen	struiken	bomen
dikte	4 – 6 cm	8 – 12 cm		12 – 21 cm		25 – 50 cm	> 50 cm
gewicht	45 – 75 kg		80 - 120 kg	120 - 200 kg		> 300 kg	
schuinte	0° tot 60°	0° tot 45°		0° tot 30°		0° tot 20°	0° tot 10°
gebruik	sedumdak		kruiden-gras- turfdak		daktuin	verblijfsdak	verkeersdak
	zonnepanelen			waterbuffering		groengrasdak	

For water retention, the amount of water stored usually varies from 7 to 15 cm of water height.

Examples (in section) of an intensive "roof" garden: