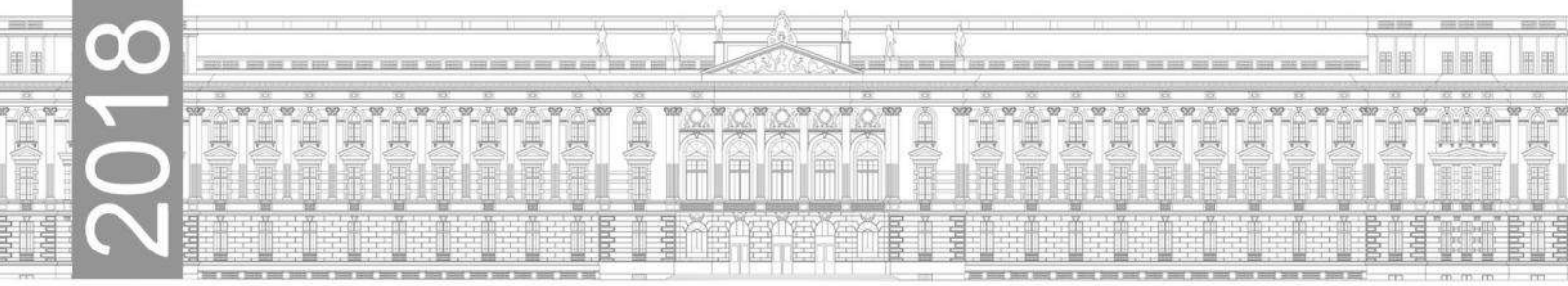

ADAPTIVE FACADES 2018

BELGRADE

BOOKLET

Adaptive Facades Training School 2018
"Retrofitting Facades for Energy Performance Improvement"

3th to 7th of September 2018
University of Belgrade, Faculty of Architecture, Belgrade, Serbia

Edited by
Professor Dr. Aleksandra Krstić-Furundžić
Ass. Professor Dr. Budimir Sudimac

Organised and sponsored by

cost EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

European COST Action TU1403
Adaptive Facades Network

UNIVERSITY OF BELGRADE FACULTY OF ARCHITECTURE

Book title
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Technical Assistance
Aleksandra Ugrinović

Training school 2018 logo
Aleksandra Krstić-Furundžić

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The research published in this book was conducted during the Adaptive Facades Training school in Belgrade realized within the project COST Action TU1403 - Adaptive Facades Network. We are very grateful to Prof. Dr. Andreas Luible, chairman of the COST Action TU1403, and Prof. Dr. Uta Pottgiesser, member of the Working Group 4 (Dissemination and future research), whose suggestions supported the organization of the Training School 2018 in Belgrade.

Research within the Workshop can be useful for research in the field of architectural design and energy efficiency of buildings, as well as contribute to further research within national scientific projects, such as TR36035 and III43007.

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Adaptive Facades Network

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FACULTY OF ARCHITECTURE

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1.1. Organising Committee

Prof.Dr. Aleksandra Krstić-Furundžić
University of Belgrade, Faculty of Architecture, Serbia

Dr. Aleksandra Krstić-Furundžić, Ing.- Arch., is Professor at the University of Belgrade – Faculty of Architecture. Several times was the head of the Department of Architectural Technology. Professional experience as an educator, architectural design practitioner, researcher, and editor. Expert domains: Architectural constructions, Innovative façade and roof technologies, Energy efficient buildings, Passive and active solar systems, Industrialized construction, Building refurbishment technologies. She holds classes at Bachelor, Master and Doctoral studies at the Faculty of Architecture, University of Belgrade. She was a visiting professor at the Faculty of Architecture, University of Banja Luka, BiH. She participates in the National Energy Efficiency and Technological Development Programs, and in a number of international projects within the framework of European Cooperation in the field of Scientific and Technical Research, where she was also a lecturer and trainer in Training Schools of several COST Actions, such as COST Action TU1205, TU1104, TU1403 and CA16235, and for the last three she was also the organizer. She is Co-Founder and Technical Director of International Academic Conference on Places and Technologies, which has for several years been recognized at the regional level and beyond. Member of the Editorial Board of two international journals, and several professional associations. Author of several books, a significant number of chapters in international and national monographs and scientific papers published in Energy and Buildings Journal, Renewable & Sustainable Energy Reviews and other international journals.

Ass.Professor Dr. Budimir Sudimac
University of Belgrade, Faculty of Architecture, Serbia

Dr. Budimir Sudimac (M), Ing.- Arch., is Ass. Professor at the University of Belgrade – Faculty of Architecture, Department of Architectural Technology. His research is mainly focused on innovative building envelopes using green wall components. Vice Dean for Finance at the Faculty of Architecture, University of Belgrade. In parallel to pedagogical engagement, he undertakes professional work in the areas of architecture and urban design as a single author or member of different teams. Author of several chapters in international and national monographs, scientific papers published in international journals and international and national conference proceedings. He is member of the Scientific council of international scientific journal SPACE & FORM and member of the Editorial Board of the national magazine "TEHNIKA". Member of the Scientific Committee of several international conferences. Participates at architecture and architecture-urbanism competitions and presents his works at group exhibitions in country and abroad.

1.2. Preface
by Aleksandra Krstić-Furundžić

Introduction

Facades as part of the building envelope are considered to be the most important for achieving the proper indoor comfort, for reducing the consumption of energy from fossil fuels and thus the CO2 emissions. The fact that newly constructed buildings represent a small percentage in relation to the total building stock indicates the importance of buildings refurbishment, while retrofitting of facades is crucial for energy performance improvement. Different refurbishment measures are available to improve thermal, light, acoustic and air comfort, as well as aesthetic values. Design of energy efficient buildings is based on achieving appropriate energy performances, i.e. energy savings and energy gains from renewable energy sources.

The point is to achieve active relationship between the building and the environment through the application of heating, cooling, ventilation and daylighting technologies that are based on natural forces (as pressure, temperature and moisture differences) and the use of renewable energy, thus reducing environmental pollution. Establishing active relationship between the building and its surroundings means adapting to natural and built environments, location; climate, annual and daily cycles (changes); various needs of users. In this respect, the concepts of adaptive facades have been developed and are constantly evolving.

One of the objectives of the project "Adaptive Facades Network" - COST Action TU1403, within the framework of European Cooperation in the field of Scientific and Technical Research, is to create the basis for exploiting recent technological developments in adaptive façades and energy efficient buildings, and to help train the future generation of façade R&D professionals in Europe. Therefore, 2nd Training School was organized by the COST Action TU1403 and the Faculty of Architecture, University of Belgrade.

The purpose of the Training School 2018

The aim of the Training School "Retrofitting Facades for Energy Performance Improvement", held in September 2018 at the University of Belgrade, Faculty of Architecture, was to educate students on adaptive facade systems and assess the possibilities of their application in façade retrofitting and resulting energy and environmental benefits. In the period of five days, from 03 to 07 September, the teaching process included a theoretical block and workshop (more detailed information about the content and organisation is given in the schedule). During the theoretical block, frontal lectures were held by 12 lecturers, experts in the fields related to innovative facades, from 8 universities from Europe, and five tutors helped the creative work of participants during the workshop. A total of 33 participants, PhD and Master students, from 17 European universities had the opportunity to learn more about the design phases for adaptive facade systems that included: Conceptual Design, Materials and Technologies; Performance Evaluation and Mock Ups & Testing and Modelling/Numerical Simulation.

The education and training process

The education process included the following steps:

- Lectures ex-cathedra on concepts and technologies of adaptive facades and façade retrofitting.
- Early stage investigators - ESI workshop. PhD and Master Students had the opportunity to discuss individual research topics within interdisciplinary teams.
- 3-days Workshop on the integration of innovative façade technologies into the building retrofitting.
- Two phases of project presentation in front of the critics and evaluation expert committee – concept presentation and final presentation.

A very intense week of lectures and workshops enabled participants to learn from professionals and colleagues, and meet fellow researchers from other European universities for networking.

Particular importance was given to social activities that included visit to locations selected for case studies (typical Belgrade office and residential building), sightseeing of several historical locations in the city center, welcome dinner, and Belgrade nightlife, guided by locals. This, like all other activities during the Training school, contributed to the strengthening of friendship and business relations among participants.

Photo documentation of the Lectures (Photos: A. Krstić-Furundžić)

About the Training School

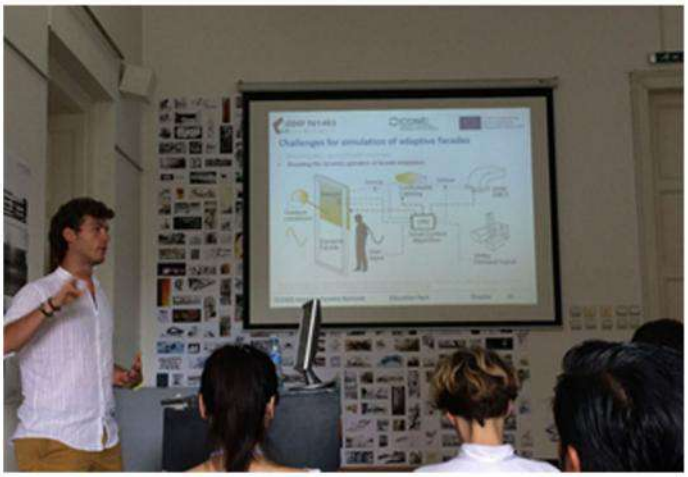


Photo documentation of the Lectures (Photos: A. Krstić-Furundžić)

Training School showed the presence of an adaptive facade network and represented the acquisition of knowledge and skills of experts of various backgrounds from different European universities.

List of lecturers and topics		
Name and Surname	**Affiliation**	**Lecture Title**
Dr. Marcin Brzezicki	Wroclaw University of Science and Technology, Poland	Adaptive Facade Concepts and Typologies
Miren Juaristi Gutiérrez	University of Navarra, Spain	Smart and Multifunctional Materials and their possible application in façade systems
Dr. Mark Alston	University of Nottingham, Faculty of Engineering, UK	Climate adapted facades for Belgrade
Dr. Aleksandra Krstić-Furundžić	University of Belgrade, Faculty of Architecture, Serbia	Building refurbishment in the context of adaptive facades
Dr. Budimir Sudimac	University of Belgrade, Faculty of Architecture, Serbia	Green wall systems for energy savings in buildings
Dr. Mislav Stepinac	University of Zagreb, Faculty of civil engineering, Croatia	Structural concepts for adaptive facades
Dr. Chiara Bedon	University of Trieste, Department of Engineering and Architecture, Italy	Structural aspects & case studies
Dr. Fabio Favoino	TEBE Research group, Department of Energy–PoliTO, Italy	lecture 1: Building performance simulation of adaptive facades, lecture 2: Performance, Time conscious building envelopes
Dr. Roman Rabenseifer	Slovak University of Technology in Bratislava, Slovakia	Post Occupancy Performance Evaluation
Riccardo Pinotti	UNIBZ Free University of Bolzano / EURAC Institute of Renewable Energy, Italy	Building modelling using Trnsys software
Dr. Thaleia Konstantinou	Delft University of Technology, Faculty of Architecture, The Netherlands	Manager of Early Stage Researchers (ESI) Workshop/Session

About the Training School

During the Workshop, participants developed concepts to improve the energy performances of facades of two post-war high-rise buildings in Belgrade and learned how these concepts can be validated and improved with actual simulation tools. The research and creative work of trainees was assisted by 6 trainers of different professional backgrounds, which additionally contributed to the multidisciplinary approach, which is generally considered essential in the design of innovative facades. The projects were presented in two phases to the critics. The first phase included presentation of the concept of improvement of the facade of the existing building with an explanation of the approach, various scenarios for facade improvement and criteria for decision making, as well as the functional and visual characteristics of the selected solution. This allowed trainees to get additional suggestions for further project development. The second phase was the final presentation of the entire project, with technical solutions and energy performance analysis. The design solutions have been evaluated by the expert group. All participants received certificates for attending the Training School 2018 in Belgrade.

Practical work and research during the 3 days' innovative façade design workshop were organized through 7 workgroups-teams with members of different background (architecture, engineering, building physics), who have a research interest in facade design and engineering, and adaptive facades in particular. Under given design conditions, physical circumstances and technological constraints, using up-to-date knowledge, for certain types of buildings in Belgrade, facade improvement has been created in order to achieve better functional, energy and environmental effects. The trainees have expressed a responsible approach in considering the issue of keeping or replacing the existing façade and proving their attitudes.




Photo documentation of the Workshop (Photos: A. Krstić-Furundžić)

Conclusions from the workshop

The process of designing the improvement of the facade implied several stages. On the first day of the Workshop, the existing situation, limitations and disadvantages were considered, and the concepts of facade with the integration of innovative facade technologies were defined and discussed. The next two days were dedicated to the elaboration of new facade concepts by digital simulation and modellmaking, as well as numerical simulations to verify the energy consumption for heating and cooling. In the case of a business building, it can be noticed that some of the teams took into account the fact that the building is one of the symbols of the Moderna period with dark color and hexagonal shape, and therefore proposed a replica of the existing facade using innovative technologies. On the contrary, there was a vision that the existing facade should be completely replaced with a new innovative concept. Both approaches have resulted in interesting and realistic solutions with positive effects. In the case of a residential building, the improvement of the existing facade is considered suitable and the application of adaptive systems as a preferred solution in order to improve the energy performance and appearance of the building.

The overall/general impression is that trainees through their projects have shown a significant understanding of the design issues of innovative facades. A very balanced quality of projects has made the selection of the best proposals complex, but three projects have been awarded, among which are two proposals for improving the facade of the office building and one for the residential building.

1.3. Schedule

		Morning 9:00-11:00	11:00-11:30	11:30-13:00	13:00-14:00	Afternoon 14:00-16:00	16:00-16:30	16:30-18:30	Evening 20:00-23:00
Monday	Room 200 **Registration 8:30-9:00**	Room 200 **Aleksandra Krstić-Furundžić** Welcome and an introduction to the Training School program **Marcin Brzezicki** Adaptive Facade Concept and Typologies, Kinetic Facades (WG 1) (45 min) **Miren Juaristi Gutiérrez** Smart and Multifunctional Materials and their possible application in facade systems (WG 1) (45 min)	Room 254 **Coffe break**	Room 200 **Mark Alston** Climate Adapted Facades for Belgrade (WG 1) (45min) **Aleksandra Krstić-Furundžić** Building refurbishment in the context of adaptive facades (WG 1) (30 min) **Budimir Sudimac** Green wall systems for energy savings in buildings (WG 1) (20 min)	Room 254 **Lunch break**	Room 200 **Thaelia Konstantinou** ESI Workshop and Teambuilding Part 1 PhD/Master Posters/progress reports discussion of individual themes/topics in interdisciplinary teams (same teams as for the workshop)	Room 254 **Coffe break**	**Thaelia Konstantinou** ESI Workshop and Teambuilding Part 2 PhD/Master Posters/progress reports discussion of individual themes/topics in interdisciplinary teams (same teams as for the workshop)	
Tuesday		Room 200 **Mislav Stepinac** Structural Concepts for Adaptive Facades (WG 2) (45 min) **Chiara Bedon** Structural aspects & case studies (WG 2) (45 min)	Room 254 **Coffe break**	Room 200 **Fabio Favoino** Building performance simulation of adaptive facades (WG3) (45min) **Roman Rabenseifer** Post-occupancy Performance Evaluation (WG 3) (45 min)	Room 254 **Lunch break**	Room 200 **Fabio Favoino** Performance - Time conscious building envelopes (WG 2) (60min) **Aleksandra Krstić-Furundžić, Budimir Sudimac, Nikola Macut** Information on site visit-Definition and scope of the workshop	Room 254 **Coffe break** 15:15-15:30	Excursion ALL Visit to locations for case studies - typical Belgrade office and residential building 15:30-20:00	Welcome dinner
Wednesday		Rooms 217, 218, 219, 220 **Workshop** "Retrofitting Facades for Energy Performance Improvement" Task: Definition and consideration of facade concept / Working in Groups Support by trainers: Marcin Brzezicki, Riccardo Pinotti, Nikola Perković, Aleksandra Krstić-Furundžić, Budimir Sudimac, Djordje Stojanović Room 254 - **Coffe break** - 11:00-11:30			Room 254 **Lunch break**	Rooms 217, 218, 219, 220 **Workshop** "Retrofitting Facades for Energy Performance Improvement" Task: Definition and consideration of facade concept / Working in Groups/ Support by trainers: Marcin Brzezicki, Riccardo Pinotti, Nikola Perković, Aleksandra Krstić-Furundžić, Budimir Sudimac, Djordje Stojanović Room 254 - **Coffe break** - 16:00-16:30		Room 200 **Concept presentation** 10 min each group with external critics: **Jelena Ivanović-Šekularac**, AF-BU, Belgrade and **Anica Dragutinović**, hs-owl Detmold	
Thursday		Room 218 **Riccardo Pinotti** Building modelling using Trnsys software	Room 254 **Coffe break**	Rooms 217, 218, 219, 220 **Workshop** "Retrofitting Facades for Energy Performance Improvement" Task: Elaboration of facade concept by digital simulation and modellmaking / Working in Groups Support by trainers: Marcin Brzezicki, Riccardo Pinotti, Nikola Perković, Aleksandra Krstić-Furundžić, Budimir Sudimac, Djordje Stojanović	Room 254 **Lunch break**	Rooms 217, 218, 219, 220 **Workshop** "Retrofitting Facades for Energy Performance Improvement" Task: Elaboration of facade concept by digital simulation and modellmaking / Working in Groups Support by trainers: Marcin Brzezicki, Riccardo Pinotti, Nikola Perković, Aleksandra Krstić-Furundžić, Budimir Sudimac, Djordje Stojanović Room 254 - **Coffe break** - 16:00-16:30			
Friday		Rooms 217, 218, 219, 220 **Workshop** "Retrofitting Facades for Energy Performance Improvement" Task: Detailed elaboration of the facade concept and preparation of the final presentation / Working in Groups Support by trainers: Marcin Brzezicki, Riccardo Pinotti, Nikola Perković, Aleksandra Krstić-Furundžić, Budimir Sudimac, Djordje Stojanović Room 254 - **Coffe break** - 11:00-11:30			Room 254 **Lunch break**	Rooms 217, 218, 219, 220 **Workshop** "Retrofitting Facades for Energy Performance Improvement" Task: Detailed elaboration of the facade concept and preparation of the final presentation / Working in Groups Support by trainers: Marcin Brzezicki, Riccardo Pinotti, Nikola Perković, Aleksandra Krstić-Furundžić, Budimir Sudimac, Djordje Stojanović Room 254 - **Coffe break** - 16:00-16:30		Room 218 **Final public presentation of the results of the Workshop** 10 min each group with external critics: **Jelena Ivanović-Šekularac**, AF-BU, Belgrade and **Anica Dragutinović**, hs-owl Detmold	Time for party. See the Belgrade nightlife, guided by locals.

Schedule of Training School 2018 (designed by A. Krstić-Furundžić)

2.0. CURRENT RESEARCH

2.1. ESI Workshop

The early-stage investigators session - ESI Workshop was dedicated to the research topics of trainees who were doctoral and master students. For four hours, it was interactive and also team building activity. The leader of this session was assistant professor Dr. Thaleia Konstantinou. Each student was obliged to prepare a poster describing his research topic, with an emphasis on the structure of the research, before taking part in the Training School. Students were divided into five-member groups with the task of discussing one of their research topics. In this way, students get to know each other. The exercise was intended, on the one hand, for students to demonstrate the ability to clearly and concisely explain the topic, and on the other hand to understand and present someone else's research. Based on lectures held by the session leader and discussion with their peers, students had the opportunity to identify ways to improve their current topics.

2.2. Participants

01 Ahmed Felimban	Delft University of Technology, Netherlands
02 Ali Aghazadeh Ardebili	University of Trieste, Italy
03 Aleksandra Ugrinović	University of Belgrade, Faculty of Architecture, Serbia
04 Ana Kontić	University of Belgrade, Faculty of Architecture, Serbia
05 Anka Mirković	University of Belgrade, Faculty of Architecture, Serbia
06 Ariadna Carrobe Montalvo	University of Lleida, Spain
07 Ashal Tyurkay	University of Antwerp, Belgium
08 Berk Ekici	Delft University of Technology, Netherlands
09 Ceciilie Gry Jacobsen	The Royal Danish Academy of Fine Arts, School of Architecture (KADK), Denmark
10 Dijana Savanović	University of Belgrade, Faculty of Architecture, Serbia
11 Federico Bertagna	University of Pisa, Italy
12 Jorge Luis Aguilar-Santana	University of Nottingham, United Kingdom
13 Juan Manuel Cruz	Norwegian University of Science and Technology (NTNU), Norway
14 Magdalena Patrus	University of Bath, United Kingdom
15 Mariana Velasco Carrasco	University of Nottingham, United Kingdom
16 Marina Bagaric	University of Zagreb, Faculty of civil engineering, Croatia

17 Martina Di Bugno	University of Pisa, Italy
18 Michael Michalis	University of Cambridge, United Kingdom
19 Milan Varga	University of Belgrade, Faculty of Architecture, Serbia
20 Milica Petrović	University of Belgrade, Faculty of Architecture, Serbia
22 Miroslav Vulić	University of Belgrade, Faculty of Mechanical Engineering, Serbia
23 Mohataz Hossain	University of Nottingham, United Kingdom
24 Neda Džombić	University of Belgrade, Faculty of Architecture, Serbia
25 Nevena Lukić	University of Belgrade, Faculty of Architecture, Serbia
26 Nikola Macut	University of Belgrade, Faculty of Architecture, Serbia
27 Paolo Bonato	Energy Engineering, Politecnico di Milano, Italy
28 Tiantian Du	Delft University of Technology, Netherlands
29 Valentina Frighi	University of Ferrara, Department of Architecture, Italy
30 Valerie Vyvial	Royal Danish Academy of Fine arts, Institute of architetcure and technology, Denmark
31 Yeşim Keskinelv	Cardiff University, United Kingdom
32 Yorgos Spanodimitriou	University of Campania "Luigi Vanvitelli", Italy
33 Zein Omar Arqoub Al-Doughmi	Cardiff University, United Kingdom

2.3. Research Posters

This section shows the posters created by the Training School participants, which represent current research of each participant.

Retrofitting Residential Building Envelope Strategy: ENVELOPE SOLAR MANAGEMENT

ADAPTIVE FACADES 2018
BELGRADE

▶ Ahmed Felimban, TUDelft, Faculty of Architecture, Department of Architectural Engineering and Technology

▶ Research information

Introduction, Background to the Research

The aim of the research is to investigate the needed building envelope techniques in managing the solar effect on building energy consumption as using the envelope (material, construction, design) as a layer of managing the solar effect for the current residential building in Saudi Arabia, In close understanding, testing and stimulation several typical residential buildings to discover advance possibilities and evaluate the current state of residential building energy consumption.

Research problem

The main problem in retrofitting residential building envelope is the initial cost and time payback with respect of the end product quality. Many alternatives are published but not tasted and stimulated in business model yet

Research Questions (Main Questions and sub question)

Main question

"How can retrofitting residential building envelope strategy be advanced to meet the building owner budget and as of today's architectural requirements?"

Sub-questions

1."What are the main causes of high energy consumption in the current typical residential building envelope"
2."How do the different building construction methods and material use effect of application of this strategy"
3. "What are the constrains of this strategy when applying in current situation"

RESEARCH Objectives

Envelope solar management strategy application has not been investigated enough after the new movement "2030 vision", the building owners are subject to pay taxes and the government stop subsidising utilities. A new strategy should be implemented to recover the gap.
This research looks into possibilities to find design strategy options and technical solutions which allow more use of renewable energy in the building envelope.

This will be done through the following objectives:
1.Defining current issue of residential building energy consumption.
2.Identify key factors of that energy consumption
3.Identify current design and constriction application
4.Analyse similar cases in other areas has similar context.
5.Appraise existing typical residential building and other type in same region.
6.Develop a retrofitting strategy.
7.Identify key challenges that must be implemented for application.
8.Validate desirable option with building owners.

RESEARCH Deliverables

(Clear description of the deliverables for the research work)

1.Review of current residential building
2. A summary of all possible strategy alternatives.
3.Building envelope retrofitting strategy

▶ **Researcher:** Ahmed Felimban
▶ **Supervisors:** Ulrich Knaack, Tillmann Klein
▶ **Time span:** 2018-2021
▶ **Contact data:** a.a.m.felimban@tudelft.nl
▶ **Associated Publications:**

- None

Design a method for risk management decision-making in resource allocation and an index for measuring the "risk-taking capability"

▶ Ali Aghazadeh Ardebili, industrial Engineering and Information, Department of Engineering and Architecture

▶ Research information

Introduction, Background to the Research (Research Theme)

The main theme is engineering risk management., there is a big gap in current literature and the methods to accept the opportunities that could have links to some threats in the projects. Nowadays Companies are looking for any opportunity to have privilege in existing competitive markets, to distribute the business, increase expected value of project or shortening the expected time of the project. The new method is heading to introduce in this PhD research project that empower project managers to pursue the new steps and gain the positive effects of a risky opportunity to open up new lines and could be a management tool to support sustainability strategies, continuous development and use innovative ways to reach objectives.

Research problem

A risk could have positive effects on the project objectives. this positive effects could be associated with new threats and decision makers avoid The risk for threats. But avoiding the risk will concurrently avoid positive effects. Therefore, this risks defined as "risky opportunity" in this project. The Problems is the shortage of an efficient index to illustrate the risk taking capability of a company and the procedure that enable decision makers to choose a risky opportunity to accept. On the other hand there is no index to evaluate the resource consumption during accepting a risk.

Research Questions (Main Questions and sub question)

Main question

1. "How the risk-taking capability could be assessed and increased?"
2. "Is it possible to use a quantitative tool to support decision-making with the aim to accept the risky opportunities and take only the positive effects?"
3. "Which resource should be chosen and how much of that resource should be employed to accept a risk?"

Research Objectives

Main objectives

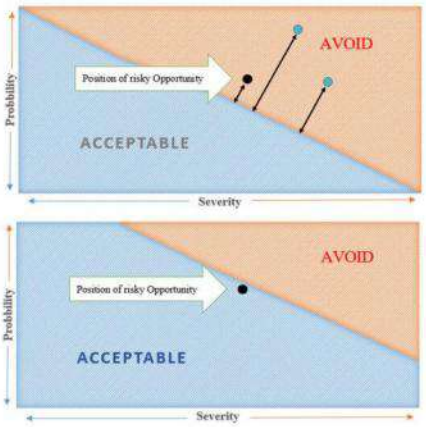
1. Design a method for evaluating (or measuring) the 'risk-taking capability' of an organization.
2. Design a method to support decision-making with the aim to accept a risky opportunity and abatement of the negative effects of the risks .
3. Identify the most efficient resource and the amount of resource consumption to make the project ready to accept a risk.

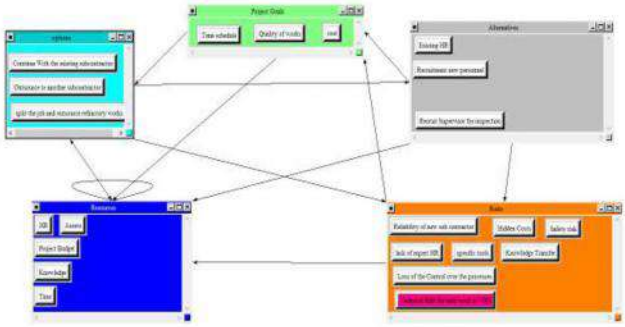
Secondary objectives

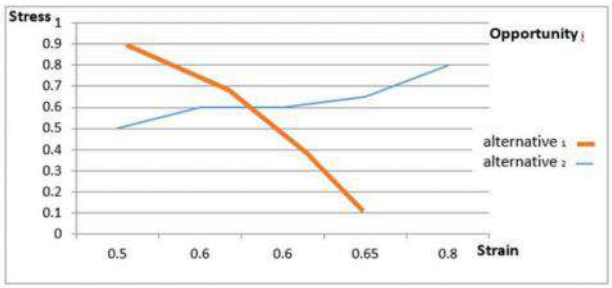
1. Introduce a method to motivating the companies in all sectors with the idea of using the positive effects of uncertainty.

Research Deliverables

Theoretical: Theoretically 3 new concept considered to fill the gaps of existing methods in accepting the risky opportunities
Methodological: Methodologically A group of curves will be the main result of this analysis that is illustrated in previous slide. To create these curves we need to consider the new terms risk taking capability, stress, and strain and follow a new process that could evaluate the opportunities and risks together in a network.
Practical: Practically with this method project managers could use an index for evaluating (or measuring) the 'risk-taking capability' of an Organization or project; Also, this method is a tool to support decision-making to support sustainability strategies simultaneously accept the risks of changes and continuous improvements. Moreover, this method could help to identify the most efficient resource and the amount of the resource consumption to get the company ready to accept a risky opportunity.







▶ **Researcher:** Ali Aghazadeh Ardebili
▶ **Supervisors:** Elio Padoano
▶ **Time span:** 2016-2020
▶ **Contact data:** ali.aghazadehardebili@phd.units.it

▶ **Associated Publications:**

- A.A. Ardebili, E. Padoano, F. Harsej (2017), Prepare Organizations to Accept risks: A Feasible Risk management, 7th international conference – Production engineering and management For Industry Sustainability, Pordenone Sep. 2017, University Consortium of Pordenone
- JURECSKA Laura, KIŠ Maja, TUMPA Andrea, AGHAZADEH ARDEBILI Ali, GAJSKI Goran, (2017) PlantPower – Phytoremediation of Contaminated Soils in Former Minefields of the Western Balkan Area, Krems, July 2017, Danube Future Training Capacity Building Proceeding.

The use of modern technologies and materials for the purpose of presenting arheological sites

▶ Aleksandra Ugrinović, PhD student University of Belgrade, Faculty of Architecture

▶ Research information

Introduction, Background to the Research (Research Theme)

The thematic area I am researching is the application of interactive technologies and materials in the reconstruction and presentation of cultural heritage with the goal of revitalizing the abandoned and ruined parts of cities. The topic of the research is based on the study of the principles of design in protected areas with a focus on the ways of presenting archaeological sites *in situ* in urban and surrounding areas, pointing to the observed problems in practice. A special accent was put on the study and monitoring of the impact of climate change on the devastation of archaeological sites and the assessment of the degree of its vulnerability.

Research problem

The topic of the research was initiated by the use of protective, balloon constructions above archaeological sites in Serbia on which the protection services have been insisting, which permanently devastate the findings and cultural landscape and do not allow the museological presentation of architectural findings. The concept of the application of protective balloon structures above archaeological sites has come from the Restoration Theory of Cesare Brandi in order to present them *in situ*. The consequences that followed the installation of protective balloon structures above archaeological sites are manifested in the form of a greenhouse effect and cause a variety of other problems. Climate change contributed to the problems arising from the coverage of archaeological sites by balloon constructions even more drastic. Due to this situation, in order to prevent further devastation, many architectural findings have been buried, with the presentation not being realized. Therefore, it is important to research the application of modern materials and technologies for the renovation, adaptation and improvement of implemented solutions by replacing the used materials to cover the site with new ones in order to mitigate the adverse effects of climate change.

Research Questions (Main Questions and sub question)

Main question

How to present archaeological sites in urban and non-urban settlements in moderate-continental climate and enable tourist offer throughout the year?

Sub-questions

1. What are the ways / opportunities for presenting archaeological sites *in situ*?
2. What are the advantages and disadvantages of the application of protective balloon constructions in order to present the archaeological sites *in situ*?
3. What technological procedures / methods are necessary to apply in order to solve the problems?

Research Objectives

The objectives of the research are to:
1. Investigate the design skills of presentation of archaeological sites *in situ*.
2. Identify constraints in design in protected environments.
3. Identify the key problems arising from the installation of protective balloon structures.
4. Refine the mechanisms for remedying the problem.
5. Recommend and specify materials that can be applied when designing in environments.
6. Develop design strategies in protected areas that will enable archaeological sites to be opened for visitors to promote their publicity and enable sustainability through use.

Research Deliverables

The research will include:
1. A case study of the implemented solutions for the protection and presentation of archaeological sites *in situ* in domestic and foreign practice.
2. Overview of key issues
3. Investigation of the influence of constructive solutions, applied material and the impact of climate change on the preservation of archaeological sites (Monitoring of changes in architectural findings; Experiment: measurement of temperature and humidity before and after replacement of the materialization of the protective structure).

Presentation of the Villa Romana del Casale, author Franco Minissi

Presentation of the Villa Romana del Casale, author Giuseppe Cascino

Archaeological site of Mediana, author of the protective, balloon construction Mile Veljković

▶ **Researcher:** Aleksandra Ugrinović
▶ **Supervisors:** -
▶ **Time span:** 2017 -
▶ **Contact data:** a.ugrinovic92@gmail.com

▶ **Associated Publications:**

Ugrinović, A. Protective constructions in the function of presenting the remains of antique heritage, in the Proceedings of the Seventh Conference on Cultural Heritage "Cultural Landscape", Institute for the Protection of Cultural Monuments of the City of Belgrade, Belgrade, 2016, 116-127.

Nano materials applications for conservation of cultural heritage: Nano- lime

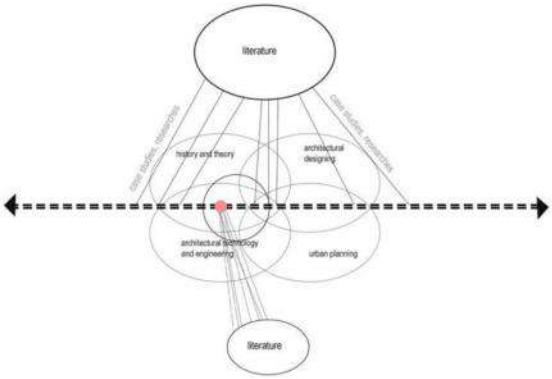
▶ Kontić Ana, PhD Student, Architecture & Urbanism, Faculty of Architecture, Belgrade

▶ Research information

Introduction, Background to the Research (Research Theme)

The technological context of architectural conservation refers to the application of scientific and technical informations and skills in the everyday practices of preservation of cultural heritage. Research in the field of protection has shown that since the industrial revolution and orientation to the use of cement mortars, there have been serious consequences in the field of architectural conservation. Degradation of natural materials, as a result of the use of cement mortar, initiated a returning to organic materials and examination of their performance and application in the protection of cultural heritage. The aim of this research is to go further and investigate the use of nano-lime in conservation of cultural heritage.

Keywords: nanotechnology, nano-materials, conservation



Research problem

Nanotechnology is considered to be the most important theoretical and applicative framework of human knowledge in the near future, breakthroughs are restricted to few applications. The problem of research is the creation of line that connects the basic criteria for conservatory treatment (compatibility, minimal intervention, reversibility), the complexity of methodological approaches in architectural conservation, and the application of scientific and technical knowledge in order to increase the understanding of various factors in the process of protection of cultural heritage.

autor fotografije: Tatjana Tripković: Detalj fasade nakon radova, Visoki Dečani

Research Questions (Main Questions and sub question)

Main question

- How nano materials can be combined with more traditional ones?
- Can using of nano materials improve the performance of standard materials, their durability, strength?

Sub-questions

What are the main approaches in nanotechnology?

How we produce nanoparticles?

What are the main properties of nanoparticles?

What are the main barriers in using nano materials in conservation of cultural heritage?

A comparative analysis of nano-lime and classical lime mortar

preuzeto sa: http://www.turismoroma.it, 18.avgust 2018

Research Objectives

-Making the theoretical context

- Filtering the data
- Comparative analysis
- Experimental research to investigate the properties of nano-lime
- Experimetnal research and comparative analysis would give the answer, what the main barriers are

-Identifiying key challenges

Research Deliverables

- Understanding correlation between conservation and nanoarchitecure
- Improve personal knowledge in technological framework of conservation of cultural heritage

▶ **Researcher:** Kontić Ana, M.Arch
▶ **Supervisors:** prof dr Nenad Šekularac, Associate Professor
▶ **Time span:** February 2018.-
▶ **Contact data:** konticana@gmail.com

▶ **Associated Publications:**

1.• Трпковић,Тијана "Нови материјали на бази креча- нанокреч", у Креч као историјски материјал, ур.Алекса Јеликић и Драган Станојевић, 115-125, Сопоћани: Републички завод за заштиту споменика културе-Београд, 2014

2. Waked, A.M. "Nano materials applications for conservation of cultural heritage", Structural Studies, Repairs and Maintenance of Heritage Architecture XII, WIT Press, 2011

Energy and Environmentally Sustainable Business-Commercial Facility

▶ Anka Mirković, University of Belgrade, Faculty of Architecture, Departmant for Architectural Tehnology

▶ Research information

Introduction, Background to the Research (Research Theme)

The aim of the research was to create a shadow from the analysis of the sun's rays at different times of the day, and thus make it easier for users of the facility to combine with the use of solar energy for the production of energy that the facility itself would use.

Research problem

The main problem was how to integrate nicely and usefully, how to make innovative architecture, something different, and that such a design responds to the task.

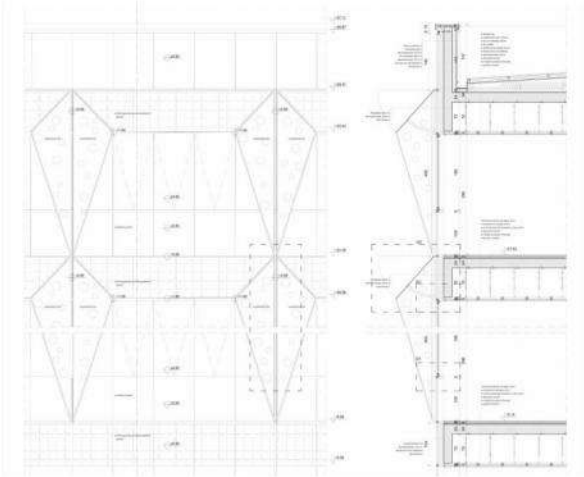
Research Questions (Main Questions and sub question)

Main question

At what angle should we put on the shadows, how to make a pattern which meets all the directions of the sun's radiation.

Sub-questions

Should we deal with the form of an object or that the object be reduced, and that the emphasis is put on the façade or the shade?
Should we project a facility with a double ventilated façade, with diminished shadows or the single curtain wall, with the concept of shade designed in the ways it could satisfy everything that is needed?



Research Objectives

Finding the position of the shades which is the best against the sun radiation.

Folding shades with the design.

Research Deliverables

The best position of the sun cover on the south side is the horizontal shade, and for the east and west side it would be vertical shade.
The best position for the panel with photovoltaic modules is horizontal to the south side because the sun is the most intense there.

▶ **Researcher:** arch Anka Mirković
▶ **Supervisors:** dr Aleksandra Krstić - Furundžić
▶ **Time span:** 2017 - 2018
▶ **Contact data:** **anca.mirkovic@gmai.com**
▶ **Associated Publications:**

Thermal behavior of earth rammed constructions built in cooperation projects.

▶ Ariadna Carrobé, Sustainable Energy, Machinery and Building research group, University of Lleida

▶ Research information

Introduction, Background to the Research (Research Theme)

Earthbag and superadobe are low-cost and environmentally friendly building techniques that use raw earth to build structural walls, usually in dome shape. This research analyzes the thermal performance and comfort of an earthbag building located in Mediterranean continental climate by experimentation in real conditions. Previous research held a construction of a prototype in the University of Lleida Campus followed by the Training Medical Center in Burkina Faso by the Emsimission NGO. Currently we are working with the Western Sahara government in order to find a constructive system that satisfies their thermal comfort needs.

Research problem

The biggest problem we had is the lack of legislation. There is no current legislation where we can base our developments on earth construction. Nowadays, people is aware of the Earth extinction and sustainable issues, so they are going back in time, copying the way our ancestors used to build so as to be more environmentally friendly, but there is no support from the big companies or government to invest more in this kind of techniques.

Research Questions (Main Questions and sub question)

Main question

How do earth rammed buildings perform in terms of thermal behavior in arid climates?

Sub-questions

- How do these buildings perform thermally in different seasons?
- What is the impact of sunlight?

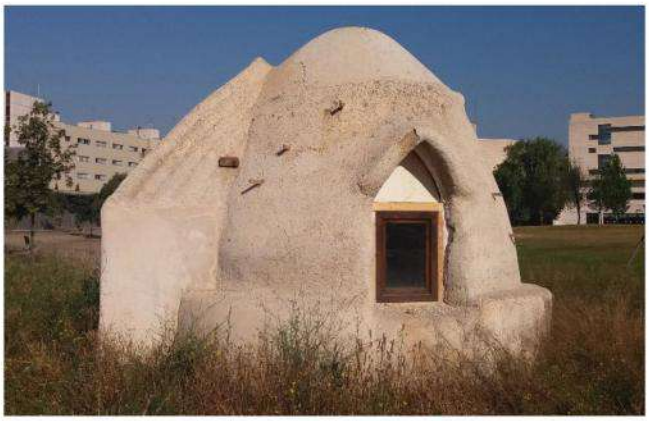
Research Objectives

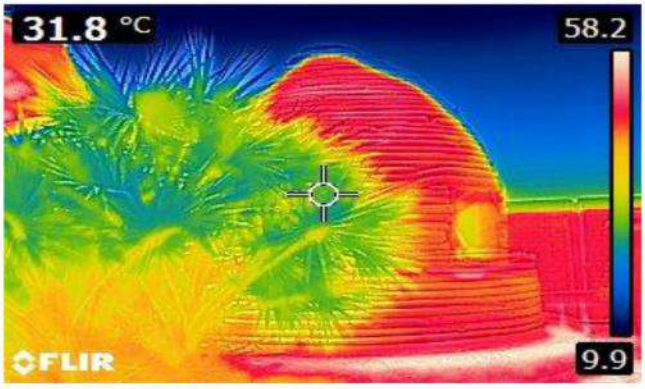
To develop this research, the next research objectives have been defined:

1. Monitoring of the prototype dome in University of Lleida.
2. Free-floating and inside controlled temperature experiments.
3. Validation of the model using Energy Plus.
4. Comparison of different models changing parameters such as the dimension of the window, the location...
5. Calculate the U-Value of the earth walls.
6. Determine the hours of thermal comfort.

Research Deliverables

- Earth construction in Burkina Faso and Western Sahara.
- Numerical models with Energy Plus to contrast thermal behavior of earth buildings.
- State of the art in earth construction





▶ **Researcher:** Ariadna Carrobé Montalvo
▶ **Supervisors:** Lídia Rincón and Ingrid Martorell
▶ **Time span:** Since december 2017
▶ **Contact data:** **ariadnacarrobe6@gmail.com**

▶ **Associated Publications:**

- Article: Improving thermal comfort of earthen dwellings in sub-Saharan Africa with passive design. (Under development)
- EUROSUN 2018 paper: Thermal monitoring on an earthbag building in Mediterranean continental climate. (Under development).

Circular Construction: Repair, Renovation and Recycling Potentials of Plastic Building Envelope Components

▶ Ashal Tyurkay, University of Antwerp, Faculty of Design Sciences

▶ Research information

Introduction, Background to the Research (Research Theme)

Post-war technology encouraged multi-layered light-weight constructions in building façade systems. Either from aesthetics point of view, or from technical functionality perspective, the incorporation of different plastics and composites in the light weight systems is almost inevitable and is done in any of the following ways: as a finishing material (exterior or interior), as a protective layer, as a joint or connection element, or as a core element (Fig. 1). The increase and variety of exterior applications in residential buildings' envelope systems is shown in Fig. 2 and is due to the improvement of weather proofing and energy savings.

Research problem

Despite all efforts to reduce the energy demands of buildings, the EU is facing an acute lack of efficient renovation of the existing building stock. Most approaches are singular and focus on adding insulation or on exchanging windows while growing amounts of building waste by composite materials – *mainly polymer modified (plastic) materials* – are ignored. A holistic approach is missing that considers the potentials of existing constructions, in particular the building envelope, as a crucial element in the energy savings and efficiency discussion.
On the other hand, the use of plastics raises concerns due to high embodied energy, its effects on health and safety, low levels of resistance against ageing, and consequential shorter life expectancy than of buildings and reduced possibilities for recycling. For these reasons, appropriate application and maintenance procedures should be applied to plastic components in building envelopes at construction/operation/post-use stage.

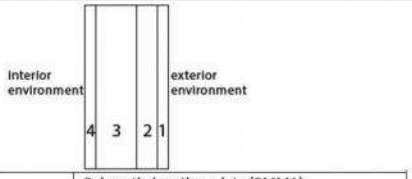
Research Questions (Main Questions and sub question)

Main question
How can the information about the performance and the embodied energy in the building envelope system context affect the maintenance process? How do we make decisions to maintain plastic components or systems of façade constructions? Why do we decide whether it should be replaced or repaired?

Sub-questions
- How is the durability and life span of plastics affected?
- How can the relation between material performance and material's embodied energy be improved?
- What are the challenges that must be resolved in order to unlock the opportunities of circular economy?
- What would be the economic benefits if plastic building components were redesigned for recycling and reusing?

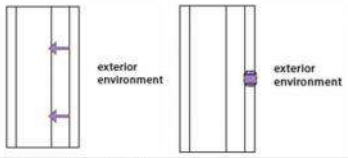
Research Objectives

Holistic approaches in the context of circular economy that take into account the potentials of the existing constructions are still quite limited in research and even more limited in practice.
In this research, it is aimed to develop sustainable strategies for maintenance (repair, renovation and recycling) of plastic building (envelope) components in post-war heritage in Belgium. Typical facade constructions and plastic building components will be identified (1). Link between performance, embodied energy and economy will be established by categorising "ageing" characteristics (2), evaluating their effects on facade performance, interpreting the performance analysis results in relation to plastic components' lifecycle before and after use stage (3), and elaborating the economic impacts of existing conditions the plastic building components are in (4). To reinforce the 'circular construction', strategies will be proposed for reintegrating the plastic building components into the lifecycle after the use stage.



a)

1_ exterior finishing (cladding)	Polymethyl methacrylate (PMMA) Epoxy resins (EP), Fibre composite systems
2_protective layers (waterproofing, thermal insulation, acoustic insulation, vapour barrier/retarder)	Polyethylene (PE), Polypropylene (PP) Polyvinyl chloride (PVC), Polystyrene (PS) Polytetrafluoroethylene (PTFE) Ethylene Propylene Diene Monomers (EPDM) Polyurethane (PUR)
3_ core	Fibre composite systems
4_ interior finishing	Fibre composite systems



b)

connections (mechanical fastening, adhesives)	Silicones (SI), Polyurethane (PUR) Epoxy resins (EP) Styrene-butadiene rubber (SBR)
joints (gaskets, sealants, fillers)	Silicones (SI), Ethylene Propylene Diene Monomers (EPDM), Butyl compounds, MS polymers, Acrylate and Polysulphide sealants

▶ **Fig. 1:** Typical plastics components in the "generic layer model" (a) and the "construction techniques" (b)

▶ **Fig. 2:** Typical exterior applications of plastic based materials in contemporary buildings (Source: Inoutic, 2018)

Research Deliverables

- Inventory of building facade constructions in Belgian post-war buildings of Flanders Region
- An integrated qualitative (performance) and quantitative (embodied energy) model to evaluate building façade systems
- Optimised strategies and business models for maintenance and re-use/recycling procedures

▶ **Researcher:** Ashal Tyurkay
▶ **Supervisors:** Prof. Dr. Ing. Uta Pottgiesser
▶ **Time span:** 2018 - 2022
▶ **Contact data:** **ashaltyurkay@gmail.com**

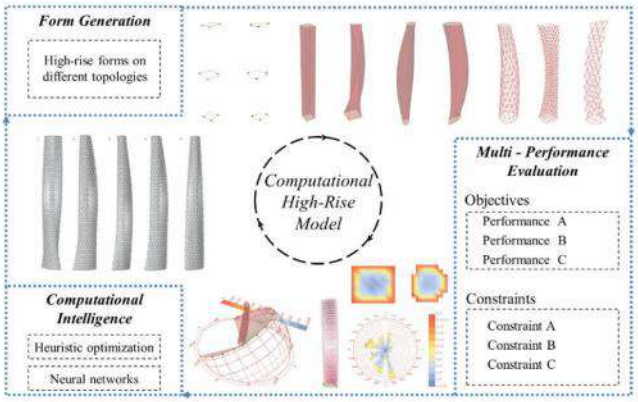
Computational Model for Self-Sufficient High-Rise Buildings

▶ Berk Ekici, TU Delft Faculty of Architecture, AE+T Department, Design Informatics Chair

▶ Research information

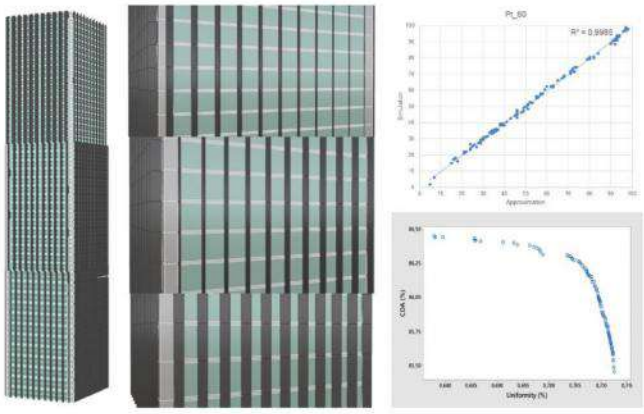
Introduction, Background to the Research (Research Theme)

The purpose of this research is to develop a computational model for designing self-sufficient high-rise buildings. Therefore two main research domains are involved. These are high-rise buildings and computational intelligence. In order to develop the computational model, three main steps are considered. These are developing parametric high-rise form generation, implementing self-sufficient criteria to evaluate the building performance, and make use of the power of computational intelligence to deal with complex design task. Within this framework the façade of high-rise buildings is one of the most important aspect to focus.



Research problem

There is no doubt that high-rise buildings suggest new habitation alternatives in metropolitan cities to cope with the urbanization trend and population growth. However, these buildings are not environmental friendly, because of their massive body. Potentials of computational intelligence can be exploited in order to design self-sufficient high-rise buildings in future.



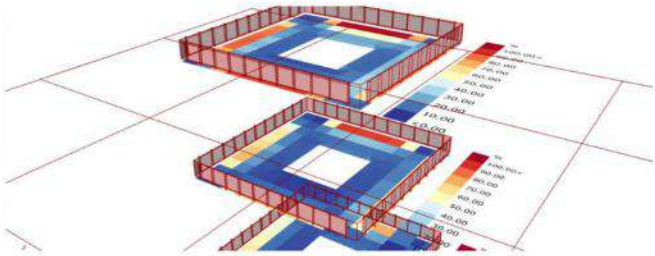
Research Questions (Main Questions and sub question)

Main questions

- Why do we need self-sufficient high-rise buildings in metropolitan cities?
- How can the adequate decision be provided for self-sufficient high-rise buildings in the conceptual design phase using computational intelligence?

Sub-questions

- What are the essential parameters for self-sufficient high-rise buildings?
- Which objective functions and constraints should be integrated in the decision making process to reach self-sufficiency in high-rises?
- How can we develop performance criteria to evaluate the final model?



Research Objectives

In spite of current studies, which focus on how to decrease energy demand of high-rise buildings in the literature, this research is taking into account self-sufficient concept, which can be an important aspect for future urbanization. In this regard, objectives of the research are listed as follows:

- Defining design parameters and performance indicators of self-sufficient high-rise buildings
- Investigating computational intelligence techniques to deal with complexity
- Developing parametric self-sufficient high-rise model
- Developing objective functions and constraints for optimization
- Testing the model by means of case studies

Research Deliverables

- Review on performance based design using computational intelligence
- Framework of self-sufficient high-rise buildings
- Validated computational model

▶ **Researcher:** Berk Ekici
▶ **Supervisors:** I. Sevil Sariyildiz, M. Fatih Tasgetiren, Michela Turrin
▶ **Time span:** 2016-2020
▶ **Contact data:** **B.Ekici-1@tudelft.nl**

▶ **Associated Publications:**

B.Ekici, *I.Chatzikonstantinou, I.S.Sariyildiz, M.F.Tasgetiren, Q.K.Pan 'A Multi-Objective Self-Adaptive Differential Evolution Algorithm for Conceptual High-Rise Building Design'. IEEE World Congress on Computational Intelligence 2016, Vancouver, 2272-2279.*

Architecture and Extreme Environment (Alaska)

▶ **Cecilie Gry Jacobsen, The Royal Danish Academy of Fine Arts Schools of Architecture, Design and Conservation, Master program: Architecture and Extreme Environments**

▶ Research information

Introduction, Background to the Research (Research Theme)

Through a site-specific approach, this master program aims to respond to present and future global challenges through research by design and community engagement in form of active expeditions to remote areas of the world. The research is going to focus on developing solutions that can address the global environmental challenges the world is facing by using Tanzania (2017-2018) and Alaska, USA (2018-2019) as stepping stones for the research.

It is the intention to investigate the design potential in working with technology by producing a 1:1 prototype and testing it on-site. It is going to be tested by performance orientated design parameters, but also as a process charged with aesthetic potential and cultural implications with sustainable aims, from building scale all the way to detail.

Research problem

As a consequence of the climatic change the temperature is rising in Alaska faster than in other parts of the world, and because of this the permafrost in the underground, the sea ice and glaciers are melting, and that leads to vulnerability for more and more communities and the need to rethink housing and building design.

Research Questions (Main Questions and sub question)

Main-question:
"What are the artistic potentials of working with technology not only as a performance orientated design parameter, but also as a process charged with aesthetic potential and cultural implications with sustainable aims in Alaska's environmental settings?"

Sub-question:
1."How to address and test the environmental difficulties in Alaska in form of an architectural prototype both technically but also ethically?"
2. "How can this prototype design and expedition to Alaska be the key stone in a site specific building design?"

Research Objectives

Through a site-specific approach, the aim is to respond to Alaska's climatic challenges through direct on-site involvement in the form of active expeditions where prototypes are put to the test and buildings are designed. This is to explore the intersection between architecture, technology, culture and environment in Alaska.

The process of the study will be:
1. Production of infographics and collecting knowledge about Alaska's geological, cultural, environmental and economic background.
2. Research and production of an architectural prototype.
3. Expedition to Alaska with engagement in local community an testing of prototype.
4. Dissertation and reflections of expedition work.
5. Creation of a site specific building design placed in Alaska.

Research Deliverables

1.Architectural site-specific prototype of building component or building strategy.
2.Work dissertation of prototype technical and aesthetic performance in the specific environment, this year in Alaska.
3. Prototype upscaled in building design.

ARCHITECTURE AND EXTREME ENVIRONMENTS

▶ **Researcher:** Cecilie Gry Jacobsen
▶ **Supervisors:** David A. Garcia, Thomas C. Bøjstrup
▶ **Time span:** September 2017 – Juni 2019
▶ **Contact data:** **Stud5724@edu.kadk.dk**
▶ **Associated Publications:**

Textile membrane structures in refurbishment of built heritage, case study: The Medieval fortified towns in Serbia (Smederevo, Ram, Maglič*)

▶ Dijana Savanović, University of Belgrade - Faculty of Architecture, Department of Architectural Technology

▶ Research information

Introduction, Background to the Research

The aim of the research is to investigate the current developments in the use of textile membranes in architecture. More precicely this research is focused on usage of **textile membrane structures in refurbishment of built heritage.** The main goal is reafirmation of built heritage. The research will be organized as a case study: the Medieval fortified towns in Serbia (Smederevo, Ram, Maglič) are considered to be the part of this study.

The idea is based on using this space for open air theaters and music events. Reafirmation of Medieval fortified towns in Serbia would be significant part of their presentation and further usage.

Research problem

As the idea is to define set of requirements that textile membrane structures should carry out in refurbishment of Medieval fortified towns in Serbia at one side, but should also fulfill acoustic requirements for music events and open air festivals at the other side, parametric formfinding of textile membrane structures would be complex. The main goal of the research is finding a tipology of solutions, that would be suitable for different types of built heritage, which can be identified as a simplification or abstraction, but choosing relevant requirements from less important ones is complex.

Research Questions

Main question

"How can the parametric modeling of textile membrane structures be advanced to meet the demands of built heritage presentation but also today's architectural requirements?"

Sub-questions

1. "What are the main barriers to the application of this type of structures in specific historical and urban landscape?"

2. "How does the abstraction of requirements affect on geometry of textile membrane structures and does it restrict the application of this type of structures?"

3. "What are the potential problems of integration of this type of structures in specific historical context like Medieval fortified towns are?"

4. "How does the integration of this type of structures in Medieval fortified towns affect on landscape design and does such interventions require rethinking of the orchestra?"

5. "Finally which textiles would be suitable for application considering all the requirements?"

Research Objectives

This research looks into options to find solutions which enable afirmation of historical places and their new further usage by aplicating textile membrane structures. This will be done through the following objectives:

1.Defining textile membrane structures, systematization of cases and finding tipology

2. Defining set of requirements that these structures in refurbishment of built heritage have to carry out

3.Segregating acoustic requirement from other ones

4.Case study: 3D modeling of these structures (applied on Smederevo, Ram and Maglič) using defined set of requirements

5.Identifying key problems that hinder or limit their application

6.Developing a structure prototype for each group of requirements that could be applied for as many different types of built heritage as possible

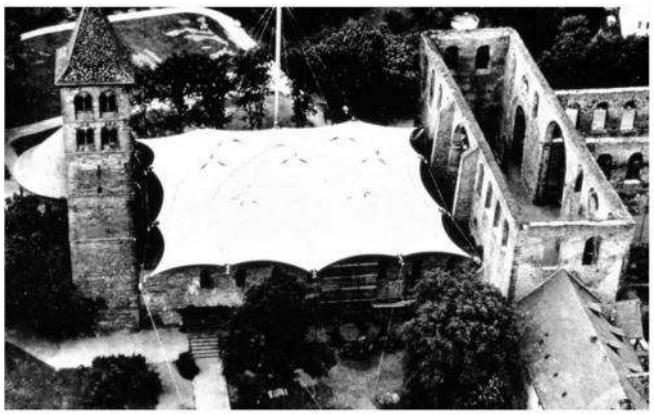
Research Deliverables

This would be 3-part research:

1. research of textile membrane structures and it's application, resulting with tipology of textile structures

2. research of principles of built heritage protection and presentation of Medieval fortified towns in Serbia, resulting with set of requirements that textile membrane structure should carry out

3. case study: application of textile membrane structures in refurbishment of Medieval fortified towns in Serbia, resulting with tipology of solutions



▶ **Researcher:** Dijana Savanović
▶ **Supervisors:** Prof. dr Aleksandra Krstić -Furundžić
Doc. dr Ana Nikezić
▶ **Time span:** January – July 2018.
▶ **Contact data:** dijana.savanovic@arh.bg.ac.rs

▶ **Associated Publications:**

**the author hasn't published this study yet, but related publications that inspired the research are in text below*

Kronenburg, Robert. "Introduction: the developement of fabric structures in architecture", *Fabric Structures in Architecture*, Josep Llorens, ed. (Cambridge: Woodhead Publishing, 2015)

Llorens, Josep and Zanelli, Alessandra. "Structural membranes for refurbishment of the architectural heritage" u *Procedia Engineering 155* (New York: Elsevier, 2016), 18-27.

Bending-Active Shading Elements for Building Skin Retrofitting

▶Federico Bertagna, Department of Civil and Industrial Engineering, School of Engineering, University of Pisa

▶Research information

Introduction

The use of fully glazed facades for office buildings presents the advantage of allowing daylight into the indoor spaces, improving the comfort and well being of the occupants. However, transparent facades can also represent a hazard for the comfort of the users as the penetration of solar radiation inside the building increases the internal thermal loads and leads to overheating during the summer. Moreover, in areas under direct solar radiation, the glare risk will also increase. The inclusion of a suitable shading system on the facade is a method to mitigate these issues, providing effective protection of glazed surfaces throughout the whole year.

This master thesis is carried out in collaboration with the Chair of Structural Design at ETH Zürich, whose headquarters (*Fig.1*) is used as a case study. In order to improve the current thermal and lighting conditions inside the fully glazed building, a lightweight external shading structure is being developed as part of a more extensive research on bending-active structures. The combination of bending-active beams, whose structural behavior is based on elastic deformations, with tensile elements – such as cables or membranes – creates a lightweight yet sufficiently stiff structures that can be used as facade components.

Research Problem

An external shading system can represent an effective solution to mitigate both overheating and daylight glare issues as it prevents direct solar radiation from entering the building through glazed facades. However, thermal comfort and glare risk are not the only parameters that have to be taken into account. The preservation of a good visual connection with the outdoors and an effective use of daylight as an alternative to artificial light are both aspects that cannot be neglected in the design process.

However, fulfilling these different requirements demands conflicting configurations of the shading system. The search for an optimal solution in terms of shape and layout of the elements consists of finding a reasonable compromise between the various parameters investigated.

Research Questions

Main Question

How can facade shading elements be designed in order to improve the energy performance of a building skin without compromising visual comfort?

Sub-questions

- What is the optimal strategy to define the geometry of the shading elements taking into account all the conflicting demands?
- How can the evaluation of visual comfort aspects such as daylight glare be included in the process?
- How can these design strategies be extended to adaptive facades?

Research Objectives

The objective of this master thesis is to provide an effective and multidisciplinary design approach, incorporating the geometrical and structural demands of the shading elements as well as their performance in facade retrofitting.

Research Deliverables

- Analysis of the current state of the building in terms of solar exposition
- Development of new metrics and evaluation tools to guide the design of the shading system defined as part of digital parametric models
- Strategies and guidelines for the design of the shading system resulting from a negotiation of geometric, structural, thermal and visual comfort demands

Fig. 1 – Case study building, South-West facade

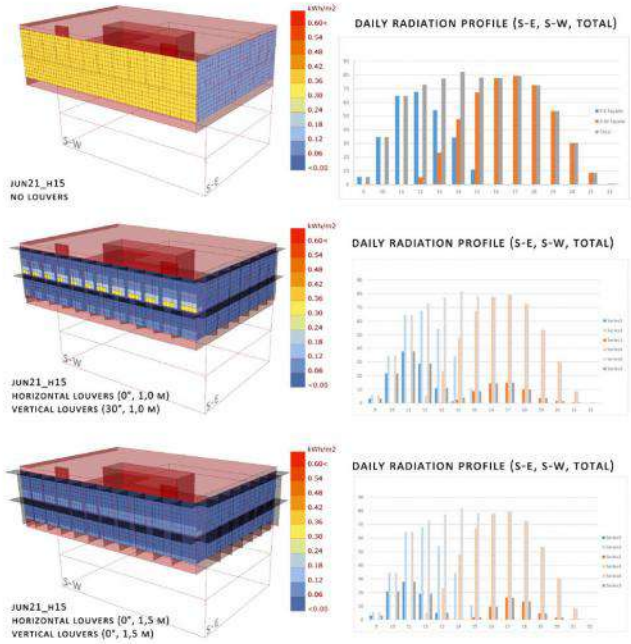


Fig. 2 – Sample of solar radiation studies considering different shading systems, South-West and South-East facades

▶Researcher: Federico Bertagna
▶Supervisors: Eng. F. Leccese (University of Pisa)
Arch. Eng. P. D'Acunto (ETH Zürich)
Arch. Eng. L. Boulic (ETH Zürich)
▶Time span: June 2018 – December 2018
▶Contact data: **f.bertagna@outlook.it**

▶Associated Publications:

- Boulic L, Schwartz J, Design strategies of hybrid bending active systems based on graphic statics and a constraint force density method, IASS Symposium 2018, Boston, 2018.
- Carlucci S, Causone F, De Rosa F, Pagliano L, A review of indices for assessing visual comfort with a view to their use in optimization processes to support building integrated design, Renew Sust Energ Rev 47 (2015), 1016-1033

Integration of Dynamic Window Technologies for Reducing Heat Transfer and Energy Harvesting

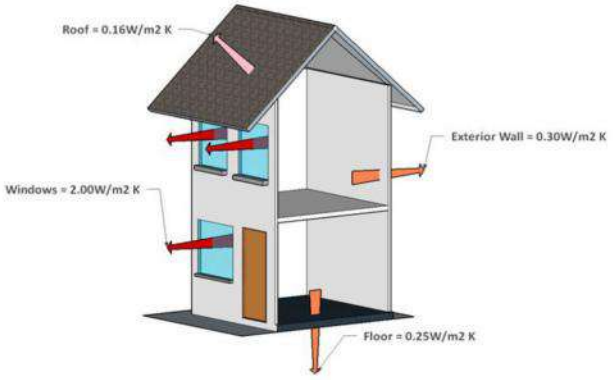
▶ Jorge Luis Aguilar-Santana, Department of Architecture and Built Environment, The University of Nottingham

▶ Research information

Introduction, Background to the Research (Research Theme)

Heat transfer through building envelope occurs mostly due to window interaction with environmental conditions; nowadays fenestration in buildings accounts for more than 40% of energy consumption in household buildings in the UK.

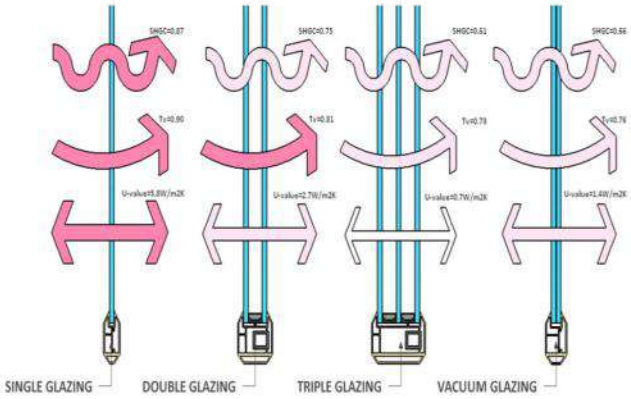
The aim of this research project is to develop an integrated ultra thin glazing to achieve thermal control in buildings, using a series of dynamic fenestration technologies (such as thermochromic, photochromic, Low-E and vacuum). The goal is to reduce the "centre-of-glazing" U-value for window with multipane composition which in recent years has been stagnated (reporting 2.5 and 0.9 W/m2K for Double and Triple Glazing respectively).



Typical U-values for traditional materials in building components. Adapt. from (Jelle, et al., 2012)

Research problem

Optimising window heat transfer by conduction and convection introducing a highly insulated glazing material integrating static and dynamic technologies for solar energy harvesting in Net Zero Carbon Buildings.



Conventional U-values, SHGC's and Visible Transmittances for SG, SG, TG and VG.

Research Questions (Main Questions and sub question)

Main question
What is the impact of windows in the overall heat gain/loss of buildings?

Sub-questions
- What are the novel technologies integrated in the window manufacturing process?
- Which are the optimal technologies to tackle heat transfer through windows?
- What is the optimal technology for electricity harvesting in glazing?

Research Objectives

Analyse and generate mathematical models to predict the optical and thermal performance of active and passive fenestration technologies and the modelling of these windows in a FEM model (Using ANSYS and E+), with a glimpse on experimental testing to measure the U-value of windows and the interaction of these integrated in a PV module.

- Research on novel technologies for glazing systems.
- Design and develop a novel fenestration technology for heat transfer reduction.
- Analyse the integration of dynamic technologies of windows for temperate and tropical conditions.

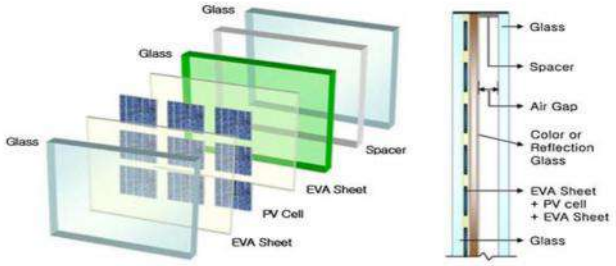


Diagram of c-Si PV window model. (Park, et al., 2010).

Research Deliverables

- Market research evaluation of current fenestration technologies.
- Report on optical, thermal and energy characteristics of glazing materials.
- The impact of windows in the energy consumption of buildings.
- Develop a mathematical model to predict the thermal behaviour of glazing materials for industrial commercialization.

▶ **Researcher:** Jorge Luis Aguilar-Santana
▶ **Supervisors:** Prof. Saffa Riffat
▶ **Time span:** 2017-2020
▶ **Contact data:** **jorge.aguilarsantana@nottingham.ac.uk**

▶ **Associated Publications:**

- *Review on window technologies and Future Prospectus. A comprehensive state of the art analysis. 17th International Conference on Sustainable Energy Technologies, Wuhan China 2018.*

Behaviour of Passive Systems of Intrinsic control in Nordic and Mediterranean Climates

▶ Juanma Cruz, Norwegian University of Science and Technology, Faculty of Architecture and Design

▶ Research information

Introduction, Background to the Research (Research Theme)

Nowadays, the building sector aims to accurately simulate and foresee the energy needs of a building according to a certain number of parameters such as thermal conductivities, cooling and heating loads or HVAC systems performances. In addition, the interest in integrating Thermal Energy Storage systems (TES) such as Phase Change Materials (PCM) in buildings has increased significantly over the last few decades, becoming a potential application to increase thermal mass in buildings.

This research analyzes the behaviour of an office building located in two different scenarios, Barcelona and Trondheim, when PCM are introduced to the building elements and when they are not.

Research problem

The use of TES can overcome the lack of coincidence between the energy supply and its demand; its application in active and passive systems allows the use of waste energy, peak load shifting strategies, and rational use of thermal energy.
However, it is not easy to determine whether these systems can work in accordance with the predicted simulation or the results will differ significantly.

Research Questions (Main Questions and sub question)

Main question

Which are the saving potentials of PCM for different climate such as the Mediterranean and the Nordic when they are applied in the building envelope and other construction elements?

Sub-questions

Could Latent Heat storage systems such as PCM be the tool to avoid installing cooling plans in heating demand climates such as Trondhiem or heating plants in cooling demand climates such as Barcelona?

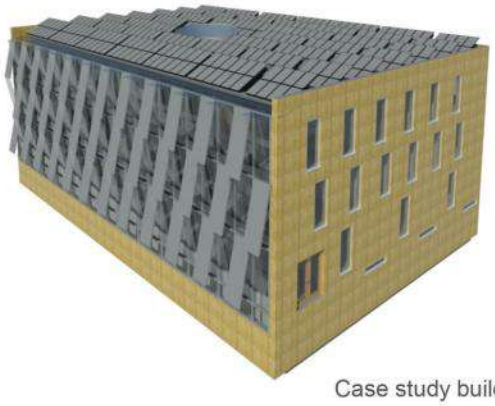
How the behaviour of passive systems of intrinsic control can be affected by factors difficult to predict and which are the factors influencing the most the activation-deactivation cycle of phase change materials?

Research Objectives

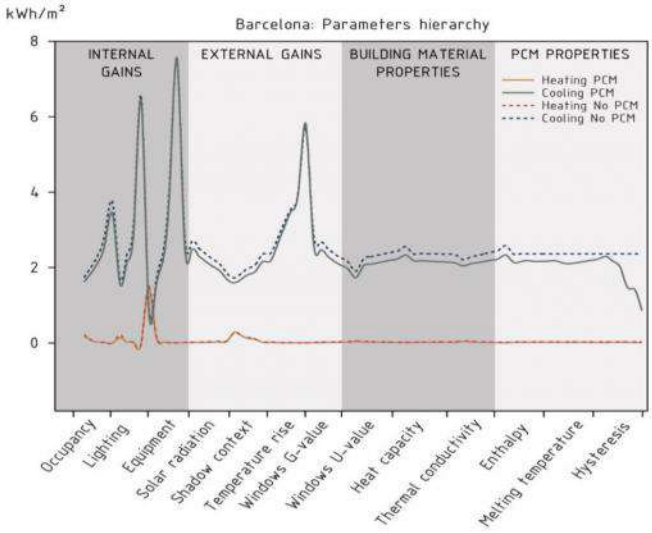
The research aims to find if there are benefits of using PCMs, to analyze the behaviour of the building, when parameters difficult to predict affect the building and eventually, to see if, using PCMs, it is possible to reduce the heating in Barcelona and the cooling demand in Trondheim, so that there is the possibility of avoiding installing a heating and a cooling plant respectively.

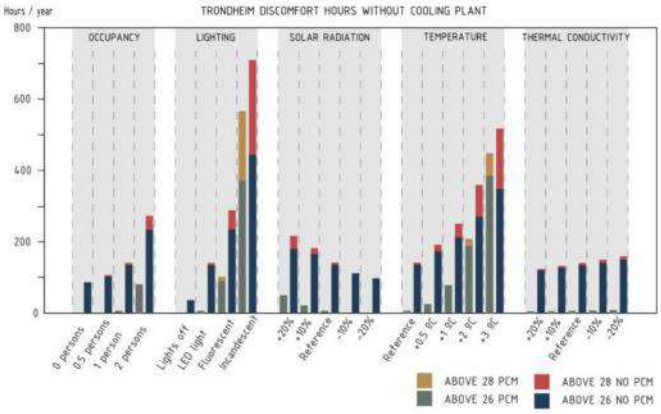
Research Deliverables

Summary of results obtained after running the simulations for all the parameters analyzed.
Graphical results showing the benefits, when there are, of using PCM in different situations in comparison with the same building when PCMs are not incorporated.
Graphical results showing the behavior PCM when some parameters, like internal or external gains are different of the predicted ones.
Diagrams showing the main factors affecting the behavior of PCM when incorporated in the building elements for different situations.



Case study building





▶ **Researcher:** Juanma Cruz
▶ **Supervisors:** Francesco Goia and Albert Castell
▶ **Time span:** Spring semester 2018 - Extendible
▶ **Contact data:** juanma.cg.88@gmail.com
▶ **Associated Publications:**

Optimal specification of Active Glazing when trying to avoid External Shading Devices

▶ Magdalena Patrus, University of Bath, Department of Architecture and Civil Engineering

▶ Research information

Introduction, Background to the Research (Research Theme)

The aim of this research is to investigate the current developments in the active glazing technology, its performance and adaptability on the market. Additionally, the study aims to assess the viability of specifying active glass for commercial developments in the northern maritime climate as an alternative to external shading devices which are often visually disturbing to building's occupants.

Working alongside smart glass manufacturers, it is proposed to explore the existing products and evaluate the current state of technology and industry's readiness to apply the technology in practice.

Research problem

Extensive research in active glazing technology has been carried out for the past few decades. Progressive advancement in materials sciences boosts its performance potential and proves its effectiveness in solar control and the likeliness to tackle existing limitations of external shading devices (i.e. view, user-control, operation and maintenance issues). Nevertheless, there are very little examples of its application in practice, and in the U.K in particular, not a single case study yet.

Research Questions (Main Questions and sub question)

Main question

How feasible as an alternative to visually disturbing external shading devices can active glazing be?

Sub-questions

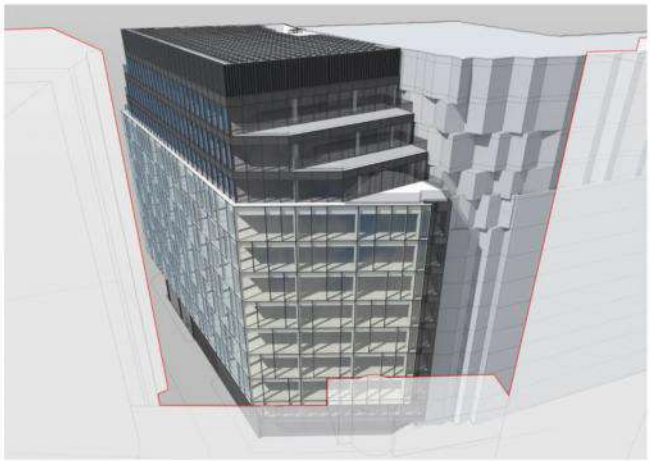
- What is the performance gap between external solar shading and active glazing technology available today?
- What are the main barriers to application of active glazing in practice?
- How can operation of active glazing be optimized to satisfy user-control and building's energy performance?

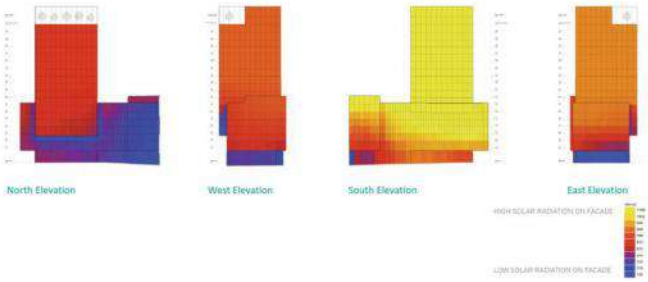
Research Objectives

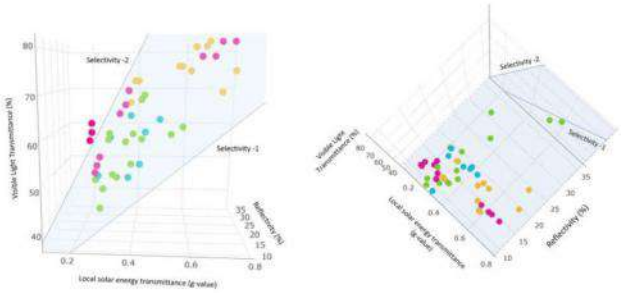
A. Determine the gaps in the knowledge (lit. review & industry survey)
B. Identify the reasons for the lack of practice despite numerous studies emphasising high potential of the application of active glazing as a form of solar control (industry survey).
C. Create active glass products database.
D. Develop a Toolbox enabling optimal specification of active glazing.
E. Test the Toolbox on a commercial case study building located in London
F. Analyse and compare the performance and capital cost of both solutions

Research Deliverables

- A summary of all key limitations related to external solar shading, active dynamic glazing and summary of desirable performance parameters.
- Review of the active glazing technology and products currently available on the market (Database).
- Toolbox enabling an optimal specification of the active glass with reference to an input project's constraints.







▶ **Researcher:** Magdalena Patrus
▶ **Supervisors:** Dr Steve Lo
▶ **Time span:** June - November 2018
▶ **Contact data:** mp2071@bath.ac.uk

The Impact of Façade Technology on the Building Energy Performance

▶ **Mariana Velasco-Carrasco**, Department of Architecture and Built Environment, Faculty of Engineering, The University of Nottingham

▶ Research information

Introduction, Background to the Research (Research Theme)

The building envelope remain as one of the most important exterior elements for building functionality. While the façade is an elegant component that helps to define the unique architectural aesthetics of the building, it also has the critical role related to energy performance and interior function of a construction.

Façades not only shape the appearance of building, they also determined the indoor climate, energy consumption and operating costs of a building. They directly influence the heating and cooling loads, and indirectly influence on lighting loads when daylighting is considered. In addition to being a major determinant of annual energy use, they can have significant impacts on the cooling system and electrical demand. Various façade types will lead to different energy performance of buildings, especially in respect of energy consumption and thermal comfort.

Research problem

- How to evaluate the facade technology?
- Which factors determine the best performance of a technology?

Research Questions (Main Questions and sub question)

Main question

How can we improve the energy performance of a building through the façade?

Sub-questions

1. How does the different façade technology impact on the energy consumption?
2. How does the climate conditions affect the suitability of the façade technologies?

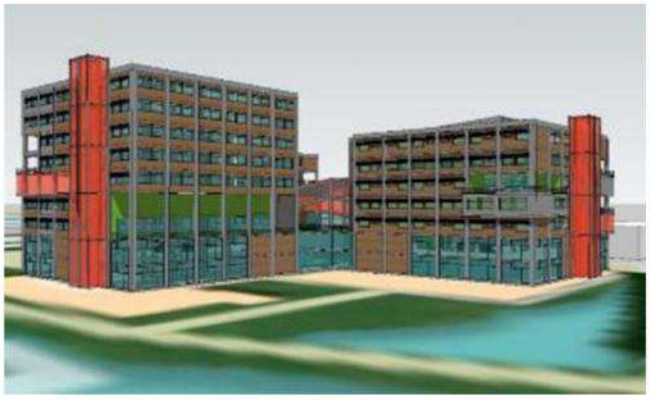
Research Objectives

1. Determine the effect of the façade in the total building energy performance.
2. Measure the performance of different facades technologies, this can be by testing or computational simulation.
3. Analyse the performance under different weather conditions.
4. Propose improvements based on the tested results.
5. Develop an innovative energy efficient façade technology suitable for climate adaptation.

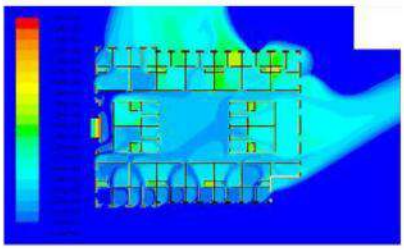
Research Deliverables

1. Review the existing façade technology.
2. Do computational and experimental testing to measure the impact of the façades technologies on the building energy performance.
3. Develop an innovative façade technology with improved energy performance.

Student Villa Retrofit Project



Facade materials



CFD Analysis

▶ **Researcher:** Mariana Velasco Carrasco
▶ **Supervisors:** Prof. Saffa Riffat
▶ **Time span:** 2017-2020
▶ **Contact data:** **mariana.velasco@nottingham.ac.uk**

HYGROTHERMAL PERFORMANCE OF A VENTILATED HEAVYWEIGHT BUILDING ENVELOPE

▶ Marina Bagarić, University of Zagreb Faculty of Civil Engineering, Department of Materials

▶ Research information

Introduction, Background to the Research (Research Theme)

The aim of the research is to investigate dynamic hygrothermal performance of a ventilated heavyweight building envelope under real climate conditions. Observed type of building envelope consists of novel prefabricated sandwich wall panels. The specificity of those panels lies in utilisation of recycled construction and demolition waste. It is proposed to explore the possibility of upscaling recycled aggregate concrete (RAC) from laboratory experiments at material scale to full-scale construction product implementation, which requires proof-of-concept of RAC's suitability for energy high-performing, moisture safe, durable and sustainable building envelopes.

Research problem

Novel prefabricated construction product was developed using recycled aggregate from construction and demolition waste. Theoretically this product is applicable for constructing low-energy buildings, however this has not yet been experimentally confirmed at full-scale in real outdoor and indoor environment conditions.

Research Questions (Main Questions and sub question)

Main question

„Can high-performance building envelopes be achieved with ventilated prefabricated heavyweight panels made from recycled aggregate concrete?"

Sub-questions

1. „How different orientations and indoor environments (use of occupants) effect the hygrothermal performance of observed RAC panels?"
2. „What is the effect of ventilated air layer on the hygrothermal performance of observed RAC panels?"
3. „What are the potentials limits of observed ventilated heavyweight RAC building envelope for different climate conditions and different terms of building use?"

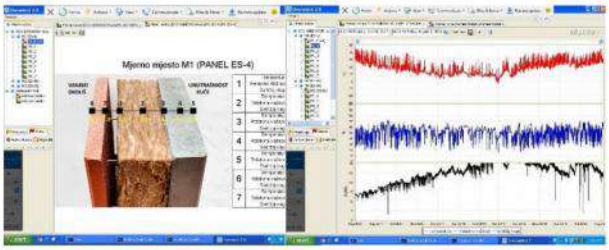
RESEARCH Objectives

Ventilated heavyweight RAC building envelope has not been researched in a detail experimental and numerical hygrothermal performance characterization.

This will be done through the following objectives:
1. Hygrothermal characterisation of two different RACs (recycled concrete and recycled brick as aggregate) at material level.
2. Full-scale hygrothermal characterisation of ventilated prefabricated RAC sandwich wall panels under real outdoor and indoor environment.
2a) Design a real-time field monitoring system.
2b) Investigate the effect of different orientation and indoor environment, as well as the influence of ventilated air layer.
3. Set-up the benchmark numerical model and validate it with experimental results – perform parametric analysis of boundary and initial conditions which should result with recommendations for design process of this envelope type.
4. Quantify basic parameters of thermal inertia and evaluate thermal comfort.

RESEARCH Deliverables

1. Review of hygrothermal performance of heavyweight building envelopes (with conventional and recycled aggregate concrete).
2. Installation of sensors, construction of family house with RAC panels, commissioning of field monitoring system.
3. Validation of numerical model. Recommendations for design process.



▶ **Researcher:** Marina Bagarić
▶ **Supervisors:** Prof. Ivana Banjad Pečur, PhD
▶ **Time span:** 2014-2020
▶ **Contact data:** mbagaric@grad.hr

▶ **Associated Publications:**

- *M. Bagaric, I. Banjad Pecur, B. Milovanovic, Preliminary monitoring results of ventilated heavyweight building envelope from recycled aggregate, IBPC2018, Syracuse, USA*
- *I. Banjad Pecur, M. Bagaric, B. Milovanovic, I. Carevic, Construction and demolition waste as a resource for sustainable, very low-energy buildings, HISER2017, Delft, The Netherlands*
- *M. Alagusic, I. Banjad Pecur, Experimental investigation of hygrothermal performance of recycled aggregate concrete, Young Researchers' Forum III 2016, London, UK*

Public School requalification: Building energy analysis and facade redevelopment

▶ Martina Di Bugno, University of Pisa, Master degree in Building Engineering and Architecture

▶ Research information

Introduction, Background to the Research (Research Theme)

The aim of the project is to improve energy performances of an old school building by working on its façade system. The research started from a specific case study with the aim of creating a standard model which is applicable to similar buildings. In fact, most of Italian school buildings were built between 1960 and 1980, and by now they have lack of energy efficiency. One of the most important aspects of energy redevelopment is how to modify the existing facades by using new technology, in order to gain higher energy performances.

Research problem

The main problem is to redevelop a system which involves many architectural features, like energy efficiency, enconomical sustainabiltiy, maintenance problems, realization, architectural identity.

Research Questions (Main Questions and sub question)

Main question

"What is the smartest way of façade and building regeneration of existing public buildings and what kind of project guidelines we should follow?"

Sub-questions

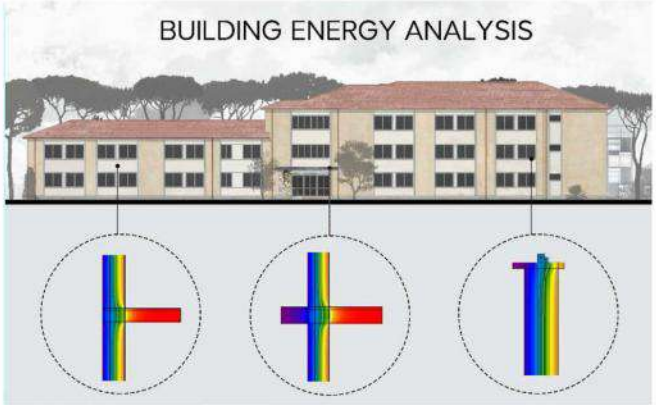
1. What kind of features should we consider when we talk of re-thinking facades?
2. How to combine architecture and energy efficiency?
3. How to make an easy maintenance facade system?
4. To adapt redeveloping system to each case- study

Research Objectives

The first step is to analyze the entire building in order to find every structural and energy weakness. After that, it's possible to focus on what the building needs: the most relevant issue is related to energy dispersion, so the main theme of the study is to research the better system to improve façade energy performances.
The thesis aim is to link façade design with sustainable building strategy as well as LEED certification: the chosen solution agrees with those requirements. In fact, the façade project includes the use of thermic panels, energy efficient windows and sun shading system, which provides an higher level of energy performances, with a reasonable economic impact.

Research Deliverables

1. Building energy analysis – energy performances and heat bridges
2. New performing facade research, final result
3. Technologies involved in energy efficiency improvement. The new building envelope is composed by thermic panels, energy efficient windows and doors, and sun shading system.



▶ **Researcher:** Martina Di Bugno
▶ **Supervisors:** Prof. Michele Di Sivo
▶ **Time span:** 2017 - 2018
▶ **Contact data:** **martina.dibugno@hotmail.it**
▶ **Associated Publications:**

- Retrofit tecnologico e funzionale delle scuole Lenci a Viareggio. Intervento secondo i protocolli di sostenibilità ambientale ed I nuovi indirizzi pedagogici (Tesi di laurea), Martina Di Bugno, Pisa, 2018

A new generation of responsive and energy efficient building envelopes

▶ Michalis Michael, EPSRC – CDT - Future Infrastructure and Built Environment, Department of Engineering, University of Cambridge

▶ Research information

Introduction, Background to the Research (Research Theme)

Recent developments in smart materials and sensing technologies provide an unprecedented opportunity to develop a new generation of façades in the form of engineered smart systems that can dynamically respond to the fluctuating external conditions and internal demands of buildings. However, it has been identified that there is a lack of effective simulation tools that can comprehensively model the dynamic behaviour of adaptive envelopes and their control strategies. This constitutes a limitation/barrier for engineering design, control and product development, which has motivated the undertaking of this research.

Research problem

Reviewing the emerging technologies and simulation tools for adaptive façades and conducting building performance simulations aim to assess their ability to predict and design adaptive façades for the next generation of healthy, productive and resource-efficient buildings. Identify opportunities, challenges and research needs for the future simulation tools for adaptive façades and their control strategies.

Research Questions (Main Question and sub question)

Main question

Can the existing Building Performance Simulation (BPS) tools comprehensively model the dynamic behaviour of adaptive envelopes and their control strategies?

Sub-questions

1. What are the limitations/barriers of the existing BPS tools regarding the modelling and performance analysis of buildings with adaptive envelopes and their control strategies?
2. What are the opportunities, challenges and research needs for the future BPS tools for adaptive façades and their control strategies?

Research Objectives

1. Review current and emerging technologies for adaptive façades, their simulation platforms and control strategies.
2. Identify opportunities, challenges and research needs for the future comprehensive and effective new simulation tools and technologies for adaptive façades and control strategies.
3. Model an existing adaptive façade case study (MATELab) and try to establish a shading system and an associated control strategy for the façades intended to be installed.
4. Compare envelope performance simulation results of two scenarios; with and without shading system and control strategies applied to the model.
5. Compare simulation results from Energy Plus and Physibel-Bisco.
6. Validate the modeling with lighting and thermal experimental measurements and data from the case study.

Research Deliverables

1. Opportunities, challenges and research needs for the future comprehensive and effective new simulation tools and technologies for adaptive façades and control strategies.
2. Comparison of six of the most widely-used software tools for modelling of adaptive building envelope systems and technologies
3. Comparison of results and conclusions derived from the simulation and performance analysis of MATELab in Energy Plus and Physibel-Bisco.
4. Comparison of results and conclusions derived from the performance analysis of MATELab with and without shading system and control strategy.
5. Research needs for the design of shading systems and control strategies in order to increase the energy efficiency of buildings and reduce the running cost and environmental effects.

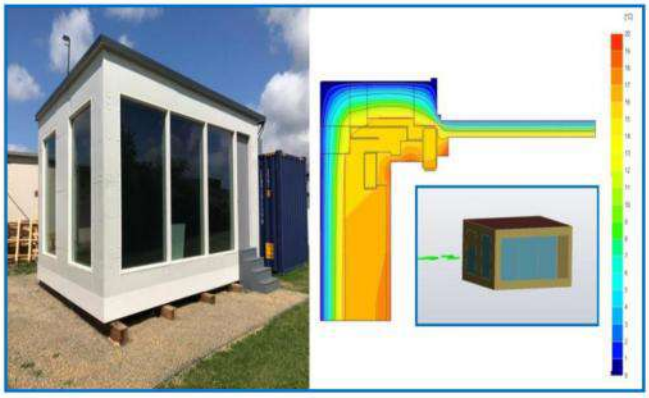


Fig. 1: Photo of MATELab (Mobile Adaptive Technologies Experimental Lab) at the University of Cambridge with part of simulation in Physibel-Bisco

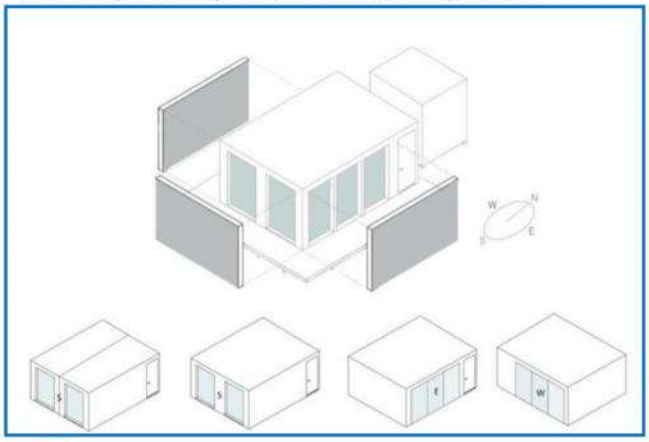


Fig 2: The flexibility of changing façade in MATELab experimental facility

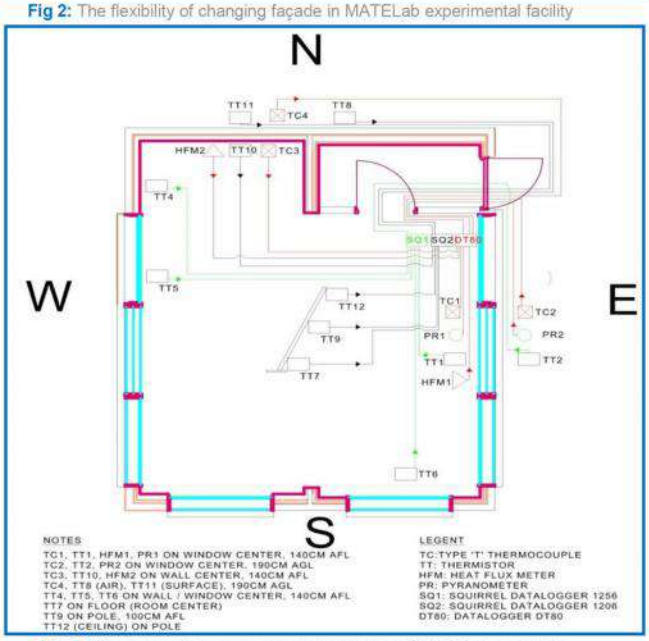
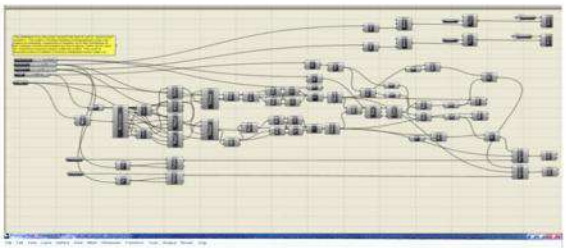


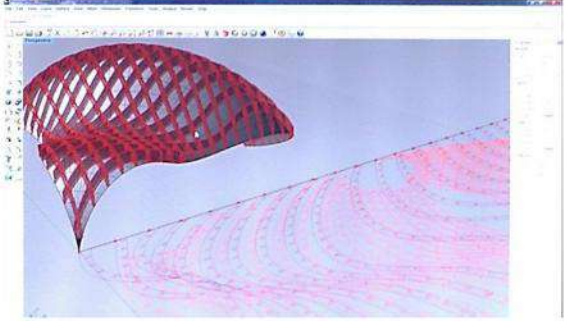
Fig. 3: The set up of the experimental validation of MATELab modelling

▶ **Researcher:** Michalis Michael
▶ **Supervisor:** Dr. Mauro Overend
▶ **Time span:** May-August 2018
▶ **Contact data:** mm834@cam.ac.uk

The impact of software tools in free form surfaces materialization

Milan Varga, PhD student,
Faculty of Architecture Belgrade University

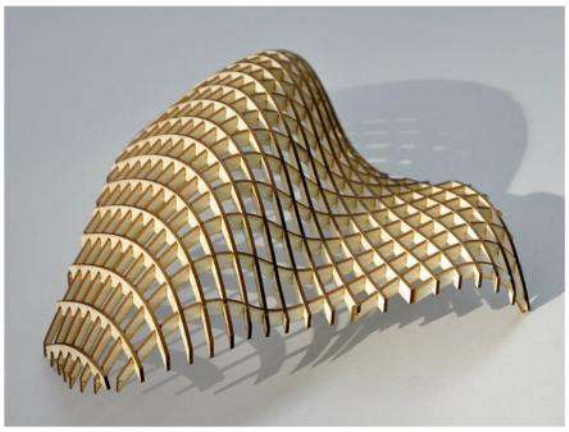




Research information

Introduction, Background to the Research (Research Theme)

With the rapid uptake of new computational tools and fabrication techniques by the architectural profession there is potential for architecture and materiality to be thoroughly examined inside the digital environment. Innovative digital technologies are redefining the relationship between design and construction and are processing the new ways of thinking about architecture.
Digital fabrication emerges, as a computerised process of production performed by machines that create objects described by digital data through utilization of automatised processes.



Research problem

The main research problem is the design of construction systems capable of handling the constanty advancing geometry of free form surfaces.
On a computer screen, forms seem to float freely, often without constraint other than those imparted by the program and by the designer's imagination. This apparent freedom seems to question the most fundamental assumptions regarding the nature of the architectural discipline, the materialisation.

Research Questions (Main Questions and sub question)

Main question
"In which way is parametric software and digital scripting affecting the design and fabrication of free form surfaces"

Sub-questions
"What are the most applicable solutions for free form surfaces construction systems"
"Which connections or joints of geometry elements are the most appropriate for different scaled objects"

Research Objectives

Familiarisation with key concepts in free form surfaces design and digital fabrication.
Identify the most common connections and materials used in inner and outer layers.
Explore the possibility of implementation in local context.

Research Deliverables

1. A summary of computational methods used to design and calculate free form surfaces geometry and construction
2. A summary of connections and elements used in their materialisation
3. New construction system prototype

Researcher: Milan Varga
Time span: 2016-2020
Contact data: vargam9@yahoo.com

Design principles for structures made of short wooden elements

▶ Milica Petrović, University of Belgrade - Faculty of Architecture, Department of Architectural Technology

▶ Research information

Introduction, Background to the Research (Research Theme)

The aim of this research is to set up criteria for the analysis of structures made of short wooden elements that would show their aesthetic, functional and technological advantages. With the advance in computer technology, the numerical analysis of complex geometries became much easier and opened new opportunities for architectural design. The subject of this presentation are structures made of short wooden elements which are created using design processes such as structural optimization and complex modeling. Structural optimization is based on form-finding principles which take into consideration static characteristics of structures and make them primary criteria for design, while complex modeling deals with the relation between real and digitals models in an infinite loop between material, simulation and design.

Research problem

Since this topic became an architectural reality no more than ten years ago, it still isn't fully developed. These new design methods are investigated through architectural pavilions in only a number of institutes, so the information is limited.

Research Questions (Main Questions and sub question)

Main question

>> Does computer design help establish a new methodology for forming structures made of short wooden elements? <<

Sub-questions

- Are complex geometries a new approach in architectural design and if so, can they be the basis for designing structures made of short wooden elements?
- Is it possible to use complex modeling as a tool in everyday architectural practice?
- Can structural optimization be used by architects as the key component of structural design and is it necessary?
- Does new design methodology change the aesthetics of a building and in what way?

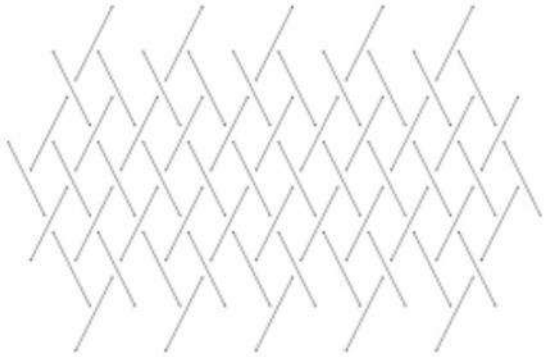
Research Objectives

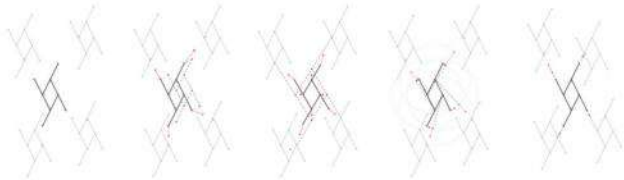
To define a methodology for designing structures made of short wooden elements, the following objectives must be fulfilled:

1. proposing a theoretical discourse regarding structures made of short wooden elements that would help determine the criteria for their analysis
2. the analysis of material characteristics which are used for building these structures
3. the analysis of structural typology
4. the exploration of possibilities for building structures made of short wooden elements through complex modeling and structural optimization
5. validation of aesthetic, functional and technological advantages of these structures

Research Deliverables

The contribution of this research is first and foremost the expansion of theoretical discourse regarding design methodology of structures. The idea is to build a prototype pavilion which would follow all the design principles defined in the research so that conclusions about the advantages and of these structures can be made.





*all the figures are from Martin Tamke's workshop at KADK, presented in the article "Generated lamella"

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▶**Associated Publications:**

Tamke, Martin, Jacob Riiber, and Hauke Jungjohann. "Generated lamella." *Acadia in:formation* (2010): 340-347.

Bletzinger, Kai-Uve, Roland Wüchner, Fernaß Daoud, and Natalia Camprubı, "Computational methods for form finding and optimization of shells and membranes." *Computer methods in applied mechanics and engineering 194* (2005): 3438-3452.

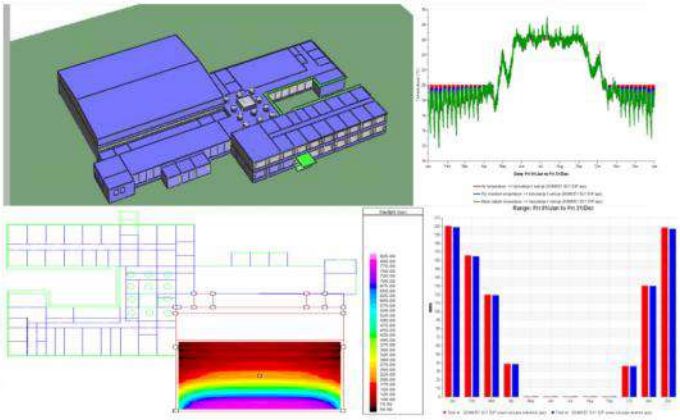
Popovic Larsen, Olga, and Andy Tyas. *Conceptual Structural Design: Bridging the gap between architects and engineers.* London:Thomas Telford Limited, 2003.

REFURBISHMENT OF UNIVERSAL SPORT HALLS BUILT IN BELGRADE FROM 1960-1980

▶ **Mirjana Miletić, PhD Studies, Faculty of Architecture, University of Belgrade, Serbia**

▶Research information

The aim of this research is to investigate the application of different passive technologies in sport halls within the sport centres that may be productive in energy saving. The case study includes sport centre built in 1974 in Belgrade, Serbia. Benefits of applying of different measures, thermal insulation, than green facades and new openings, on the building structure are investigated in the sense of reducing total annual energy consumption for space heating, as well as conditions related to the comfort of the indoor environment. All created conditions were simulated in software package Integrated Environmental Solutions Virtual Environment, IES VE 2017.



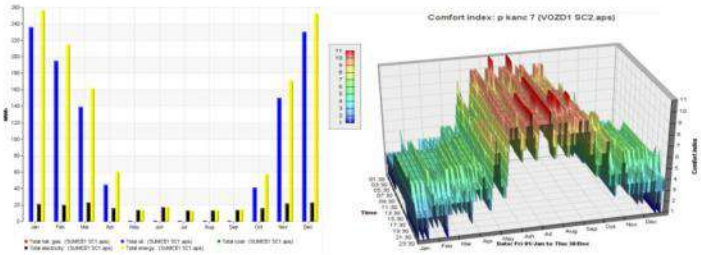
Research problem

Subject of the research is checking of possibility, strategies and techniques to achieve energy optimization in the processes of refurbishment of universal sport halls in sports centres as well theoretical and analytical audit of quality of each implemented measure according to the existing rules and defined comfort conditions.

Research Questions (Main Questions and sub question)

Main question

Basic research question is which extent in improvement we should take to improve these facilities. Research should give basic directions for improvement measures of thermal insulation materials and use of passive features.



Research Objectives

Results of this research can find direct implementation in refurbishment of sports facilities in the aim of achieving energy saving by minimizing interventions. Results can have practical use because of implementation of the measures that present realistic situation.

Research Deliverables

Practical use of results for sport buildings of defined capacity.

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▶ Associated Publications:

Miletić, M., Krstić-Furundžić, A., (2018) *Energy refurbishment of a public building in Belgrade*, Conference paper, Places and Technologies 2018, Belgrade, 26-27. april 2018. p.348-356.

Stamenkovic, M., **Miletic, M.,** Kosanovic, S., Vuckovic, G., Glisovic, S., (2017) The impact of a building shape on space cooling energy performance in the green roof concept implementation, *Thermal Science,* https://doi.org/10.2298/TSCI170425205S

Research of the potentials for the application of heat pumps from the aspect of different work modes

▶ Miroslav Vulić, Faculty of Mechanical Engineering, Department of Thermotehnics

▶ Research information

Introduction, Background to the Research (Research Theme)

The aim of the research is to investigate the various operating modes of the heat pump both for the heating and cooling function.
In addition, an important aspect is the rationalization of primary energy consumption, as well as the optimization of the entire system.

Research problem

Research problem is dimensioning of the entire heat pump system, and it is reflected through :

- Dimensioning of the heat pump;
- Dimensioning of the heat source;
- Determination of heat source.

Research Questions (Main Questions and sub question)

Main question

The main issue concerns the selection and optimization of the entire heat pump system, as well as operating modes, according to the conditions in which the facility is located.

Sub-questions

- Rationalization of primary energy consumption;
- Rentability of the heat pump plant;
- Comparison with other heating systems.

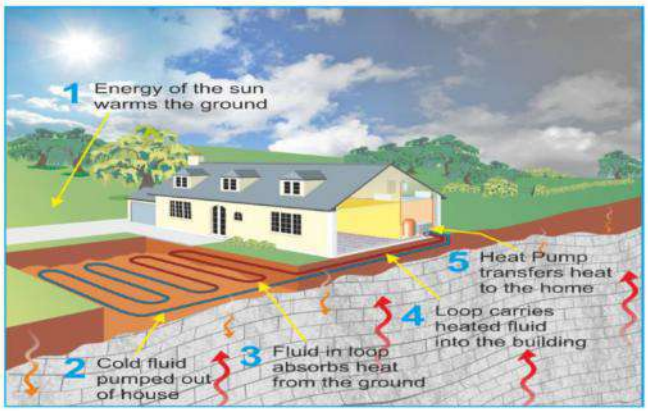
Research Objectives

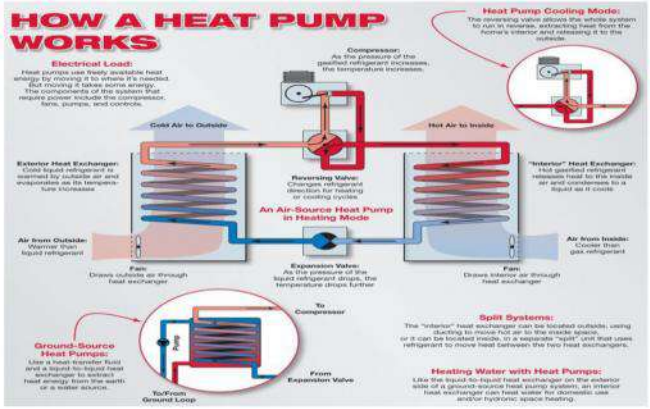
The objectives of the research are achievable through the following activities:

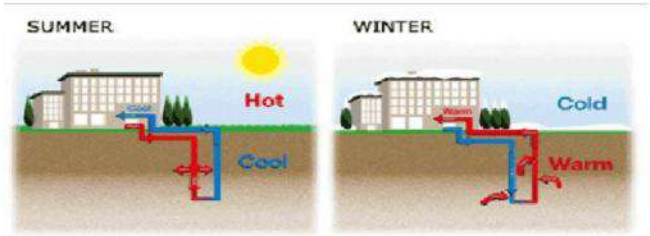
- Examination of the temperature difference of the heat source and heat sink;
- Selection of the appropriate refrigerant;
- Adequate choice of heat pump depending on the location of the facility;
- Calculating of the consumption indicators and optimum consumption;
- Comparative analysis of the optimal consumption with real parameters during the entire measuring season;
- Financial analysis through consumption, profitability, sensory, actuators and others.

Research Deliverables

- Review of the current researches in the same field;
- Data collection;
- Techno-economic analysis of heating objects with heat pump water-water / draw-well in the bivalent system with the gas boilers.







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▶ **Supervisors:**
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▶ **Associated Publications:**

- M. Vulić, K. Vujičin, Techno-economic analysis of heating objects with heat pump in the bivalent system, ICREPS 16, Belgrade, Republic of Serbia
- M. Vulić, K. Vujičin, Application of Linear Regression Analysis in Practice – Plant for Building Heating with Heat Pumps, KGH 2016, Belgrade, Republic of Serbia
- M. Vulić, K. Vujičin, Using of geothermal energy in the function of environmental protection, KGH 2017, Belgrade, Republic of Serbia

Building Façade and Ventilation Strategy: Improving Environmental Condition of Workspaces of Garment Factories in Bangladesh

▶ Mohataz Hossain, Department of Architecture and Built Environment, The University of Nottingham, Nottingham, UK

▶ Research information

Introduction, Background to the Research (Research Theme)

In the tropical climatic context of Bangladesh, most of the workers in garments factories suffer from discomfort in their workspaces and a range of health problems due to the high indoor temperature and poor air distribution. These workspaces, with a deep floor-plate and low ceiling heights, usually employ forced cross-ventilation using extract fans located on the external walls. However, the existing active ventilation strategy is unable to provide the workers with necessary thermal comfort. This research aims to identify viable design strategies that can improve the indoor thermal comfort within the workplaces of existing multi-storey garment factories in Bangladesh.

Research problem

There is an absence of studies based on field evidence from garment factories that quantify the issues surrounding existing thermal conditions in different production workspaces during various climatic seasons. Moreover, no previous research identified the feasible solutions designed to improve the indoor thermal performance of both existing and new garment factory workspaces.

Research Questions (Main Questions and sub question)

Main question

"What are the viable design strategies that can improve the thermal comfort and indoor environmental condition of workspaces within existing RMG factories in the tropical climate of Bangladesh?"

Sub-questions

A. What are the factors that influence the thermal environment within workspaces in RMG factories and how do these vary between the seasons of Bangladesh?

B. What are the thermal comfort guidelines and the workable design strategies to minimise the environmental issues within these workplaces?

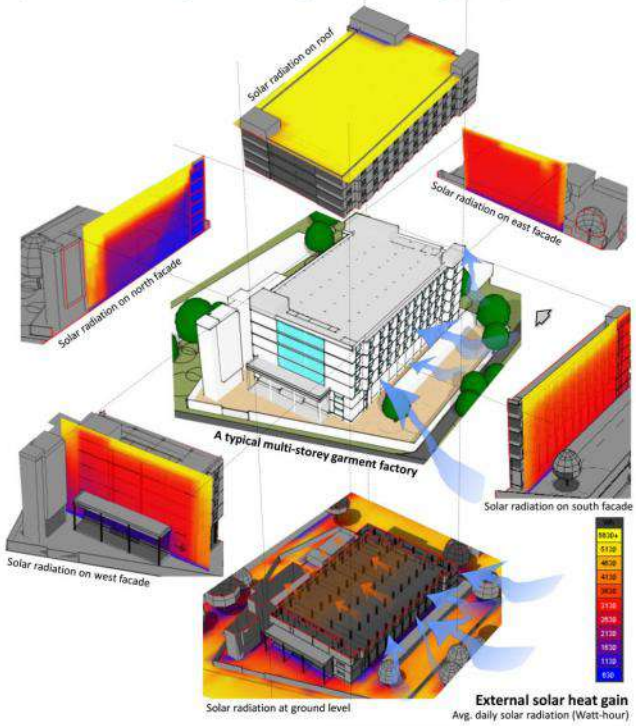
C. To what extent are the workable design strategies beneficial in terms of improving workers' thermal comfort within the workspaces?

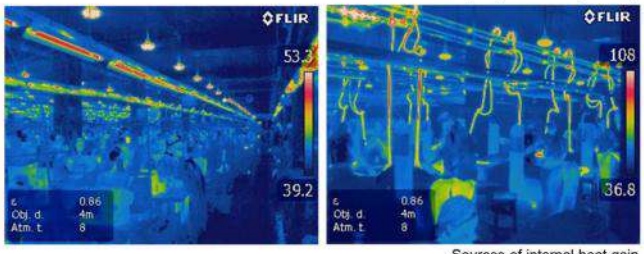
Research Objectives

1. To identify the environmental design parameters that influence the indoor thermal comfort of workspaces, including those of RMG factories, in a tropical climate.
2. To identify and assess the feasibility of passive design strategies in existing multi-storey RMG factories of Bangladesh.
3. To identify the key parameters that influence the thermal environment of workspaces in existing RMG factories during the climatic seasons in Bangladesh.
4. To identify thermal comfort guidelines and workable design strategies to minimise the issues (based on Objective 3) within RMG workspaces.
5. To explore the environmental benefits of applying the workable design strategies in existing RMG factories.

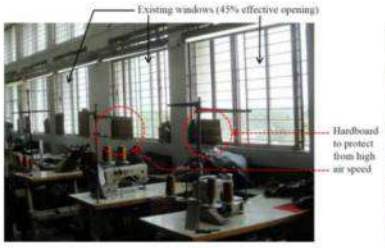
Research Deliverables

1. Review of suitable thermal comfort guidelines and design strategies.
2. The key design parameters influencing the indoor thermal comfort of garment factory workspaces.
3. Adaptive thermal comfort guidelines and workable design strategies to minimise the existing issues based on field survey.
4. Quantifiable effect of retrofitting existing building facades and changing ventilation strategies on indoor thermal environment.





Sources of internal heat gain



Existing windows and building facades

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▶ **Contact data:** mdmohataz.hossain@nottingham.ac.uk

▶ **Associated Publications:**

- *M.M. Hossain, B. Lau, R. Wilson & B. Ford. Effect of Changing Window Type and Ventilation Strategy on Indoor Thermal Environment of Existing Garment Factories in Bangladesh, Architectural science review, 60(4), 299-315, 2017.*
- *M.M. Hossain, B. Lau, R. Wilson & B. Ford. Air Temperature vs Energy Efficiency of Workspaces: A field investigation in garment factories during cool-dry season, SET 2016, Singapore. 2016.*
- *M.M. Hossain, B. Lau, R. Wilson & B. Ford. Evaluating Ventilation Performance of Work-Spaces in Ready-made Garment Factories: Three case studies in Bangladesh, PLEA 2015, Bologna, Italy. 2015.*
- *M.M. Hossain, B. Ford. & B. Lau. Improving Ventilation Condition of Labour-intensive Garment Factories in Bangladesh, PLEA 2014, Ahmedabad, India. 2014.*

Investigation of composite plywood material as element of Exoskeletion structure

▶ Neda Džombić, PhD student, University of Belgrade, Faculty of Architecture

▶ Research information

Introduction, Background to the Research (Research Theme)

Plywood is one of the important wood-based composites produced from different species of trees, made by bonding together pieces of wood in perpendicular direction between each other. Curent application of plywood panels in architecture primarly is non-structural aplication, that is application for coating elements, constructive aplication as secundary elements of structure (horizontal and vertical diaphragms). In order to expand their application, methods for improving the quality of veneer panels are being examined today. The most common method is the reinforcement of veneer sheets by materials based on polymer reinforced fibers (FRP). This reinforcement creates new composite products whose constructive characteristics are significantly improved.
The aim of the research is to investigate possibilities and needs of use and application of new composite plywood material as primary structural elements, elements of spatial structures or the entire structure of architectural objects.
Keywords: plywood, engineered wood, FRP, spatial structures, structural elements

Research problem

Problem of research is observation behavior of the new constructive material and its advantages, disadvantages and limitations. This material is new one, and its application is being tested on small objects and pavilions. However, production of complex geometry or curved elements has not been tested yet.

Research Questions (Main Questions and sub question)

Main question

- What are the potential limits of composite plywood material and can we used it for entire structure of architectural objects?
- For widening its application panel shear strenght is important mechanical characteristic, how can we improve it?

Sub-questions

- How can we produce panels of curved geometry, without damaging the structure of panels?
- What are the potential limits of this products?

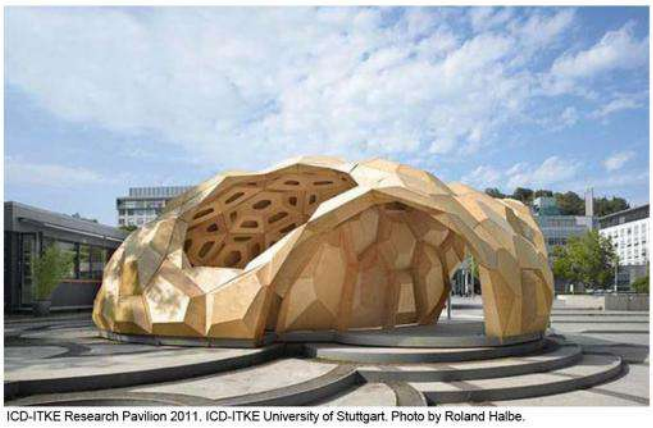
Research Objectives

Application of composite plywood panels is not investigated. Previous research is based on experimental testing its mechanical properties. This research should analyse previous research of mechanical properties and find possibility of application this panels in architecture.

- Analyse mechanical properties of panels reinforced with glass or carbon polymers.
- Comparative analysis of products different reinforced.
- Experimental research of panels mechanical properties.
- Identify key problems that hinder or limit their architectural application.
- Examine the possibility of forming free forms of this material.

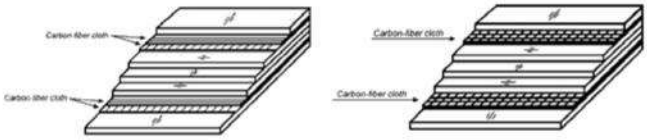
Research Deliverables

- A summary of all key problems prioritised by importance.
- Summary of desirable performance parameters.
- Make prototype model of object in small scale to test structural behaviour.



ICD-ITKE Research Pavilion 2011. ICD-ITKE University of Stuttgart. Photo by Roland Halbe.

Rryuichi Ashizawa Architects. Folded structure at Aqua Metropolis Osaka Event Photo by RAA.



▶ **Researcher:** Džombić Neda, M.Arch
▶ **Supervisors:** Nenad Šekularac, Associate Professor
▶ **Time span:** 2015-
▶ **Contact data:** dzombic.neda@gmail.com

▶ **Associated Publications:**

Bal, Bekir Cihad, İbrahim Bektaş, Fatih Mengeloğlu, Kadir Karakuş, / H. Ökkeş Demir. 2015. „Some technological properties of poplar plywood panels reinforced with glass fiber fabric." *Construction and Building Materials* 101 (Part 1): 952-957.

Bal, Bekir Cihad, / İbrahim Bektaş. 2012. „The effects of wood species, load direction, and adhesives on bending properties of laminated veneer lumber." *BioResources* 7 (3): 3104-3112.

Davalos, Julio F., Pizhong Qiao, / Brent S. Trimble. 2000. „Fiber-Reinforced Composite and Wood Bonded Interfaces: Part 1. Durability and Shear Strength." *Journal of Composites, Technology and Research* 22 (4): 224-231.

Building performance simulations of the adaptive facade systems
- determination of problems and possibilities

▶ Nevena Lukić, Faculty of Architecture, University of Belgrade, Department of Architectural Technologies

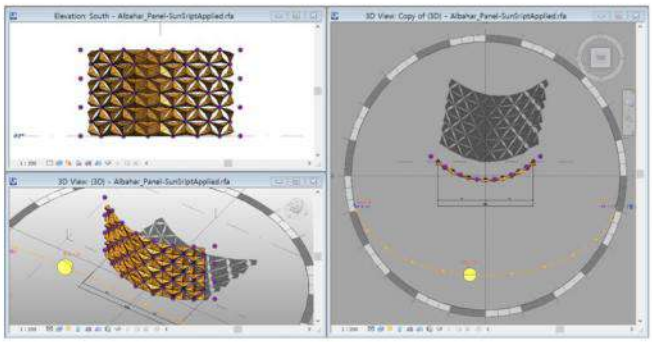
▶ Research information

Introduction, Background to the Research (Research Theme)

Adaptive facade systems have a potential of both significantly reducing the energy use in buildings and improving the level of indoor environmental quality still responding to the application of innovative materials and design solutions. The adaptive facade systems, while having large technical potential and many concepts developed are not widespread solutions. The problem in further development and mass implementation of these systems is the lack of information and systematic approach in the architectural research, which could be overcome with the use building performance simulation. Building performance simulation has the potential of providing the needed information to all sides included in the designing process of these systems as well as various simulation activities testing the performance of the adaptive facade concept insuring adequate building comfort.

Research problem

Building performance analysis is an adequate tool for testing performance of different facade concepts, but it is usually used in the static conditions analysing traditional systems and materials. Adaptive facade systems regard more complex approach because of their capability to change their behaviour in real time, according to indoor-outdoor parameters, innovative materials and systems used, occupant behavior, etc. Through this research the potential of building performance analysis is examined, as well as the problems that need to be overcome in order to contribute to the further development of adaptive facade systems and their greater application.



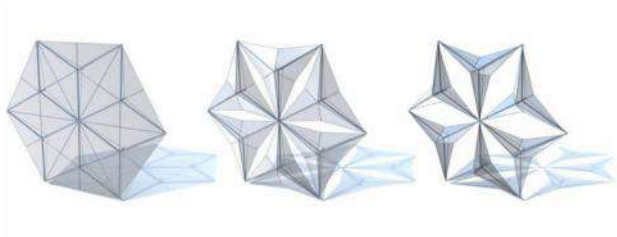
Research Questions (Main Questions and sub question)

Main question

What are the problems regarding building performance simulations of the adaptive fasade systems?

Sub-questions

- How are the adaptive facade systems classified?
- Is it possible to use current building performance softwares and how?
- Are the results of building performance analysis compatible with occupant feedback and in-situ analysis?



Research Objectives

The aim of the research is to determine problems regarding building performance simulations of the adaptive fadace systems – lack of systematic approach in analysis of adaptive facade systems, availablility of adequate softwares and possible usage, as well as comparison of performance analysis results in regard to occupant feedback and in situ analysis.
The objectives of the research are:

- Systematization of the existing literature and types of classification of adaptive façade systems
- Defining the methodology of building performance analysis of adaptive facade systems - criteria for the analysis of adaptive façade systems, software / software combinations and types of analysis
- Comparing building performance analysis with in-situ measurements and occupant response

Research Deliverables

- Review of current research and systematization of current Adaptive facade systems
- Methodology for building performance analysis of adaptive facade systems
- Case study results

▶ **Researcher:** Nevena Lukić
▶ **Supervisors:** prof. dr Aleksandra Krstić Furudžić
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▶ **Associated Publications:**

-

An example of adaptive facade design and building performance analysis

Image source:
1. https://s-media-cache-ak0.pinimg.com/originals/86/17/2d/86172dda91bca38e698f50fd6b94b0bf.jpg
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3. https://images.adsttc.com/media/images/55e6/fb60/4d8d/5dd1/7300/130d/large_jpg/adic-responsive-facade-abu-dhabi-uae-research-3.jpg?1441200985

*This research is a topic of the Research Seminar during Phd studies - Architecture-technology-environment (supervised by prof. Dr Aleksandra Krstić – Furundžić)

Problems of reconstruction of reinforced concrete façades

▶ Nikola Macut, University of Belgrade, Faculty of Architecture, Department of Architectural Technology

▶ Research information

Introduction, Background to the Research (Research Theme)

Research theme is related to the analysis of possibilities of reconstruction and energy renovation of facades of residential multifamily buildings in New Belgrade (Serbia), built since late 1950s until the late 1970s, which today present architectural heritage. Buldings were constructed by the use of prefabricated and semi-prefabricated systems and reinforced concrete was the main applied material. Today after approximately 50 years of exploitation those buildings are not in the good condition and facades have various types of damages so they need large scale reconstruction and also energy renovation.

Research problem

The basic research problem presents the affects of applied reconstruction and renovation principles on the protection of original appearance of reinforced concrete facades which have to be reconstructed and energy renovated.

Research Questions (Main Questions and sub question)

Main question

-"How is it possible to reconstruct or repair elements of facades and do energy renovation without changing the original appearance of those elements?"

Sub-questions

1. "How do the geometries of façade elements affect to the possible applied principles of reconstruction and energy renovation of analysed facades?"
2. "How do the applied finishing layers (coatings, exposed concrete, coulier, ceramic or glass tiles) of façade elements affect to the possible ways of reconstruction and energy renovation?"
3. "How do the types of façade damages affect to the scales of reconstruction?"
4. "What are the main principles for preventing the original appearance of façades during the processes of their reconstruction and energy renovation?"

Research Objectives

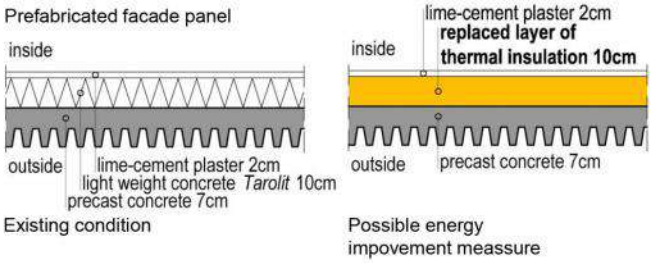
This research was done throughout specific steps in case of creating possible methodologies for reconstruction and energy renovation of reinforced concrete facades:

1. Field research and taking photos of buildings and their facade damages,
2. Mapping of present damages,
3. Analysis of technical drawings of selected buildings,
4. Analysis of different types of literature which are related to research topic,
5. Creating typology of present damages,
6. Analysis of possible meassures for reconstruction and energy renovation,
7. Creating possible methodologies for reconstruction and energy renovation in case of selected residential buildings.

Note: Steps 2., 3. and 4. were done parallel.

Research Deliverables

1. Creation of typology of present facade damages of analysed buildings.
2. Creation of methodologies for facade reconstruction and energy renovation.
3. Results of analysed applied methodologies for reconstruction and energy renovation in case of preventing original appearance of facades.



▶ **Researcher:** Nikola Macut
▶ **Supervisors:** Ana Radivojević
▶ **Time span:** 2013-2019
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▶ **Associated Publications:**

- *N. Macut, A. Radivojević, Prefabricated concrete facade and their existing condition: case study of New Belgrade's residential buildings, SAHC 2016, Leuven, Belgium*
- *N. Macut, A. Radivojević, Problem of protection of original appearance of prefabricated concrete facades and energy improvement measures-example New Belgrade, P&T2016, Belgrade, Serbia*
- *N. Macut, A. Radivojević, Preservation of original appearance of exposed concrete facades, case study: Residential block 23, New Belgrade, P&T2018, Belgrade, Serbia*

On the integration of PCM in Building-Integrated Solar Thermal systems

▶ Paolo Bonato, Eurac Research, Institute for Renewable Energy

▶ Research information

Introduction, Background to the Research (Research Theme)

The PhD topic focuses on multifunctional facade elements that embed solar thermal collectors. Building Integrated Solar Thermal technologies (or BIST) consent to exploit the solar radiation impinging on the façade to cover part of the thermal loads of a building (space heating or DHW) in both tertiary and residential applications. In this context, the possibility to integrate a complete solar thermal system (harvesting, storage and emission of solar heat) can represent an innovative and interesting plug and play solution for curtain wall façade modules.

Research problem

Previous research activities on a first prototype of multifunctional façade element embedding a complete solar thermal system (picture on the side) have shown that the a critical and limiting issue to this solution is represented by the thermal storage. A water storage does not represent an acceptable solution, as the geometry of the tank is very limited to the design of the façade module and result into low heat capacity and high thermal dispersion due to the high surface to volume ratio). The use of a higher energy density storage would be beneficial to the performance of the system.

Research Questions (Main Questions and sub question)

Main question

"How convenient is the integration of PCM in a BIST as thermal energy storage in building facades?"

Sub-questions

1. "What are the main technological limits to the integration of PCM in façades (durability, fire resistance..)?"
2. "What are the energy benefits that can be achieved integrating PCM in a BIST system?"
3. "Which are the advantages of such technology with respect to the state of the art?"

Research Objectives

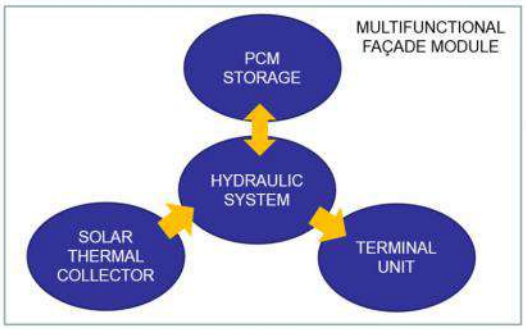
The research questions will be tackled with different approaches considering the energy, the technological and the economical aspects of the façade-integration of a solar thermal system with PCM.

In order to do so, the following reseach objectives are identified:
1.Defining the state of the art of the use of PCM as storage, in solar thermal system and integrated in facade.
2.Identify critical technological issues that could limit the application of some PCM material in this context.
3.Develop a new concept of façade element integrating a solar thermal system with PCM.
4.Manufacture and test a first prototype of the multifunctional façade element.
5.Develop a calibrated numerical model of the energy system.
6.Assess the energy performances of the energy system in a set of boundary conditions.
7.Assess the cost-effectiveness of the overall solution.

Research Deliverables

State of the art about the use of PCM as storages and in façade.
Summary of the technological limits to the integration of PCM in facade.
Prototype of the developed multifunctional façade .
Review of the energy performance and of the LCCE of the façade module.

SunRise Project, Credit: Stahlbau Pichler Srl



▶ **Researcher:** Paolo Bonato
▶ **Supervisors:** Matteo D´Antoni (Eurac Research)
▶ **Time span:** 2019-2022
▶ **Contact data:** **paolo.bonato@eurac.edu**
▶ **Associated Publications:**

- *IEA SHC Task 56, «Building Integrated Solar Envelope Systems for HVAC and Lighting,» 2016.http://task56.iea-shc.org/.*
- *Bonato, P., D'Antoni, M., Fedrizzi R., On the development of a façade-integrated solar water storage, Journal of façade design and envineering (JFDE), Volume 6, Number 2, (2018).*

Automatic Generation of Architectural Space Layout to Optimise the Energy Performance of Office Buildings

▶ Tinatian Du, TUDelft, Faculty of Architecture, Department of Architectural Engineering and Technology

▶ Research information

Introduction, Background to the Research (Research Theme)

The space layout design is one of the most important phases of the architectural design, and the automatic generation of space layout has shown great potential as a design aid. The automatic generation shows the ability to speed up the design process and have the capacity of a much larger objectives. Research has also shown that space layouts can have a significant impact on the improvement of energy performance. The combination of the automatic generation of space layout and the optimisation of energy performance is expected to be greatly helpful for the development of an energy efficient design in the early design phase.

Research problem

1. Although the potential of space layout generation to optimise energy performance seems big, it is not fully explored.
2. Only several studies have tried to combine automatic generation of space layout with the energy performance optimisation.
3. The current research lacks the integration of different aspects of energy performance.
4. The automatic space layout generation lacks the contemporary spatial typologies of office buildings.

Research Questions (Main Questions and sub question)

Main question

1. What is the relationship between space layout and energy performance of office buildings?
2. How can space layout be automatically generated to improve energy performance of office buildings?

Sub-questions

1. How to assess the different energy performance aspects and how to integrate them?
2. How to build the model of automatic space layout generation?
3. Which parameters of space layout are most influential for energy performance?
4. Which space layouts are optimal for energy performance given certain case studies?

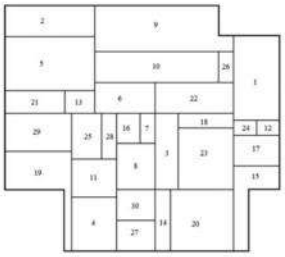
Research Objectives

1. Explore the relationship between space layout and energy performance;
2. Develop the methodology of automatic space layout generation for architects in the early design phase;

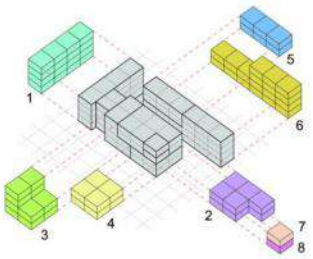
-Optimise energy performance, considering the integration of different aspects of energy performance.
-Focus on the contemporary spatial typologies and requirements of office buildings.

Research Deliverables

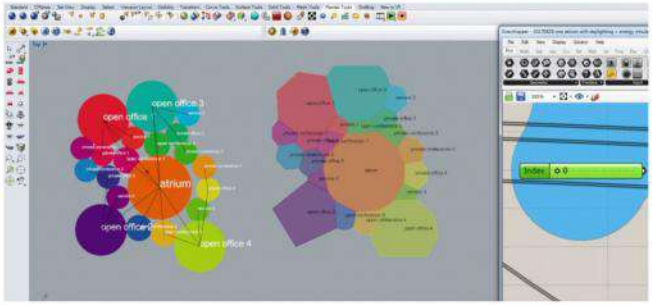
1. The methods and tools for the assessment and integration of energy performance, especially for office buildings.
2. A model for the automatic generation of energy efficient space layouts for office buildings.
3. The knowledge about the parameters' effects on the energy performance of office buildings.
4. The knowledge about the relationship between space layout and energy performance of office buildings.

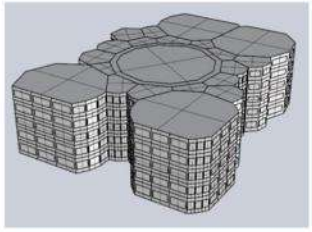


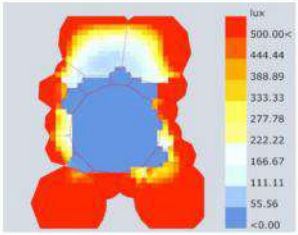
Jankovits et al. 2011

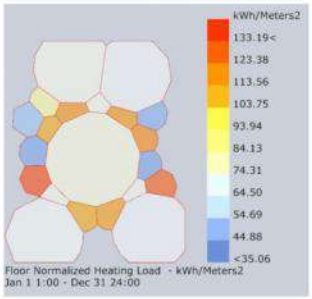


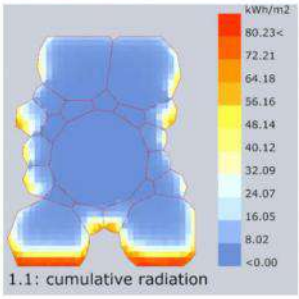
Dino, 2016











▶ **Researcher:** Tiantian Du
▶ **Supervisors:** Prof.dr.ir. Andy van den Dobbelsteen, Dr.ir. Sabine Jansen, Dr. Michela Turrin
▶ **Time span:** 2017 to 2021
▶ **Contact data:** T.Du@tudelft.nl

▶ **Associated Publications:**

- *Du, T., Turrin, M., Jansen, S., van den Dobbelsteen, A., & Biloria, N. A Review on Automatic Generation of Architectural Space Layouts with Energy Performance Optimization.*

References:

- Dino, Ipek Gürsel. 2016. "An Evolutionary Approach for 3D Architectural Space Layout Design Exploration." *Automation in Construction* 69: 131–50.
- Jankovits, Ibolya, Chaomin Luo, Miguel F Anjos, and Anthony Vannelli. 2011. "A Convex Optimisation Framework for the Unequal-Areas Facility Layout Problem." *European Journal of Operational Research* 214(2): 199–215.

Smart Architecture

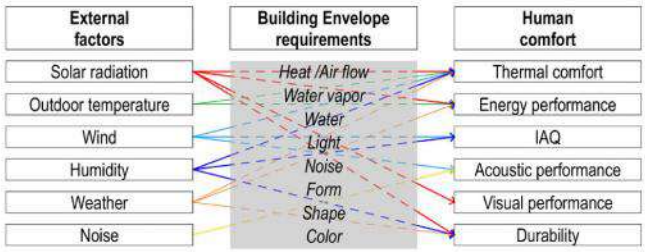
Adaptive (transparent) components for the improvement of building envelope performance

▶ **Valentina Frighi,** Department of Architecture, University of Ferrara

▶ Research information

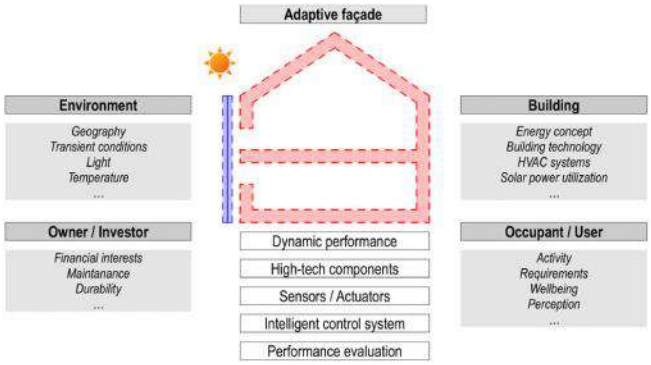
Introduction, Background to the Research (Research Theme)

The aim of the research is to investigate the domain of Smart Adaptive Building Envelopes, identified as models able to respond to current architectural requirements.
Within this scope, Transparent Building Components have been analysed as major responsible for building energy consumption and end-users' comfort.



Research problem

Since the most of technological innovations employed in Smart Buildings addresses glazed components, due to their shortcomings in building systems, this research aims at develop a novel concept of Smart Window able to face current building needs as well as to solve a still existing lack of guidance on how such innovative glazing technologies could be integrated in buildings in a way that maximises their performance.



Research Questions (Main Questions and sub question)

Main question

How can Transparent Building Component be advanced to become "Smart" and meet the demands of todays' architectural requirements?

Sub-questions

1. How building envelope concept has evolved over time? And, accordingly, what are today building (materials, etc.…) requirements?
2. What can be defined SMART in current architecture?
3. How architectural technologies have evolved accordingly and innovated building practices as well?

Research Objectives

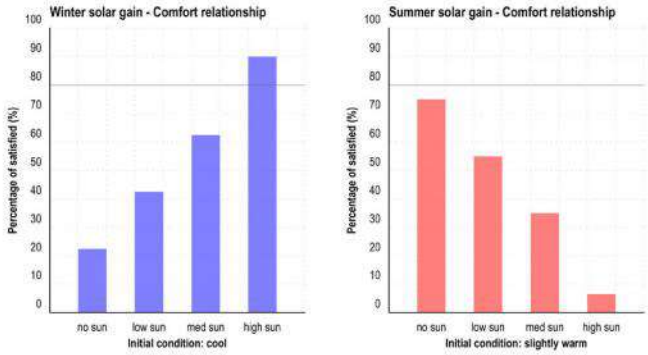
The main objective is to provide an insight in the applications and design of Smart Adaptive Building Envelope systems, focusing the attention on Transparent Building Components.

Other related objectives are:

1. to understand how innovative technologies have "shaped" architecture over years, becoming technological answers to current critical needs;
2. to provide a systematic characterization of Smart Buildings, recognizing which technologies provided building envelope with adaptive features, developing a mapping of adopted strategies and identifying common patterns to help further development of high-potential innovative smart, adaptive building components;
3. to provide a supporting database of different technological solutions and applications of adaptive smart buildings, as a first stage to evaluate current and future trends of adaptive facades;
4. to classify existing glazing technologies to reach for the development of a novel concept of Smart Window, able to overcome the shortcomings of existing technologies;
5. to define strategical addresses for building application of systems and glazed component with adaptive features, though the development of guidelines and recommendations.

Research Deliverables

1. New concept of SMART in architecture.
2. Database of Smart Adaptive Buildings.
3. Review of Advanced Glazing Technologies, through the development of a Matrix for the definition of compliant solutions.
4. Smart Window concept/prototype
5. Strategical addresses for building applications of systems and components with adaptive features.



▶ **Researcher:** Valentina Frighi
▶ **Supervisors:** Giovanni Zannoni, Fabio Conato, Arben Shtylla
▶ **Time span:** 2016 - 2019
▶ **Contact data:** frgvnt@unife.it

▶ **Associated Publications:** *just mentioned a few for space's reasons*

Frighi V. (2017), "Glass in building sector: does the ideal window exist? […]", in (Eds.) S. Brown, S. Larsen, K. Marrongelle, and M. Oehrtman, Proceedings of The 5th International Virtual Conference on Advanced Scientific Results (SCIECONF-2017), Vol.5, pp. 233-238 Zilina, Slovakia [eISSN 1339-9071] [cdISSN: 1339-3561] [ISBN: 978-80-554-1337-2]

Frighi V. e Conato F. (2017), Smart Architecture in Digital Revolution, in MD JOURNAL, vol. 4/2017, pp.170-179, Ferrara:Laboratorio Material Design, Media MD [online - ISSN 2531-9477] [print - ISBN 978-88-85885-00-4] (double blind-peer review).

Frighi V. e Conato F. (2018), Smart Materials. Innovazione tecnologica per un nuovo linguaggio architettonico, in L'UFFICIO TECNICO, vol. 1-2/2018, pp. 7-15, Sant'Arcangelo di Romagna (RN):Maggioli Editore [ISSN 0394-8293] (scientific commitee).

Main Title Research Title

▶ Valerie Vyvial, Royal Danish Academy of Fine arts, Institute of architetcure and technology

▶ Research information

Introduction, Background to the Research (Research Theme)

The aim of the research is to investigate the current developments in the use of a vegetated facade as a cladding material in extreme conditions as climate change poses a real risk to society and the built environment. As temperature continue to rise and as cities across Europe develop rapidly, the need for facades that cope against such heat is needed. Vegeated facades offer the process of evapotranspiration, where water evaporates from the vegetation reduces the adjacent air temperature.
The aim of this study is to look into exploring its application with regards to the geolocation of different vegetation and its efficiency and its possible execution in different cities across Europe with different profiles. I would like to extend the research into exploring façades that can work in application in Alaska, where I will be doing field work for 5 weeks in November.

Research problem

The main problem is the lack of specific local diversity and research into the most efficient use of vegetated facades in the Europe. The problem extends to Alaska where research into the biodiversity can be researched and applied to its location.

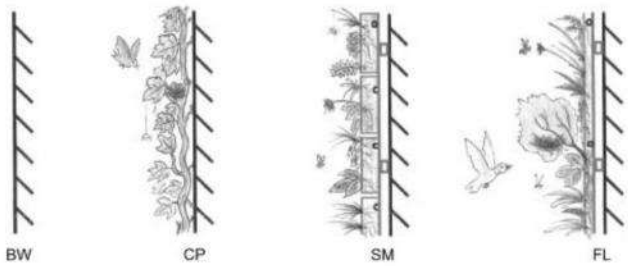
Research Questions (Main Questions and sub question)

Main question

" How can vegetated facades be optimised in the region of Europe to meet the acceleration of climate change in developed cities? Can this research be applied to Alaska where climatic conditions are colder?

Sub-questions

1. What are the limitations and barriers for manufacturing that prevent the development of such sort?
2. What are the downside of using such façade systems ?



Research Objectives

Vegetated facades has the possibility to transform cities into greener cities yet it has not been implemented to the scale as other countries do such as Singapore. This research looks into options to find design solutions and technical details which enable more flexible design that can be implemented in Europe as well as Alaska in where I will have the opportunity in November to potentially conduct first hand field work.

▶ **Researcher:** Valerie Vyvial
▶ **Supervisors:**
▶ **Time span:**
▶ **Contact data:** **vavy1765@edu.kadk.dk**
▶ **Associated Publications:**

Research Deliverables

1.Review of vegetated facades and its efficiency in reducing solar gain
2.A summary of different types and varieties of vegetation that is applicable and easily used depending on locality – Alaska and Europe

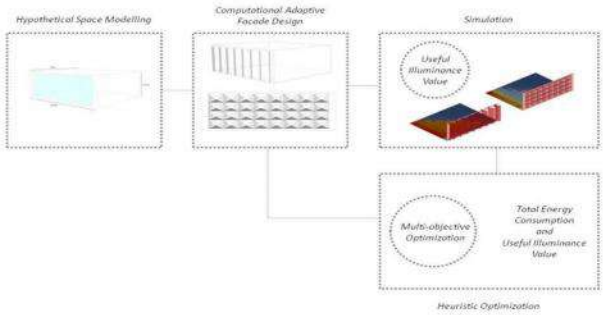
Multi-objective Optimization in Adaptive Facade Design

▶ Yesim Keskinel, Izmir Institute of Technology Faculty of Architecture, Architecture Department

▶ Research information

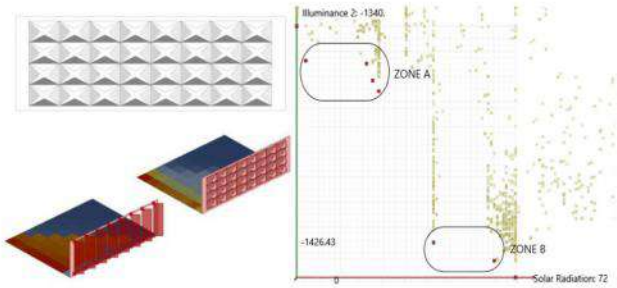
Introduction, Background to the Research (Research Theme)

The aim of this research is finding the best alternative adaptive façade design by comparing single oriented and double oriented façades to obtain low energy consumption and high illumination values in an office room. The process consists of three main title. These are designing two different oriented adaptive facade, simulate them in terms of their illuminance value of horizontal working plane and evaluate their building performance in multi objective way .



Research problem

The key point of the designing adaptive facade is creating balance between different performance aspects, such as solar radiation energy consumption and useful daylight illumination value in office room. To reach the minimum in energy consumption while reaching maximum in effective daylight usage is the challenge of this study.



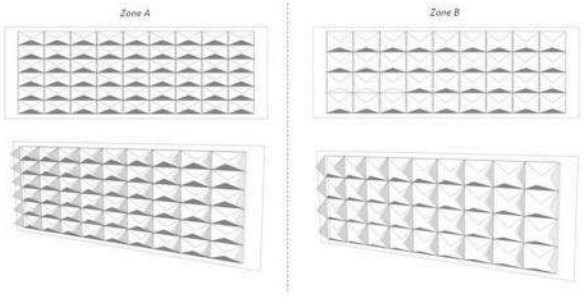
Research Questions (Main Questions and sub question)

Main question

-Why do we need multi objective optimization in adaptive facade design?
-What is the role of adaptive facades on building performance?

Sub-questions

-Which type of adaptive facade is more convenient to requests?
-Do double oriented facade use daylight more effective way?
-What are the significant differences between single and double oriented façades in terms of building performance.



Research Objectives

Different oriented façades have not been researched in a detail in current studies.On the other hand, multi opjective optimization in adaptive facade design has a significant role to evaluate their performance.
The reserach objectives would be as follows;

- Designing the parametric models of adaptive façades.
- Simulate their useful illuminance value.
- Evaluate them in terms of different performance aspects.
- Understanding the role of multi-objective optimization in adaptive facade design.

Research Deliverables

-Comparison of different oriented adaptive facade designs
-Evaluate multi-objective optimization in adaptive facade design

▶ **Researcher:** Yesim Keskinel
▶ **Supervisors:** Mustafa Emre İlal
▶ **Time span:** 2017-2019
▶ **Contact data:** yesimkeskinel@iyte.edu.tr
▶ **Associated Publications:**

WALLED: Smart Module for Lighting and Media-Building

▶ Yorgos Spanodimitriou, University of Campania 'Luigi Vanvitelli', Department of Architecture and Industrial Design

▶ Research information

Introduction, Background to the Research (Research Theme)

The research is aimed at developing an innovative smart module capable of combining the advantages of a double skin façade with those of a media façade. In order to reach this objective, the module will be a smart element capable of combining the possibility to improve the thermal performance of opaque and transparent building façades with the characteristics of dynamic lighting, in which different technologies (LED, OLED, sensors...) will be integrated. Many modules could be connected to each other in order to realize complex compositions. In the architecture field, these complex compositions can be used as an external "technological second skin" of a building.

Research problem

The main problem in the integration of the two façade systems is to guarantee the desired optical and thermal performance despite the integration of complex plant systems, as well as the possibility to integrate the module into existing double skin façade systems. To overcome this problems, accurate design and testing of the prototypes is required.

Research Questions (Main Questions and sub question)

Main question

- "How is possible to integrate into a single module the components to realize a double skin façade and a media façade?"

Sub-questions

- "Which are the performance parameters to follow in the design phase?"
- "Which kind of content can be displayed?"
- "What is the commercial potentiality for this technology?"

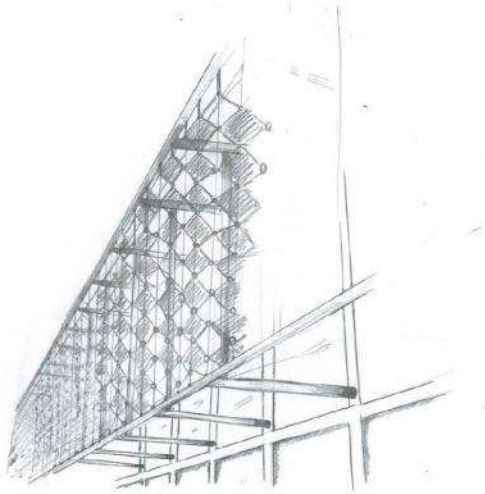
Research Objectives

To answer the questions and achieve a functioning product, the research will be lead through five main objectives:

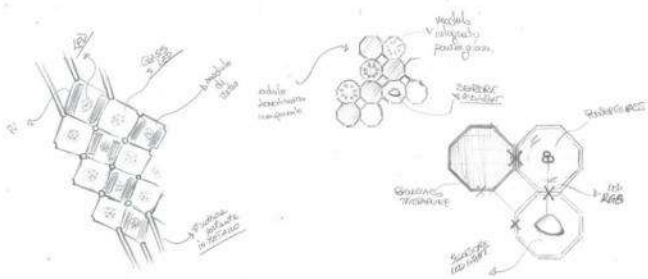
1. Define a state of the art of innovative materials and brief design;
2. Prototype a WALLED module;
3. Experimental characterization through laboratory measurements;
4. Calibration and validation of simulation models;
5. Development of full-scale demonstrators.

Research Deliverables

The research will deliver a functioning prototype of the WALLED module and a viable methodology to design, test and simulate this kind of technology, based on state of the art analysis, laboratory experiments and on-field surveys. The aim is also to realize a solid research method for other future projects in this field.



Sketch showing the development of a concept module on an entire façade.



Sketches for the module from the concept stage.

▶ **Researcher:** Yorgos Spanodimitriou
▶ **Supervisors:** Prof. Ing. Sergio Sibilio
▶ **Time span:** 2018-2021
▶ **Contact data:** **yorgos.spanodimitriou@unicampania.it**

▶ **Associated Publications:**

- *Sibilio et al., Adaptive and dynamic facade: a new challenge for the built environment, Le vie dei Mercanti 2018, Napoli, Italy*

Post-Occupancy and Performance Evaluation of Climate Adaptive Façades

▶ Zein Al-Doughmi, Welsh School of Architecture, Cardiff University

▶ Research information

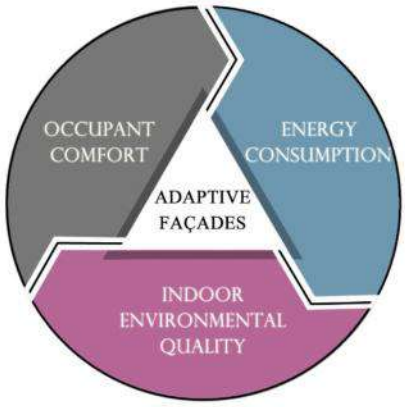
Introduction, Background to the Research (Research Theme)

The increase in energy prices as a result of the energy crisis and the emerging perspective of related environmental complications opened an eye to the importance of façades in the triangle of architecture, energy and comfort, paving the way for Climate Adaptive Building Envelopes (CABS). Façade adaptation holds many forms, variations and terms, many of those types fall under the characteristics of one another but this study will deal with dynamic façades specifically. The research will look into the efficiency of dynamic adaptive façades as a vital part of the building. Efficiency in this research will include three main cores: energy consumption, occupant comfort and satisfaction and Indoor Environmental Quality (IEQ). Studies have shown the influence of the three elements on each other and eventually on the building's efficiency. The efficiency assessment will be conducted through a Post-Occupancy evaluation method on a number of buildings with dynamic façades..

Q1, Thyssenkrupp Quarter, Essen, Germany

Research problem

Although there are many studies that analysed the theory of Climate Adaptive Façades (CAF), the research in the efficiency assessment of such façades is limited and constrained to the analysis of computer simulation models. A few number of papers looked into occupant satisfaction of CAF. The assessment was done through the use of questionnaires as a qualitative form of POE. Due to the façade's complexity and interactive nature with the surrounding environment and occupants, a lack of performance benchmarks were found in the field of adaptive façades. Also, little to no studies have investigated evaluation methods and protocols for such façades.



Research Questions (Main Questions and sub question)

Main question

"How do Dynamic Adaptive Façades influence buildings in regards to energy consumption, IEQ and occupant comfort and satisfaction?"

Sub-questions

- "How suitable are the current POE methods in evaluating Climate Adaptive Façades?"
- "How does IEQ, occupants and energy consumption effect one another?"
- "What effect do automated façades and controlled environment in workspaces have on occupants satisfaction?"
- "Are current IEQ factors enough to investigate the IEQ in adaptive spaces?"

Kolding Campus, South of Denmark University, Denmark

Research Objectives

- To evaluate the performance of Climate Adaptive Façades in regards to energy and occupant satisfaction
- To investigate the potentials of CAF as an energy efficiency solution in buildings
- To compare CAF potentials to static and conventional façades
- To assess the effect CAF has on occupants in workspaces
- To find the performance gap by comparing a performance simulation model to the data collected from the monitoring of the case studies
- To develop an initial evaluation method suitable for CAF
- To compare IEQ factors in conventional spaces with IEQ factors in spaces affected by CAF

Research Deliverables

- Initial POE method to evaluate CAF
- Occupant behaviour and satisfaction with adaptive façades
- A strategy to determine the conditions to use CAF instead of static facades

▶ **Researcher:** Zein Al-Doughmi
▶ **Supervisors:** Prof. Chris Tweed, Dr Simon Lannon
▶ **Time span:** 2018-2022
▶ **Contact data:** AL-DOUGHMIZO@CARDIFF.AC.UK

▶ **Associated Publications:**

AL-DOUGHMI, Z. (2016). Investigating the Potentials of Climate Adaptive Façades as a Solution for Energy Efficiency in Buildings: Practitioners' Perspective. Masters dissertation. University of Liverpool

3.0. WORKSHOP

3.1. Task

Workgroups have to design different variants of the improvement of existing facades by applying adaptive façade systems, and to assess the thermal and light comfort and reduction of energy consumption and CO2 emissions, but also compare the advantages and disadvantages of particular solutions.
It is important that the methodology of the workshop provides the possibility of identifying and comparing the specificity of design for different physical circumstances and technological limitations.
Under given design conditions, using up-to-date knowledge, for certain types of buildings in Belgrade, improvement of the envelope was created in order better functional, energy and environmental performances to be achieved.

Location: Belgrade, Serbia

Building types:

1. Office buildings
Building type: - high-rise building, stand-alone,
Facade type: - glass suspended façade (curtain wall).

2. Residential buildings
Building type: - high-rise stand-alone reinforced concrete prefabricated building,
Facade type: - prefabricated reinforced concrete panels.

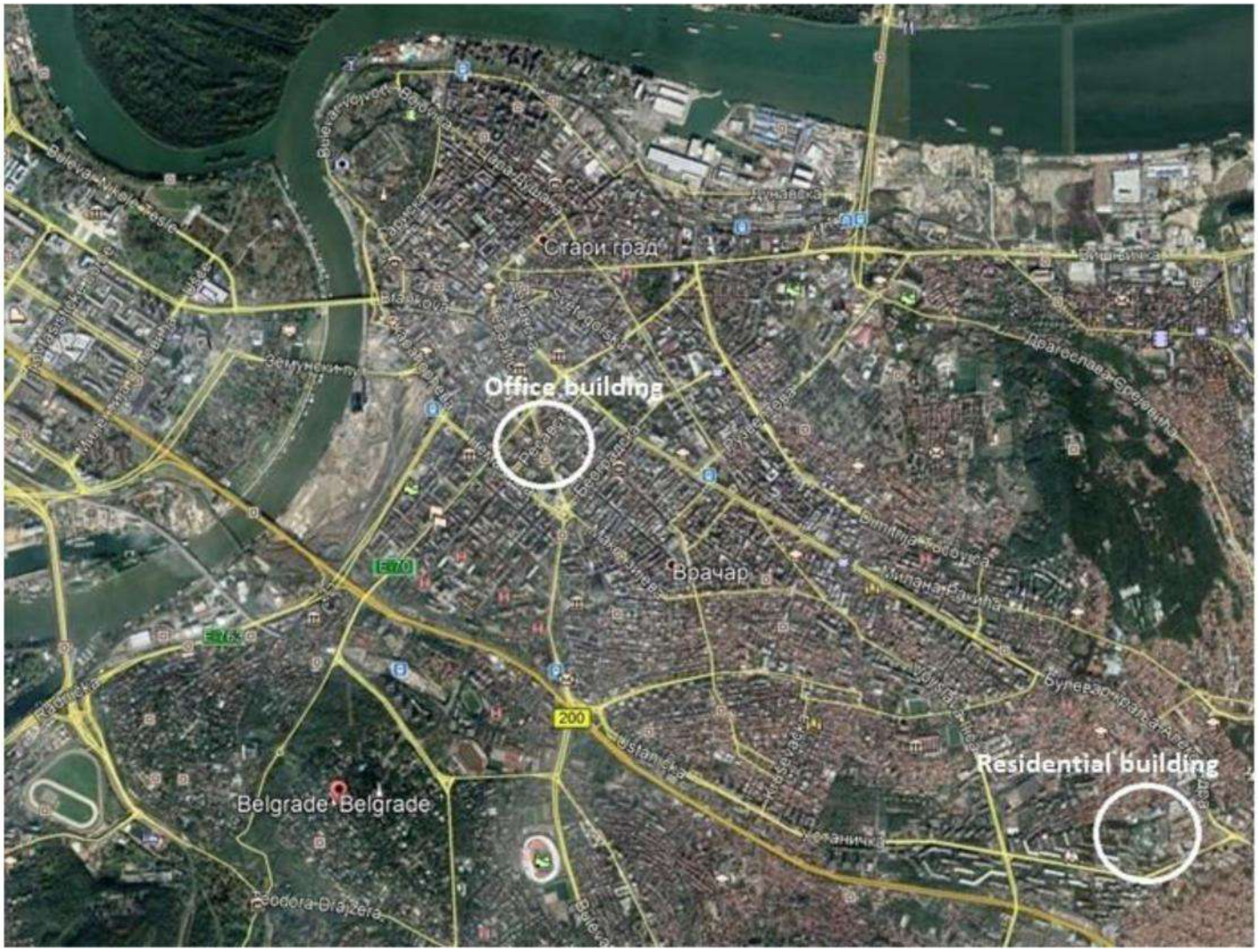
It is planned that 5 groups design improvement of the facade of an office buildings (Task 1), and that 2 groups create improvement of the façade of a residential building (task 2). Formation of groups was realized during the session - ESI Workshop and Teambuilding that was held on Monday afternoon. Groups were composed of trainees of different professional backgrounds.

Task 1 - to create a facade improvement for a typical office area at the height of one floor using the concept of an adaptive facade.

Task 2 - to create the improvement of the facade for the proposed floor of apartment building (at the height of one floor) using the concept of an adaptive facade.

Wednesday was dedicated to the design of the facade improvement / consideration the existing situation and definition and consideration of facade concept. Thursday and Friday were dedicated to modelling and numerical simulations to check the energy consumption for heating and cooling and the quality of lighting / Elaboration of facade concept by digital simulation and modellmaking. Improved models were compared with the existing situation and energy savings and reduction of CO2 emissions assessed.

Trnsys demo version is selected/preferred for calculating energy performances - a trnsys 18 demo version which can be download from the web at: http://www.trnsys.com/demo/ .
In order to build the geometrical model (via Trnsys3D plug-in) to be used by Trnsys, trainees had to install SketchUP Make 2017. This can be downloaded from https://www.sketchup.com/download/all



Belgrade google map with marked locations of buildings/case studies

Workshop

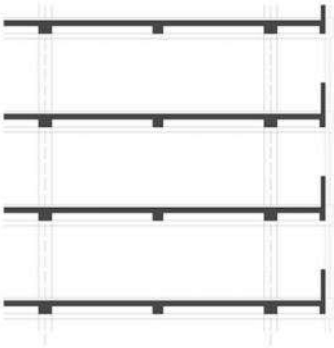
"Retrofitting Facades for Energy Performance Improvement"

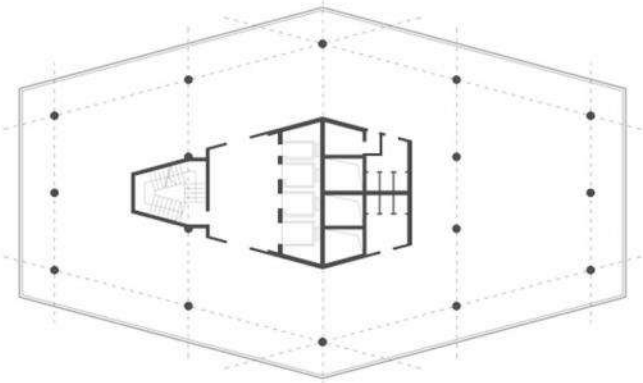
Task 1 - Case study I - Office building

"Beogradjanka", Masarikova 5

- Constructed 1969 - 1974.
- Height 101 m.
- Number of floors 23.
- Architect Branko Pešić

The task is to design a facade improvement for a typical office area at the height of one floor using the concept of an adaptive facade.





Digital version of the layout and the cross-section prepared by Nikola Macut

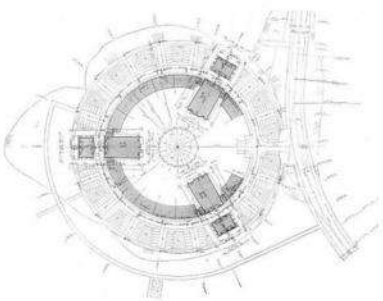
Task 2 - Case study 2 - Residential building

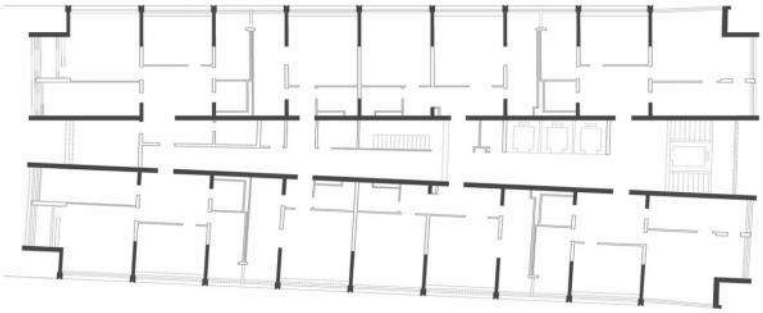
Konjarnik, East Gate of Belgrade, Rudo

- Constructed 1973 - 1976.
- Height 85 m.
- Number of floors 28.
- Architect Vera Ćirković

Task is to create the improvement of the facade for the proposed floor – sixth floor of apartment building (at the height of one floor) using the concept of an adaptive facade.

Situation





Digital version of the layout and the cross-section prepared by Nikola Macut

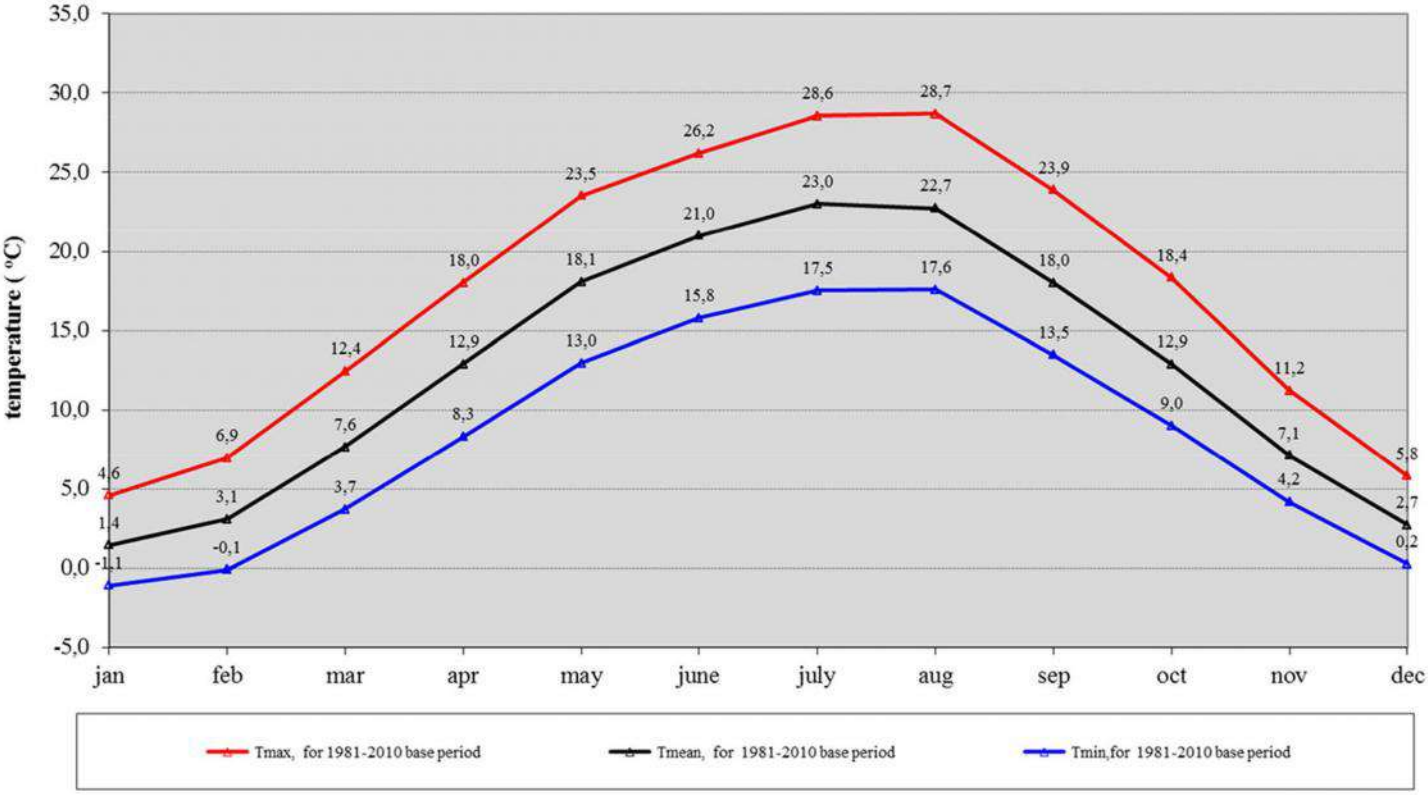
Climate characteristics of Belgrade

Belgrade is located in the northern hemisphere, at latitude 44°48'14.4"N and longitude 20°27'54.5"E. Belgrade has a moderate continental climate, with four seasons. Data on the Belgrade climate are taken from the Report prepared by Republic Hydrometeorological Service of Serbia and official web presentation of Belgrade city.

Air temperature

Autumn is with longer sunny and warm periods than spring. Winter is not so severe, with an average of 21 days with temperature below zero. January is the coldest month, with average temperature of 0.1°C. Spring is rainy. Summer arrives abruptly. The average annual air temperature is 11.7°C. The hottest month is July (22.1°C). The lowest temperature in Belgrade was recorded on January 10, 1893 (-26.2°C), and the highest on August 12, 1921 and on September 9, 1946 (41.8°C). From 1888 to 1995 only six days with temperature of over 40°C were recorded. The average annual number of days with temperature higher than 30°C - the so-called tropical days - is 31 and that of summer days with temperature higher than 25°C is 95.

Maximum, minimum and mean air temperature for the 1981-2010 base period for Belgrade



Republic Hydrometeorological Service of Serbia, Basic climate characteristics for the territory of Serbia, Available at: http://www.hidmet.gov.rs/

Insolation

The highest insolation of about 10 hours a day is in July and August, while December and January are the cloudiest, with insolation of 2 to 2.3 hours per day. Belgrade is the city with global irradiance of 1,341.8 kWh/m2 (according to program Polysun 4), and 2,123.25 sunny hours per year.

Wind

The characteristic of Belgrade climate is also Košava - the southeast wind, which brings clear and dry weather. It mostly blows in autumn and winter, in 2-3 days intervals. The average speed of Košava is 25-43 km/h but certain strokes can reach up to 130 km/h.

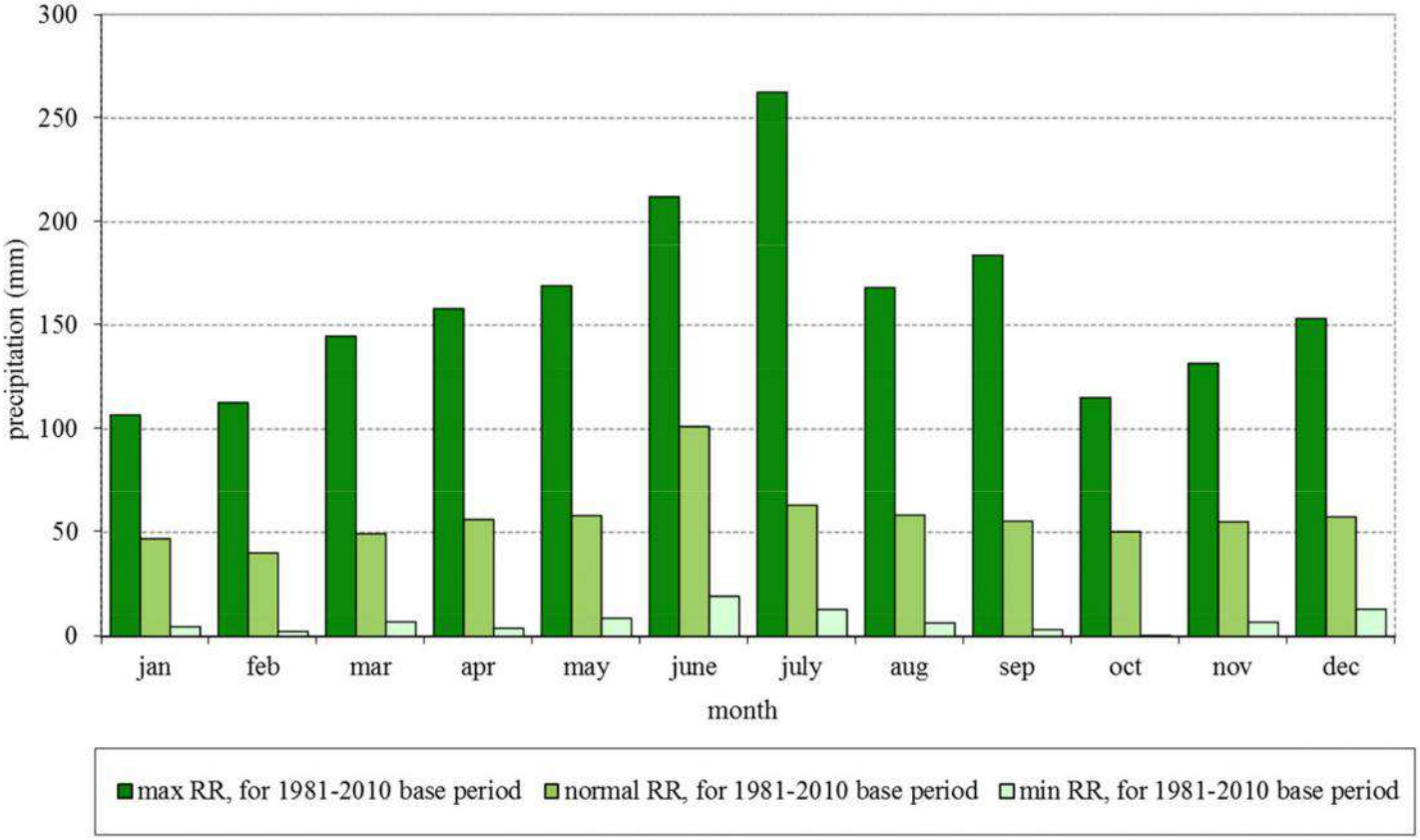
Atmospheric pressure and average relative humidity

Mean atmospheric pressure in Belgrade is 1,001 millibars and mean relative humidity is 69.5%.

Precipitation quantity

The average annual rainfall on Belgrade and its surroundings is 669,5 mm. The rainiest months are May and June. The average number of snowy days is 27, snow cover lasts from 30 to 44 days, and its average thickness is 14 to 25 cm.

Monthly mean, maximum and minimum precipitation sums for the 1981-2010 base period for Belgrade



Republic Hydrometeorological Service of Serbia, Basic climate characteristics for the territory of Serbia, Available at: http://www.hidmet.gov.rs/

3.2. Workgroups - Teams

Case study I – Office building		
Team 1	Ahmed Felimban Ali Aghazadeh Ardebili Martina Di Bugno Magdalena Patrus Nevena Lukić	Delft University of Technology, Netherlands University of Trieste, Italy University of Pisa, Italy University of Bath, United Kingdom University of Belgrade, Faculty of Architecture, Serbia
Team 2	Tiantian Du Marina Bagarić Zein Omar Arqoub Al-Doughmi Ceciilie Gry Jacobsen	Delft University of Technology, Netherlands University of Zagreb, Faculty of civil engineering, Croatia Cardiff University, United Kingdom The Royal Danish Academy of Fine Arts, School of Architecture (KADK), Denmark
Team 5	Aleksandra Ugrinović Dijana Savanović Mariana Velasco Carrasco Paolo Bonato Yeşim Keskinel	University of Belgrade, Faculty of Architecture, Serbia University of Belgrade, Faculty of Architecture, Serbia University of Nottingham, United Kingdom Energy Engineering, Politecnico di Milano, Italy Izmir Institute of Technology, Turkey
Team 6	Ana Kontić Milan Varga Valentina Frighi Michael Michalis	University of Belgrade, Faculty of Architecture, Serbia University of Belgrade, Faculty of Architecture, Serbia University of Ferrara, Department of Architecture, Italy University of Cambridge, United Kingdom
Team 7	Miroslav Vulić Neda Džombić Yorgos Spanodimitriou Mohataz Hossain	University of Belgrade, Faculty of Mechanical Engineering, Serbia University of Belgrade, Faculty of Architecture, Serbia University of Campania "Luigi Vanvitelli", Italy University of Nottingham, United Kingdom
Case study II – Residential building		
Team 3	Federico Bertagna Ariadna Carrobé Montalvo Juan Manuel Cruz Nikola Macut Mirjana Miletić	University of Pisa, Italy University of Lleida, Spain Norwegian University of Science and Technology (NTNU), Norway University of Belgrade, Faculty of Architecture, Serbia University of Belgrade, Faculty of Architecture, Serbia
Team 4	Jorge Luis Aguilar-Santana Anka Mirković Berk Ekici Milica Petrović Ashal Tyurkay	University of Nottingham, United Kingdom University of Belgrade, Faculty of Architecture, Serbia Delft University of Technology, Netherlands University of Belgrade, Faculty of Architecture, Serbia University of Antwerp, Belgium

3.3. Case studies

This section presents the posters of the participants of the Training School as the results of the workshop, which show the participants' understanding of the application of adaptive facade concepts in retrofitting facades for energy performance improvement.

For the Case study I - Office Building "Beogradjanka", facade improvement solutions are presented on the posters of five teams, followed by the proposals of two teams for Case study II - Residential Building "Rudo", East Gate of Belgrade.

Case Study: Office building

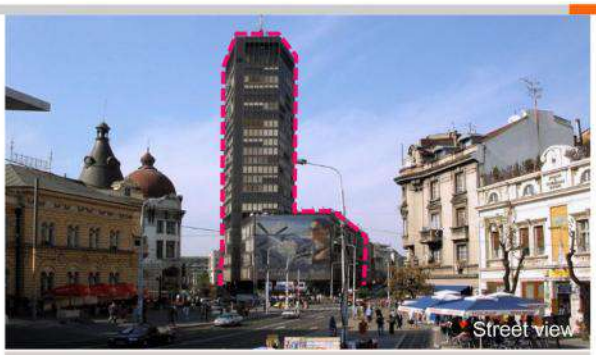
ADAPTIVE FACADES 2018
BELGRADE

▶ Ahmed Felimban, Ali Aghazadeh Ardebili, Martina Di Bugno, Magdalena Patrus, Nevena Lukic

PROJECT DEVELOPMENT PROCESS

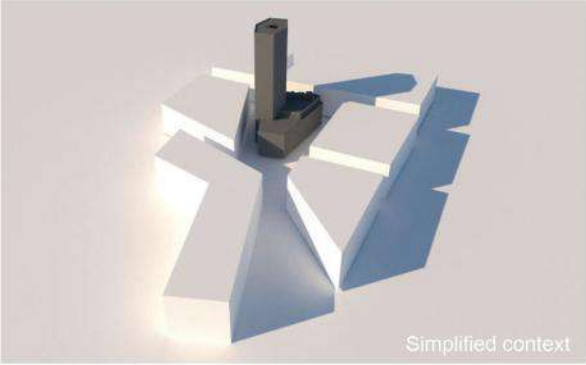
Location

- High-rise commercial unit located in central Belgrade
- Semi-dense urban environment
- The talles building in the city



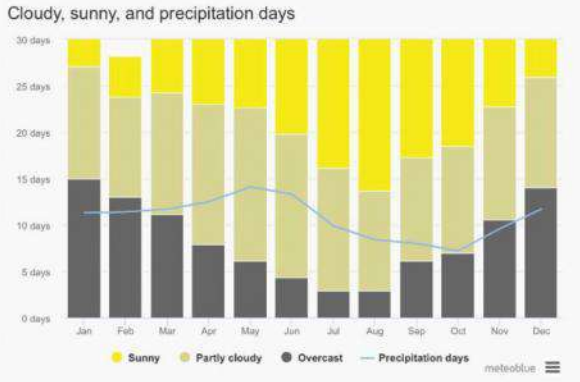
Limitations and decisions

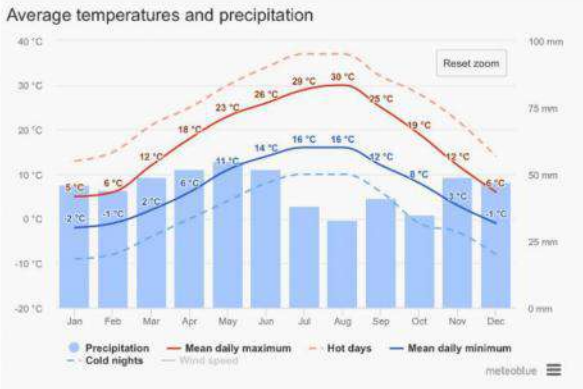
- Maintain the form
- Sustain the uniformity
- Maintain the materiality (dark colours to follow the initial architectural concept of *a black building in the 'White City'*)
- Maintain the prominence of the building on the city's skyline
- Sustain and highlight the hisorical value fo the building
- Holistic approach to accommodate and address the existing conditions

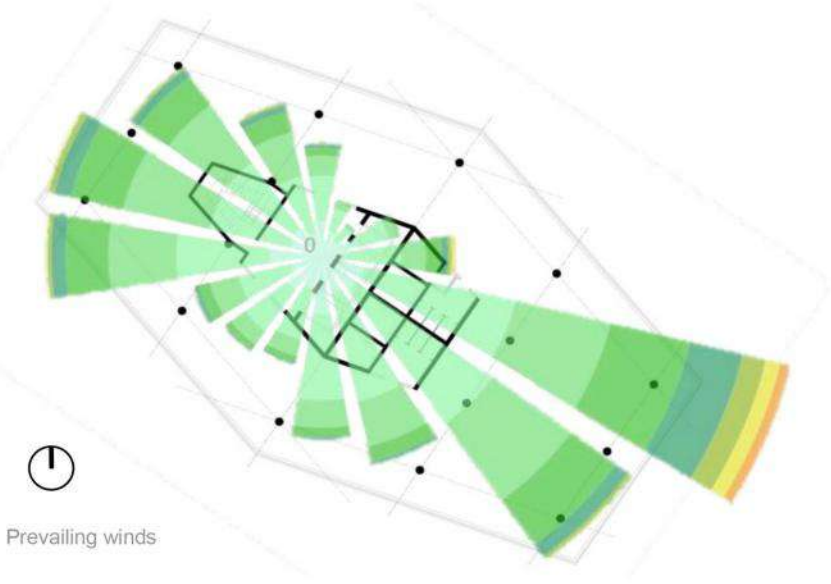


Façade concept

- Address the prevailing winds → E-W axis orientation optimal for natural ventilation
- Maximize solar gains in the winter
- Control glare
- Solar control on southern-oriented facades
- Heat loss prevention
- Improved insulation inside the cladding panels







Option 1: improving the fabric of the existing facade

- Maintained form & structure of the building
- Cost-effective solution
- Minimized costruction waste
- Less controvertial solution
- Minimal potential for operational issues

Improved energy efficiency

Option 2: new facade fabric with kinetic shading

- Innovative & trendy solution
- More cost-imposed
- Construction waste generation
- Potential for better solar control in summer
- Operational & installation issues
- Uncertainty of the performance

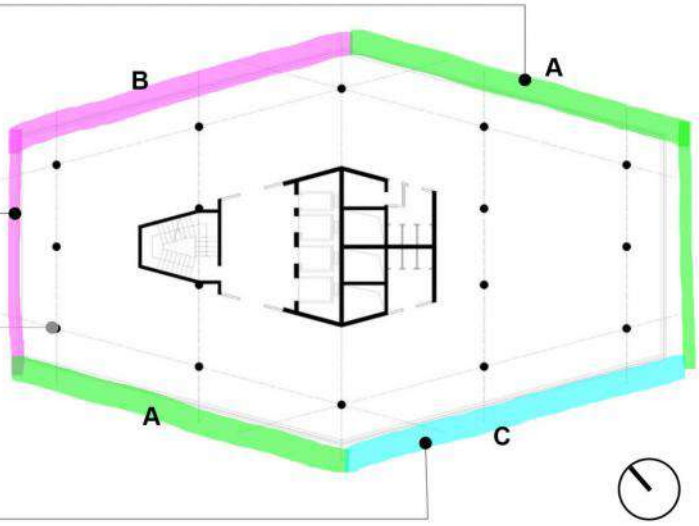
Façade adaptability

Double skin facade with low iron glazing to maximize transparency and boost natural ventilation

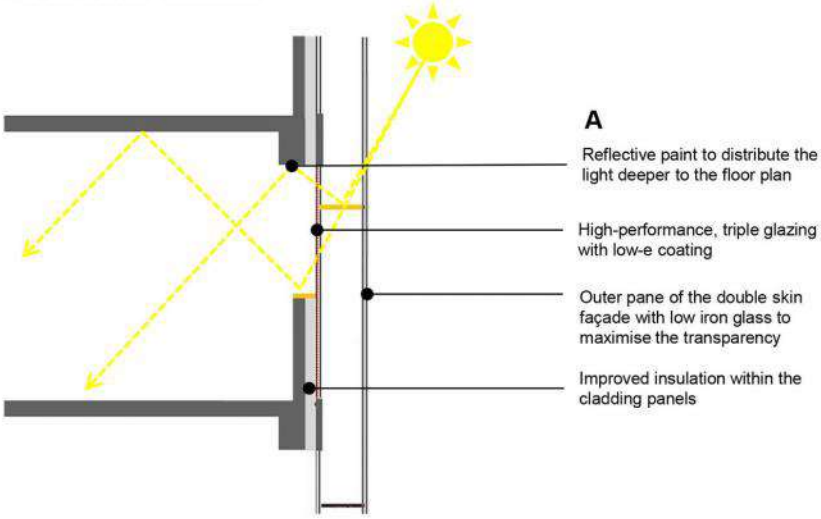
Triple glazing with low-e coating on #5 to minimize heat loss

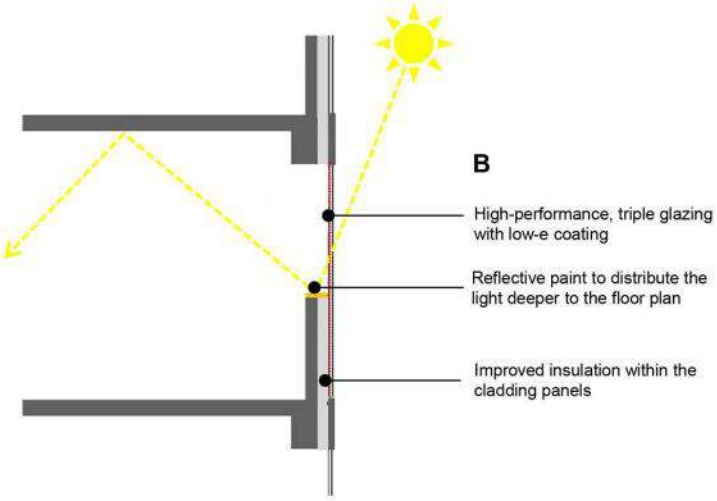
Exposed concrete columns to store heat

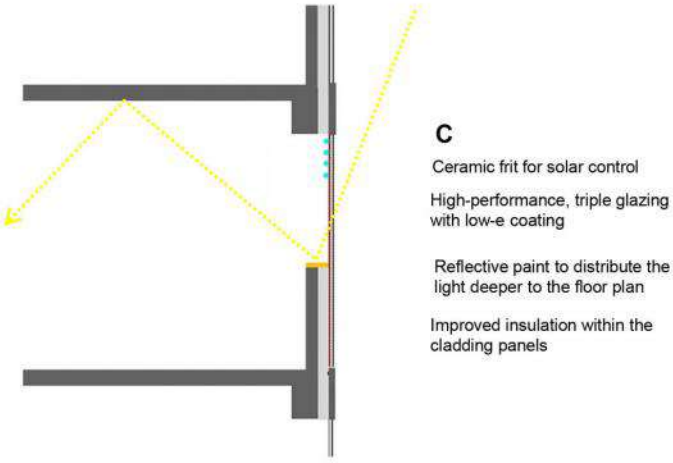
Triple glazing with low-e coating on #5 and ceramic frit for solar control



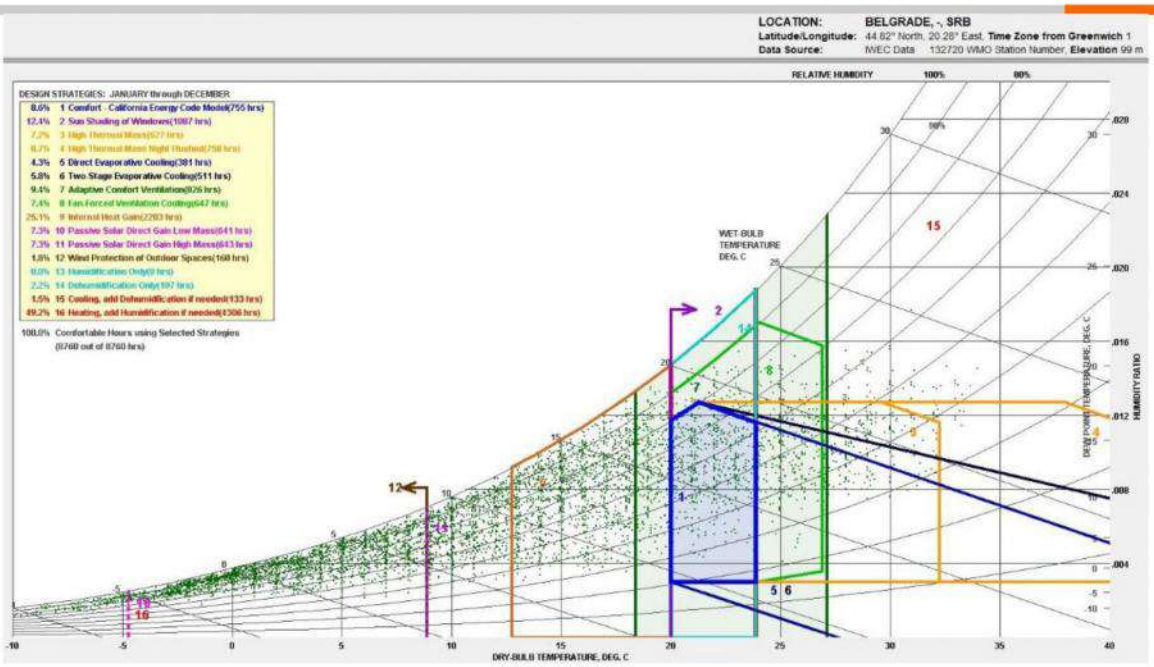
Technical details



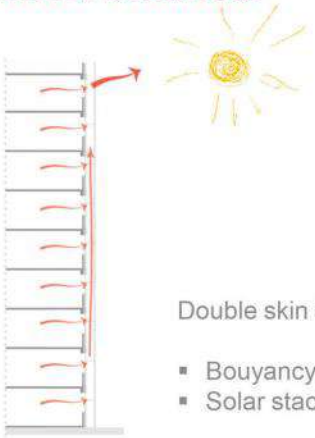




- Psychometric analysis to investigater optimal indoor environmental conditions:



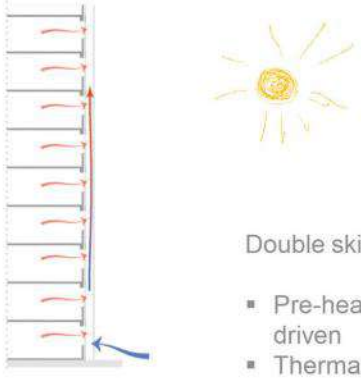
Summer behaviour



Double skin facade:

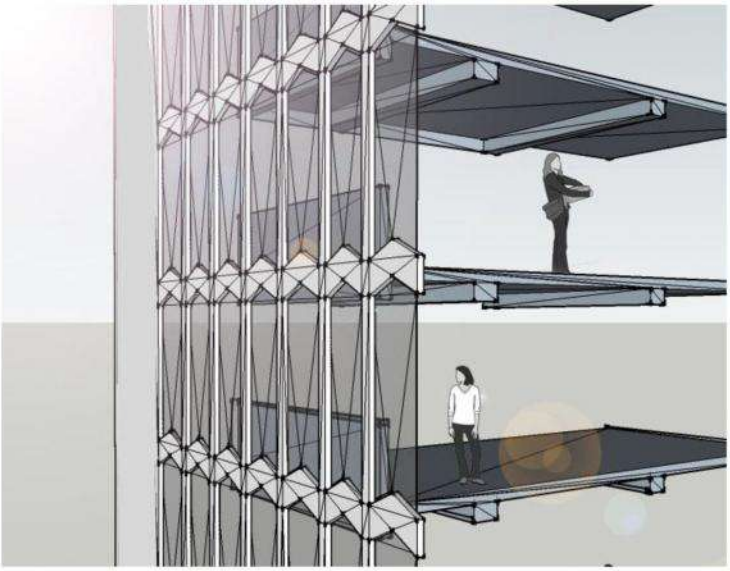
- Bouyancy driven cooling
- Solar stack extract

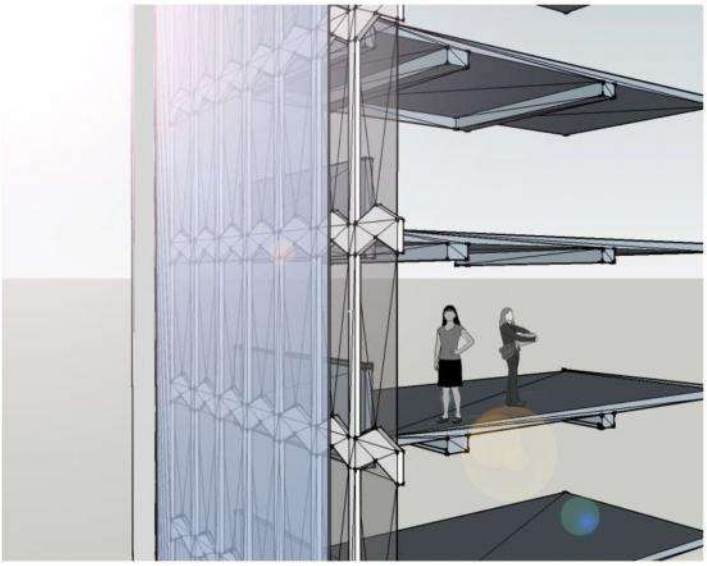
Winter behaviour



Double skin facade:

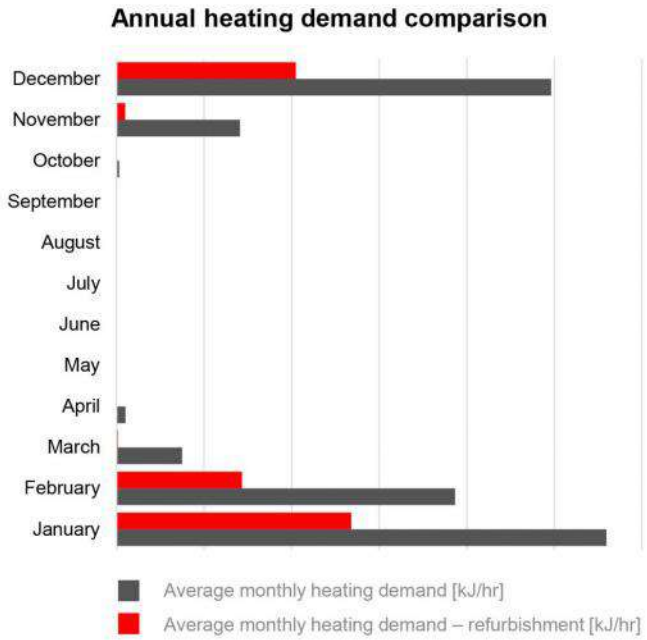
- Pre-heated ventilation, bouyancy driven
- Thermal buffer

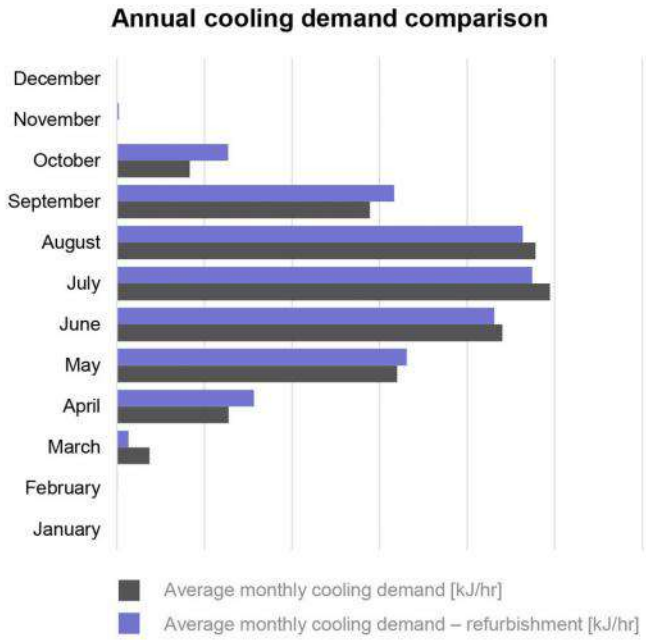




Simulations and results

The simple simulation was based on the office space conditions, including standard loads and 100% occupancy scheduled between 8am and 6pm between Monday to Friday and 0% occupany during the weekends.



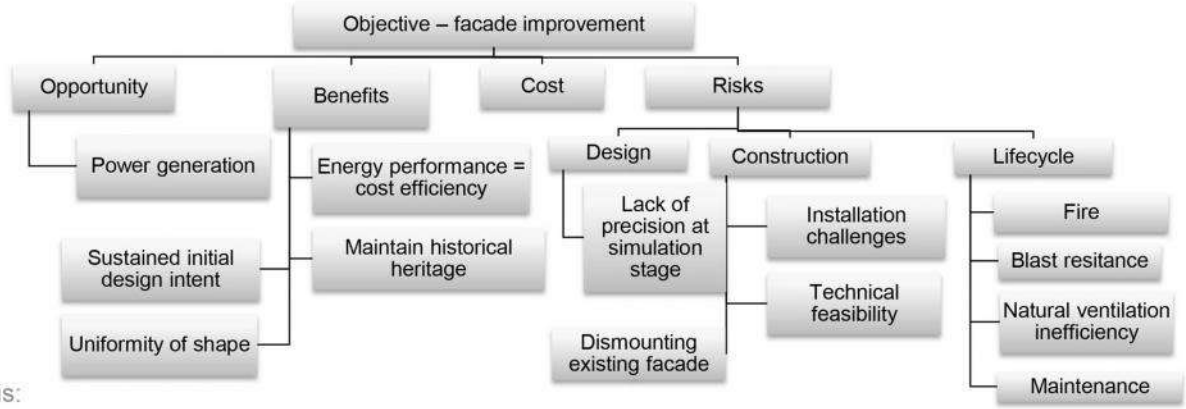


Basic fabric improvement of the existing facade (excluding the proposed double skin facade) results in:

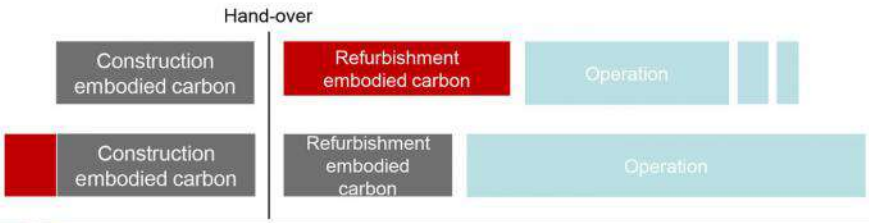
- Heating dempand improved by 67%
- Cooling demand lowered by 2%

Additional computational fluid dynamics simulations are necceessary to asses the performance of the proposed double skin facade on the south-west and north-east faces. Nevrtherless, it is assumed that cooling loads shall be offset by up to 70% due to the natural ventilation.

Conclusion



- Whole life carbon analysis:



Case Study: Beogradjanka

ADAPTIVE FACADES 2018
BELGRADE

▶ **Authors: Taintain Du, Marina Bagaric, Zein Al-Doughmi, Cecilie Gry Jacoben**

RETROFITTING THE FAÇADE OF BEOGRADJANKA

Location

The Beogradjanka is a commercial office building located on the corner of Kralja Milana and Masarikova and was the first skyscraper in the city centre of Belgrade.
The Beogradjanka was constructed between 1969 – 1974, and the building is still the highest building in Belgrade and a symbol of the city by being a black building in the "white" city. It is composed of a RC load-bearing structure with curtain walls (aluminium frame and double-glazed insulating glass units).

Climate and current situation:

The climate in Belgrade is quite diverse and goes from being really hot in summers to cold in winter. Belgrade is within the Cfa climatic zone, which means it is a warm and humid most of the year. Generally the temperature is increasing because of climate change, so in the future the need of cooling will be our primary focus. Identified „problems" are:

- **High heating loads** in winter period;
- **High cooling loads** in summer period (solar gains) and during whole year (internal gains from office equipment and activities);
- **High lighting loads**;

Design target:

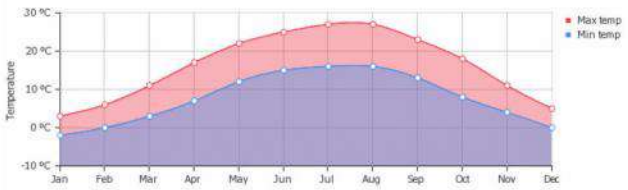
- **Reduce** heating needs;
- **Reduce** cooling needs;
- **Ensure** acceptable level of occupants' comfort;
- Adaptive with existing facades;
- Added arhitectural value

Solutions:

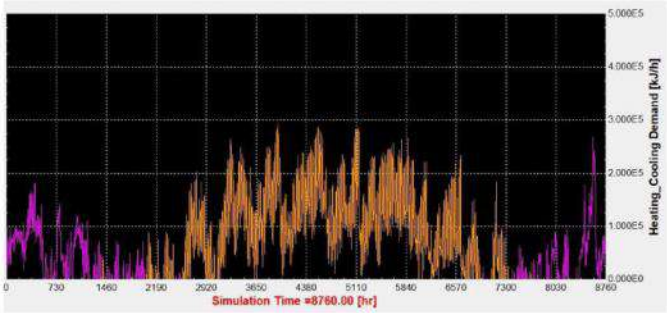
- **Natural ventilation;**
- **Double facades with integrated PVs;**
- **Phase Change Materials (PCM)**

Reference: Waagner-Biro, Manchester, UK

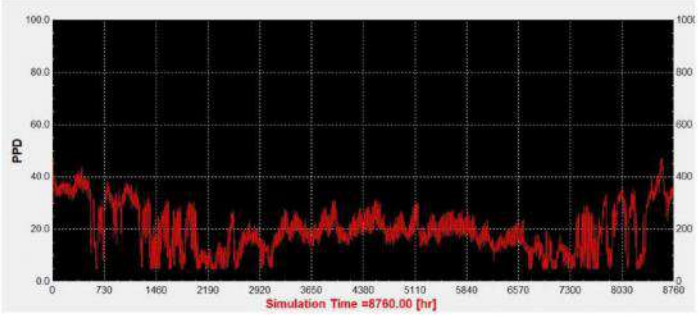
Beogradjanka office building



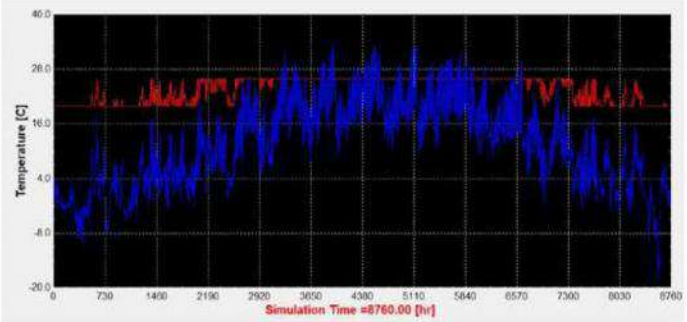
Average min and max temperatures in Belgrade, Serbia (www.weather-and-climate.com)



Existing condition of Beogradjanka: Annual Heating and Cooling demand for one characteristic storey



Existing condition of Beogradjanka: Annual PPD for one characteristic storey



Existing condition of Beogradjanka: Annual Outdoor (blue) and Indoor (red) temperature for one characteristic storey

Case Study: Beogradjanka

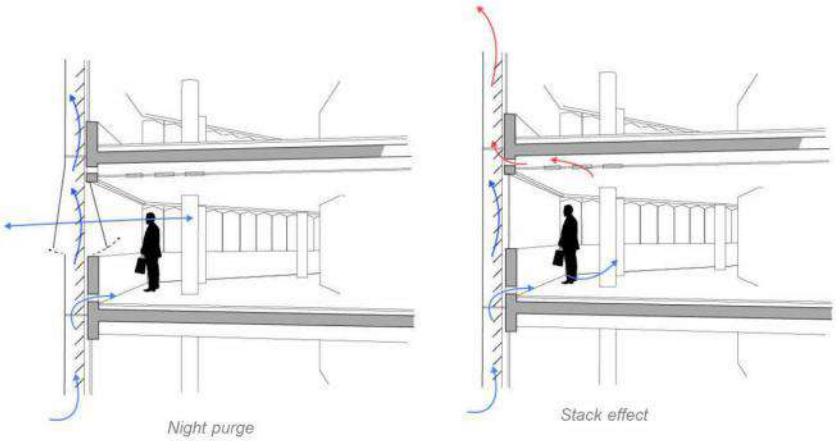
ADAPTIVE FACADES 2018
BELGRADE

▶ **Authors: Taintain Du, Marina Bagaric, Zein Al-Doughmi, Cecilie Gry Jacoben**

Façade concept

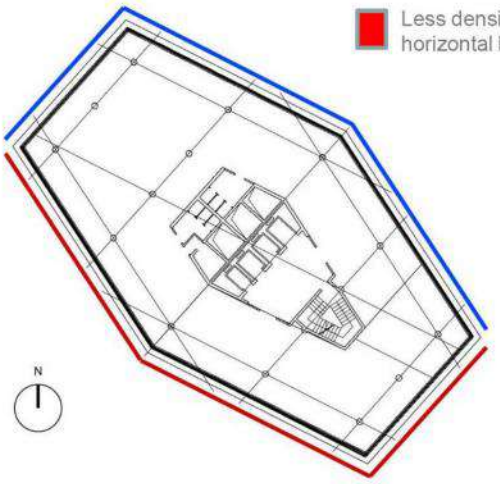
By trying to cool the building in summer and heat in winter, a combination of different strategies were used:

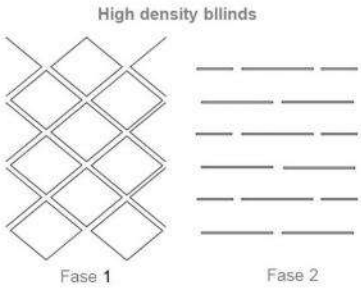
- **Stack effect** in double skin facade
- **Night purge**
- **Adaptive shading**
- **PCM** materials placed in suspended ceiling

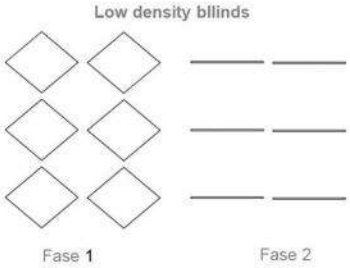


Shading

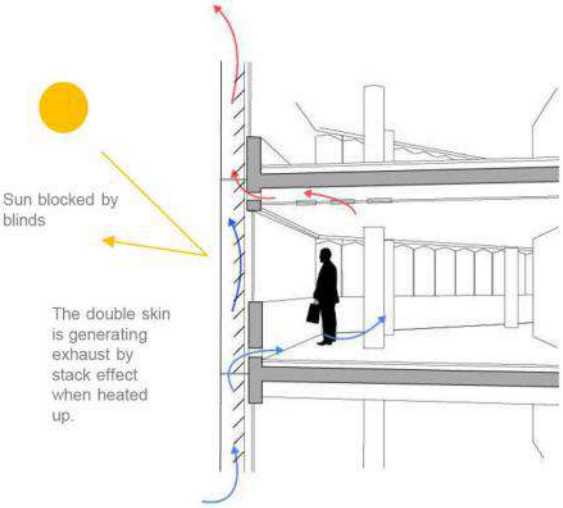
Density of movable blinds



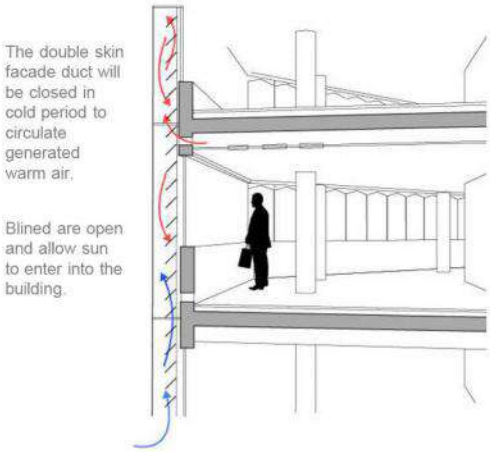




Summer behavior



Winter behavior

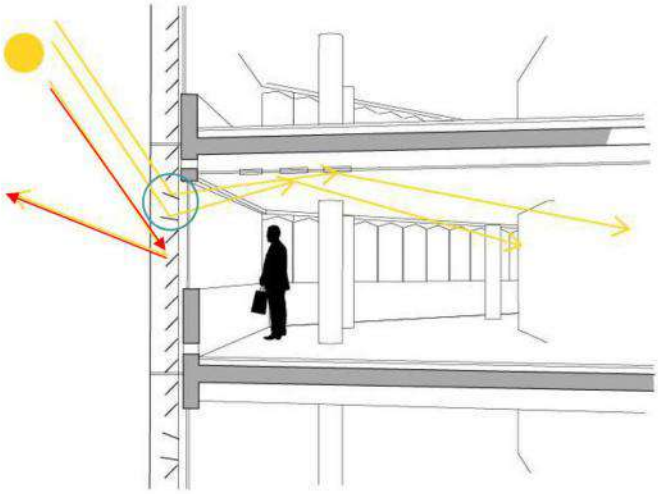


Case Study: Beogradjanka

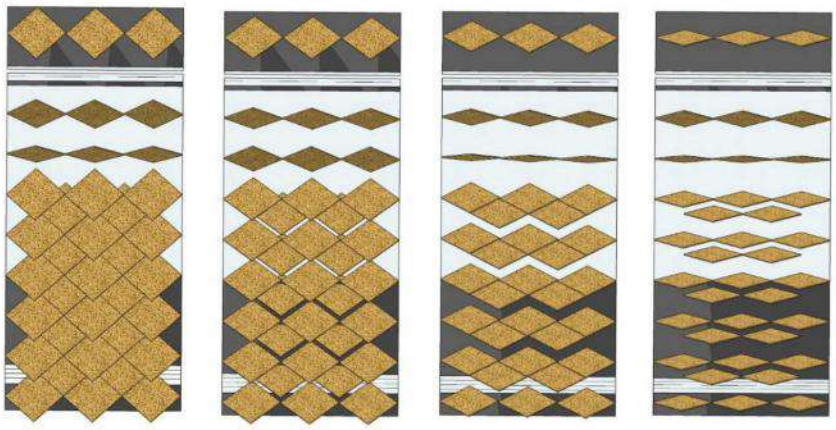
▶ **Authors: Taintain Du, Marina Bagaric, Zein Al-Doughmi, Cecilie Gry Jacoben**

Façade adaptivity

As one of the features of adaptivity, blinds within the double facade cavity is placed to give the user a possibility to block out the sun. The blinds also functions as a mean to reflect the daylight into the room



The reflection of light into the room

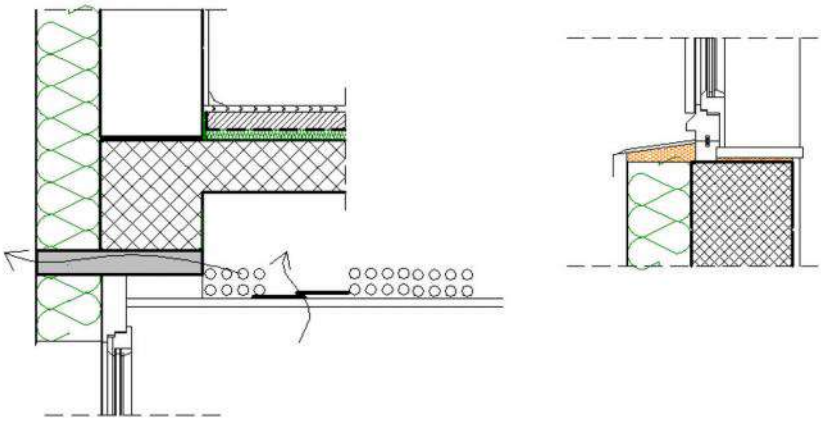


The different positions of the horizontal blinds

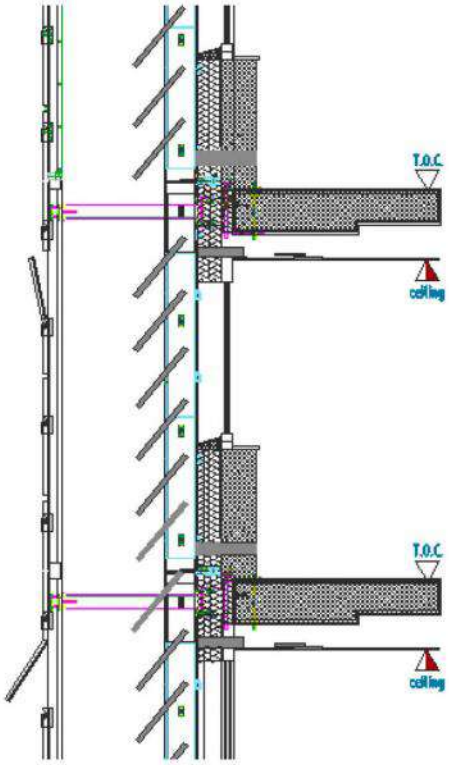
Material references: PVDF aluminium

Technical details

- **Thickness of air cavity: 40cm - 50cm** (*Reference: „Double skin façades – cavity and exterior openings dimensions for saving energy on Mediterranean climate"*)



Details of window-wall connection (minimization of thermal bridges) and PCM material location in suspended ceiling for passive maintenance of indoor air temperature

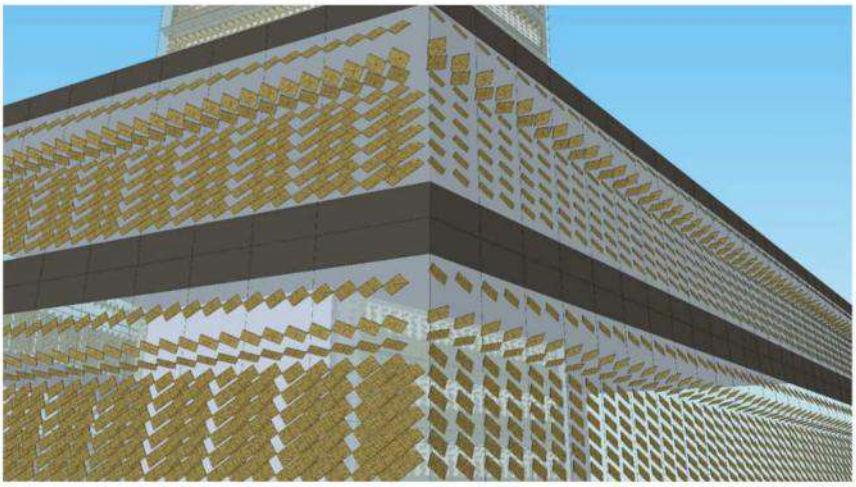


Detail of double-facade supporting structure

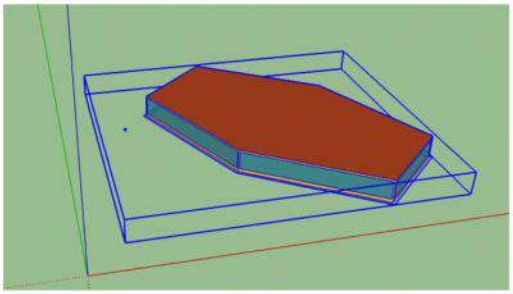
Case Study: Beogradjanka

▶ Authors: Taintain Du, Marina Bagaric, Zein Al-Doughmi, Cecilie Gry Jacoben

Model sketch



Dynamic simulation approaches (Trnsys tool):

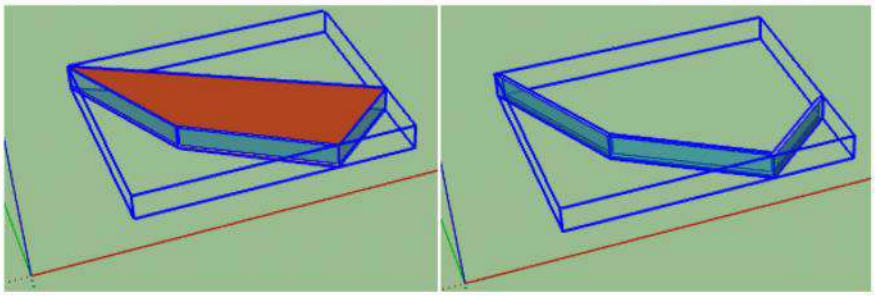


APPROACH 1 (one thermal zone)

- Whole characteristic storey = one thermal zone
- Varying heat convection coefficients (high in summer; low in winter) of facade's outer surface simulates double facade
- Results: Decreased heating demand; Unrealistic cooling demand

APPROACH 2 (two thermal zones)

- „Slice" of characteristic storey = first thermal zone; Double facade = second thermal zone
- Varying ventilation rate of second thermal zone simulates air flow in double facade
- Results: Significantly decreased cooling demand; Unrealistic heating demand



Comments on simulation:

Dynamic simulation of double façade performance is a complex process requiring high-user skills and experience as well as combining different tools to include all characteristic performance aspects of double façades (passive cooling and passive heating due to stack effect, shading, etc.). Nevertheless, both approaches indicated that double facade is capable of decreasing heating and cooling demands of Beogradjanka building.

Conclusion

Retrofitting a façade to an old building like Beogradjanka with double facade approach would be a possible solution to increase energy performance and occupants' comfort. To use adaptive façade solutions are hard to predict because simulation tools like TRNSYS have a hard time simulation the parameters of the façade system.
To predict performance in general, of kinetic adaptive facades, is a hard task for most simulation tools and therefore you can ask if kinetic facades are the right solutions. If you look at kinetic design at an architectural point of view, technology like that would generate some kind of interest of the viewer, and a façade like this would contribute to keep Beograndjanka as a landmark for Beograd.

Case Study : Refurbishment of "Beogradjanka"

ADAPTIVE FACADES 2018 BELGRADE

▶ Aleksandra Ugrinović, Dijana Savanović, Mariana Velascoc, Paolo Bonato, Yeşim Keskinel

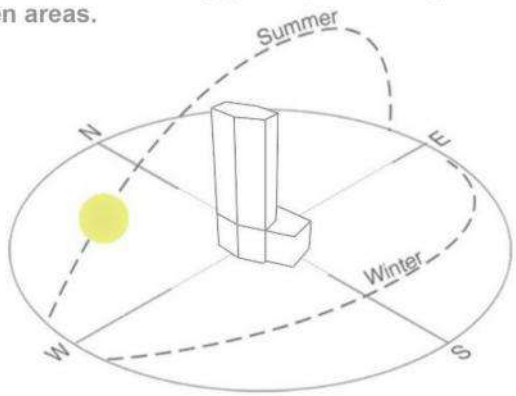
INTRODUCTION AND BACKGROUND TO THE RESEARCH

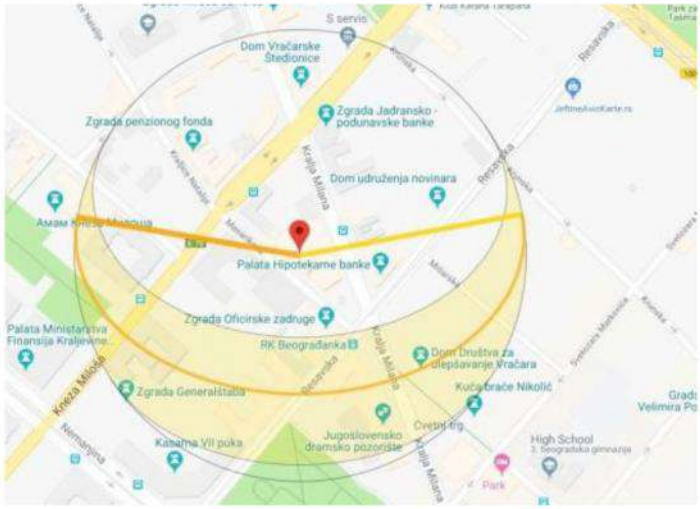
General Information

○Beogradanka or Belgrade palace is a **modern-high rise building** in Belgrade.
○The building was opened in 1974 and has about 40 000 m^2 total floor area.
○It is a commercial building.
○The first floors are occupied by a shopping mall and a retail store.
○In 1990, a restaurant was opened at the top floor.
○The building is;one of **the symbols of the city** with his **dark color** and **hexagonal shape**.
○ It is 101 m tall so represents the **dominant in space.**

Location

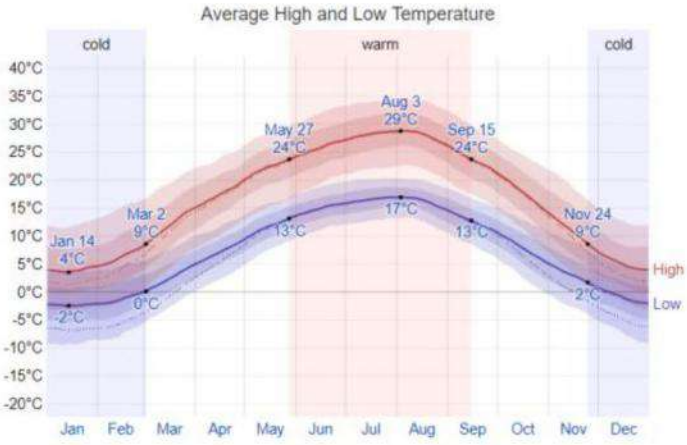
The building is located on the **crossroads of central city street.**
It is possible to find :**meeting points, cultural spaces and green areas.**





Climate

○The **summers are warm** and the **winters are very cold**.
○The average monthly air temperature is -2° C in winter
○During summer, the average temperature is 29° C.



Construction and Structure

○Facade surfaces are combination of anodized aluminum profiles of **solid panels and glass.**
○The bearing structure of the building has **concrete core** and a **column skeleton.**
○The total area of the façade is 11500 m^2 and the Window-To-Wall ratio is about 60%.
○The existing **shading system is internal.**

Case Study : Refurbishment of "Beogradjanka"

ADAPTIVE FACADES 2018
BELGRADE

▶ Aleksandra Ugrinovic, Dijana Svanovic, Mariana Velascoc, Paolo Bonato, Yeşim Keskinel

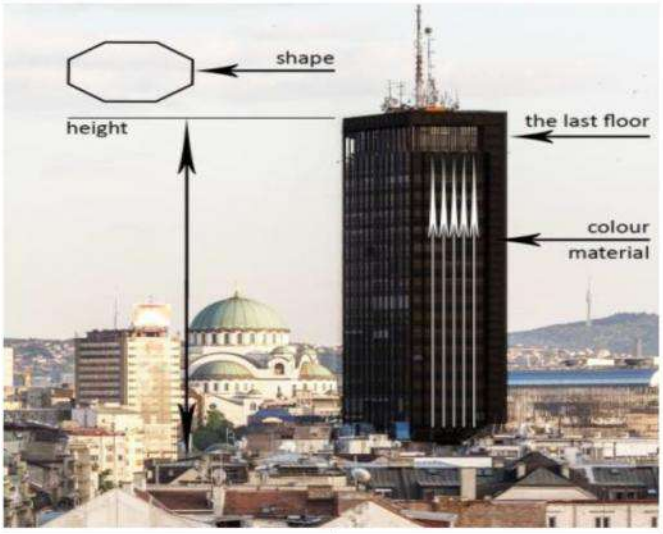
Façade concept

After analysing the advantages and disadvantages, replacing the facade was selected as the most suitable option.

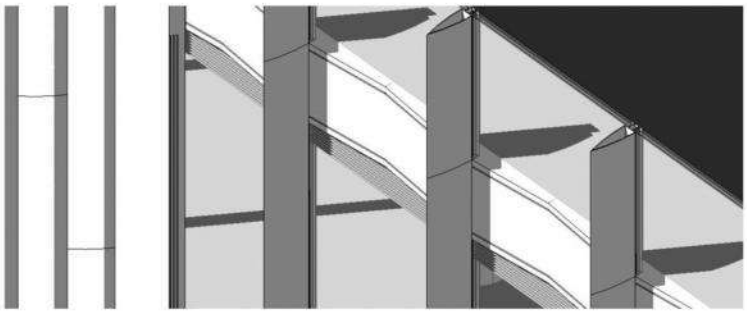
- Preserving the height of the building
- Highlight buildings' **height** by applying **vertical elements**
- Emphasise the **buildings' colour** : conserve the black unlike the "White City"
- Preserve the **shape of the building**
- Use façade materials that will indicate the **purpose of the building** (commercial)

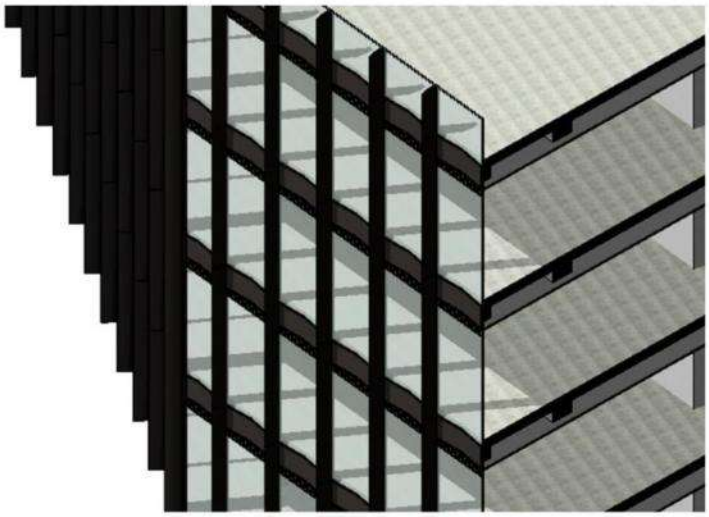
Technical details

- In replacing the façade, the following issues were emphasised;
- Installation of **suitable colored triple safety glazing** with interstitial shading device for reduction of heating load in winter and protection from glare.
- To improve thermal break, the **insulation materials** are improve with **aeregel** for reduction of heating load in winter.
- Replacement of the existing technology when needed (internal shading devices, internal seals of the glazings, cleaning of the weep holes and drainage system)



KEEP		REPLACE	
PROS	CONS	PROS	CONS
Identity	Limited range of retrofitting options	New identity and values	Disposal of old façade modules
Shorter time of construction	Structural uncertainty (double skin?)	Wider range of retrofitting options	Additional storage space and effort
(Cheaper)	Uncertains status of façade module (permeability, airtightness..)	Easier application of new materials and technologies	Longer inaccessibility of the building
	Some components already need replacement	Possibility to differenciate façade module typologies	(More expensive?)



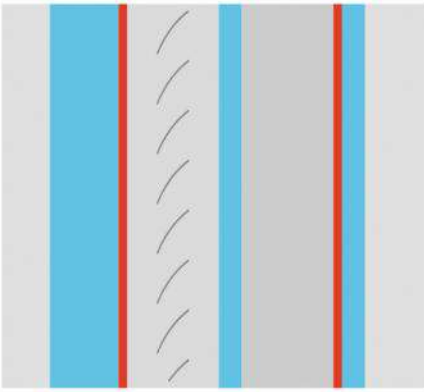


Case Study : Refurbishment of "Beogradjanka"

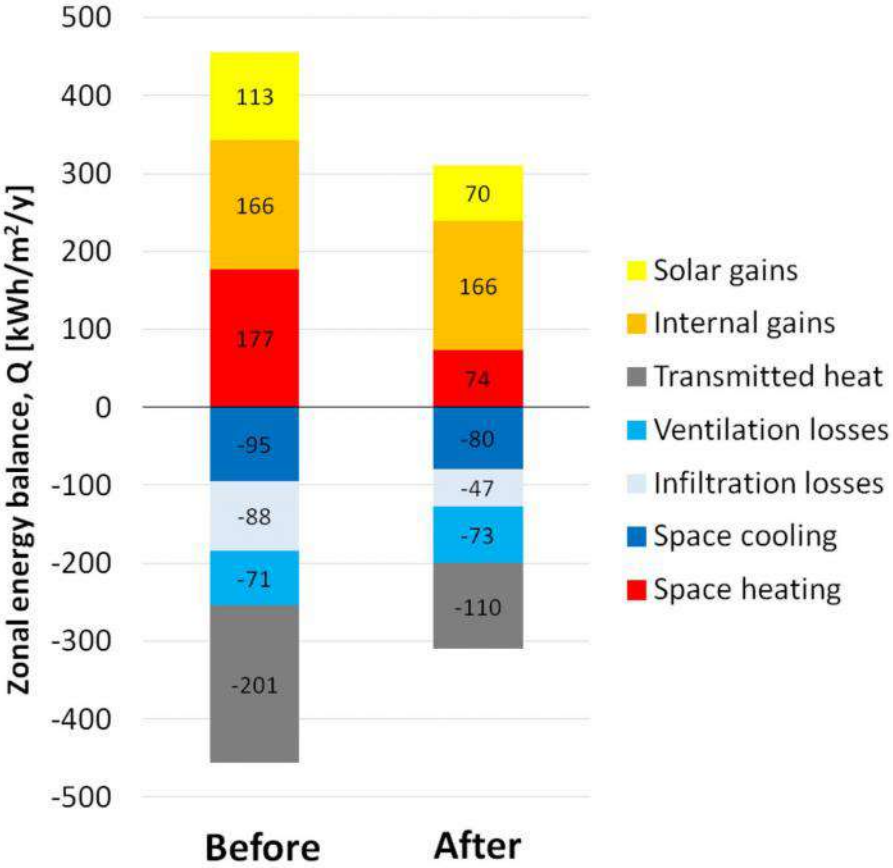
Aleksandra Ugrinovic, Dijana Svanovic, Mariana Velascoc, Paolo Bonato, Yeşim Keskinel

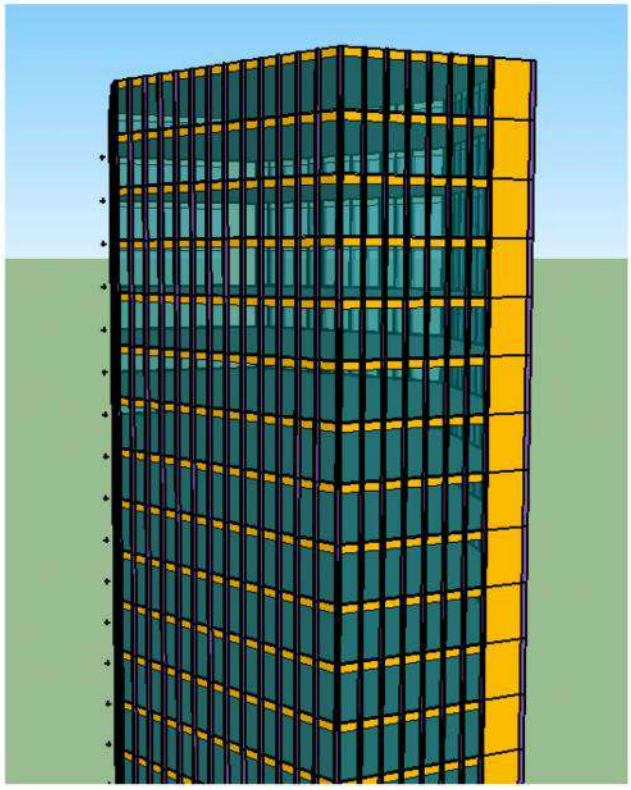
TRYNSIS Simulations Results

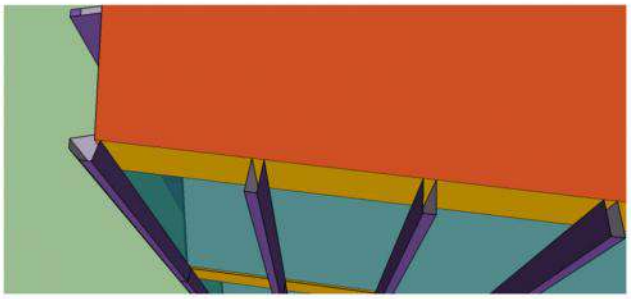
The replacement of the façade allows to reduce the space heating demand of 58% and the space cooling demand of 16% and to achieve energy-purchase savings in the order of 14 €/m2/y, i.e. about 9000 €/y for one floor.

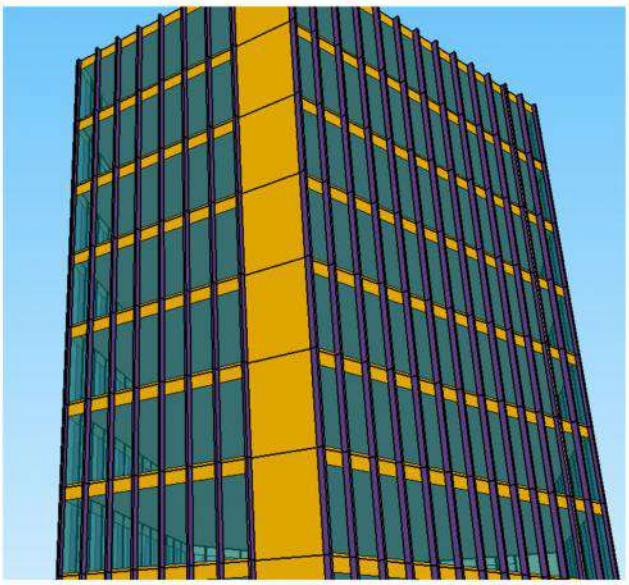


Saint Gobain + Pellini ScreenLine SL16 S157 + Selective dark coating.
Venetian system and glass chosen with a **brownish colour** to keep the old appareance.



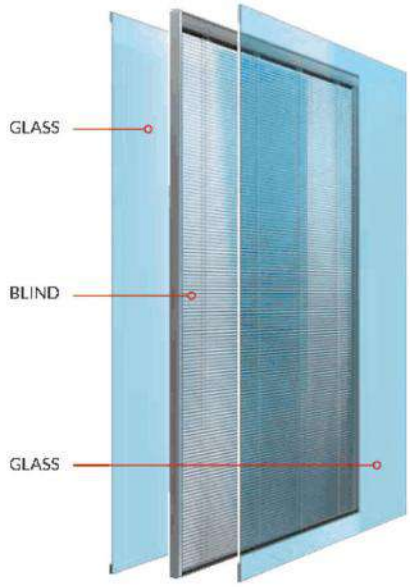


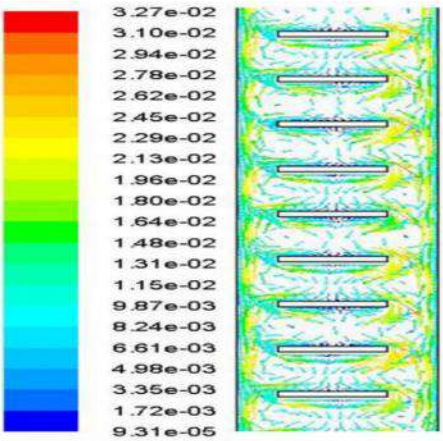




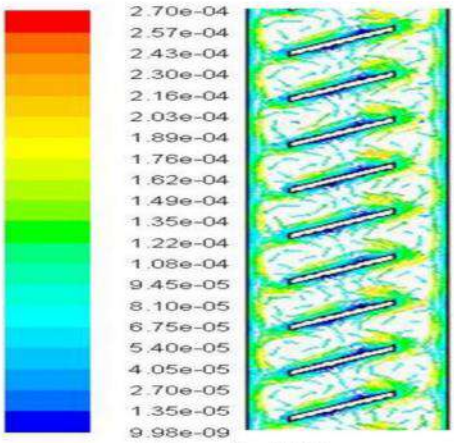
Aleksandra Ugrinovic, Dijana Svanovic, Mariana Velascoc, Paolo Bonato, Yeşim Keskinel

CFD Simulation Results

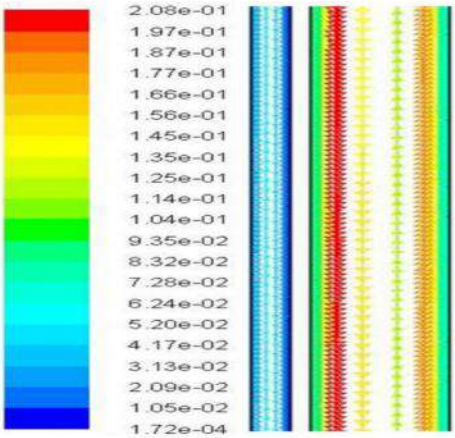




Model A



Model B



Model C

Conclusions

After an extended analysis, the following conclusions were obtained:

- The identity of the building must be preserved by conserving the **building colour** and emphasise the building **visual height**.
- The replacement of the facade would provide a **new identy and values** to the building as well as reduce the **energy consumption**.
- The **seasonal adaptability** was considered by implementing a **shading device**, which can limit heat gains during summer and maximize them during winter.

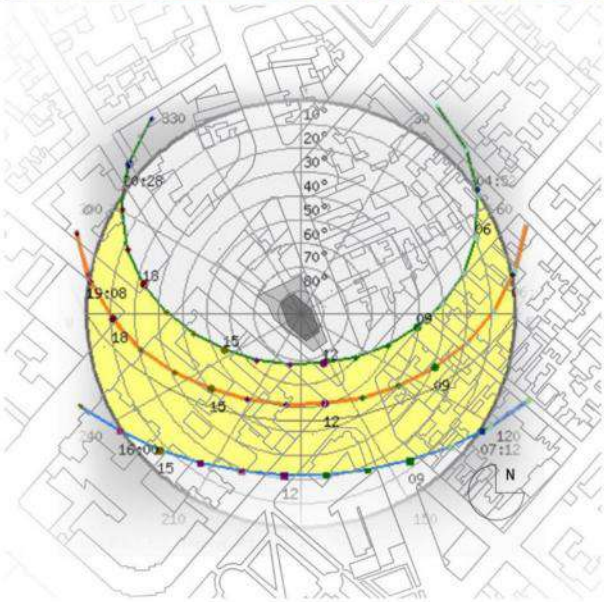
Case Study 1: Office building "Beogradjanka"

▶ Names: Ana Kontić, Milan Varga, Valentina Frighi, Michael Michalis.

Project development process

Location

Masarikova, 5
Latitude | 44.787197
Longitude | 20.457273
DMS Lat | 44° 47' 13.9092" N
DMS Long | 20° 27' 26.1828" E
Elevation (m) | 136 m



Climate and decision

Belgrade, average temperature variations over the year. Source: https://www.accuweather.com

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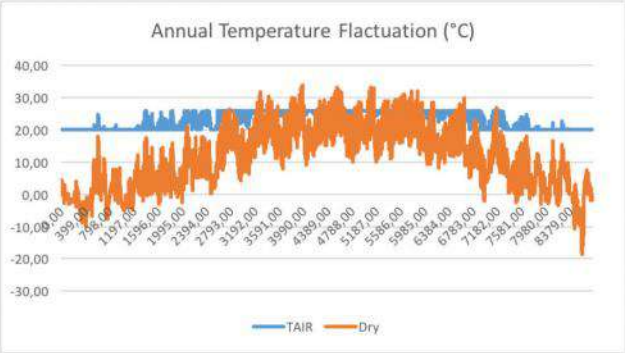
Project development process

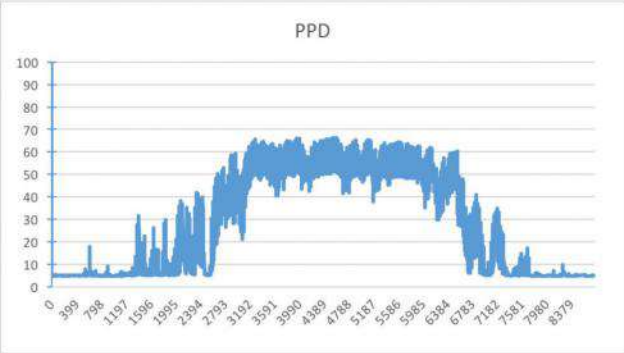
Façade concept

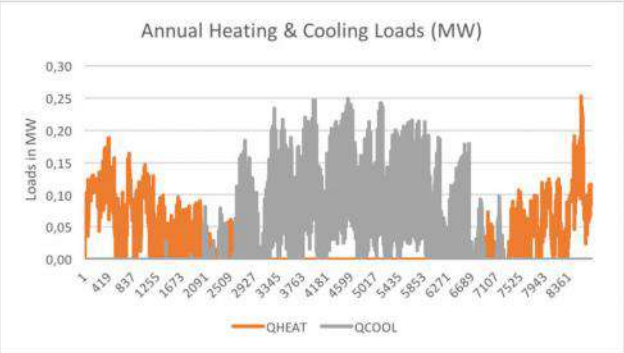
Starting points of the reasoning has been the following:
-The high temperature gap among the two seasons in Belgrade region;
-The almost total lack of (physical) communication between the external and the internal environment (due to the presence of the curtain wall);
-The building's symbolical meaning for the city of Belgrade.

Then, we identified critical issues in current existing situation and possible proposals for façade improvement

PRIMARY OBJECTIVE	THERMAL COMFORT	Insulation improvement | Interior windows placement | Moveable shading devices
PRIMARY OBJECTIVE	ACOUSTIC COMFORT	Interior windows placement | Laying optimization in the interfaces
PRIMARY OBJECTIVE	FRESH AIR SUPPLY	Enhancement of ventilation system
PRIMARY OBJECTIVE	ENERGY GENERATION	Photovoltaic integration
SECONDARY OBJECTIVE	VISUAL COMFORT	Moveable shading devices
SECONDARY OBJECTIVE	AESTHETIC	Maintain the characteristic building appearance







Simulations of the current building performance situation obtained with TRNSYS

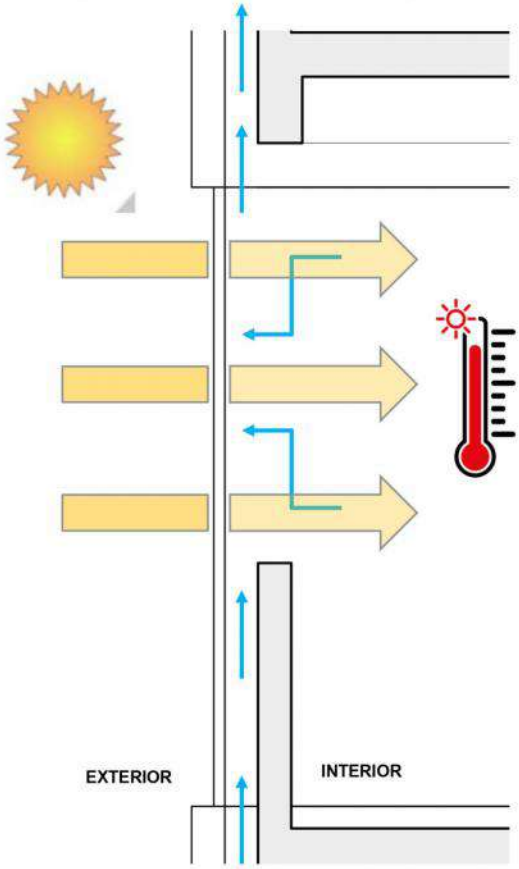
Case Study 1: Office building "Beogradjanka"

▶ Names: Ana Kontic, Milan Varga, Valentina Frighi, Michael Michalis.

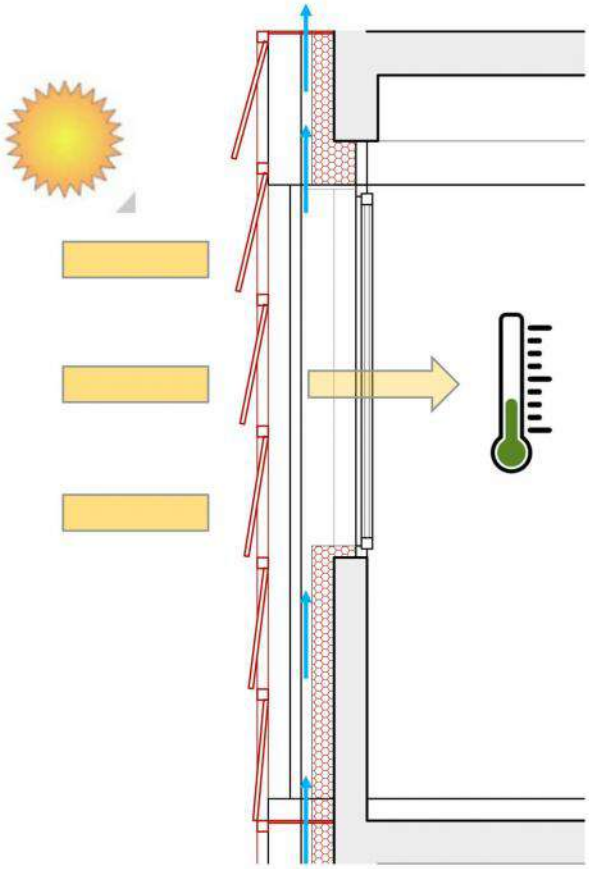
Project development process

Technical details

The intervention strategy for the energy performance improvement of the façade is mainly based on the implementation of the thermal performance of the building envelope by inserting a layer of thermal insulation and by placing a high performance window on the internal skin of the casing.
Furthermore, it been foreseen the maintenance of the existing curtain wall to which we will add a sun shading adaptive device, which possibly will allow to retrofit the facade thanks to a BMS system that will allow its control through predicted scenario, according to indoor activities and occupants behavior and preferences.



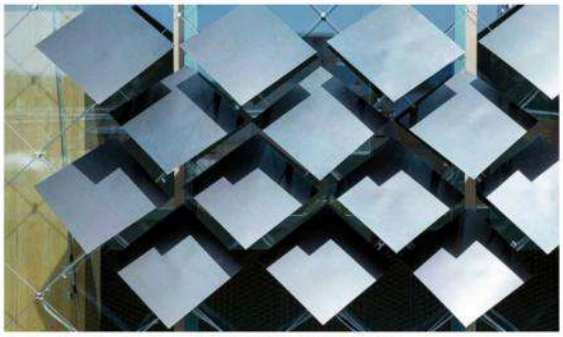
Current situation



Design situation

Museum of Paper Art (2002), Shigeru Ban Engineer(s), Shizuoaka, Japan.

Helio Trace (2012), Skidmore, Owings & Merrill (SOM).



Adaptive Solar Façade (2011), ETH Zürich.

Case Study 1: Office building "Beogradjanka"

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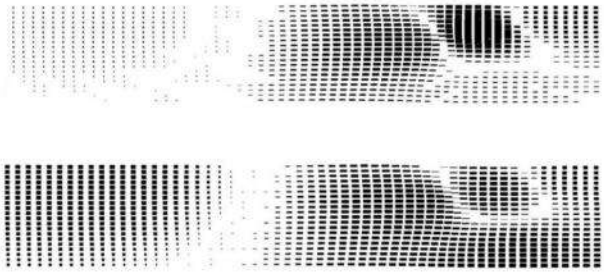
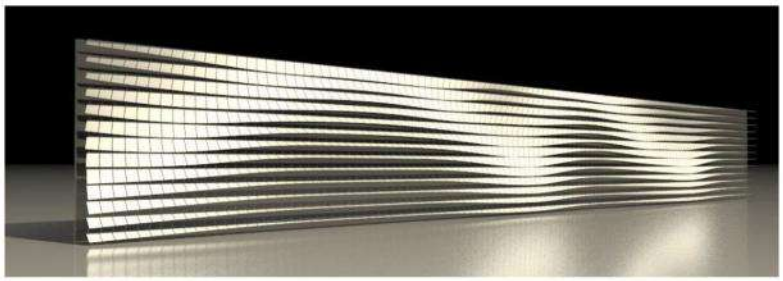
Simulations and results



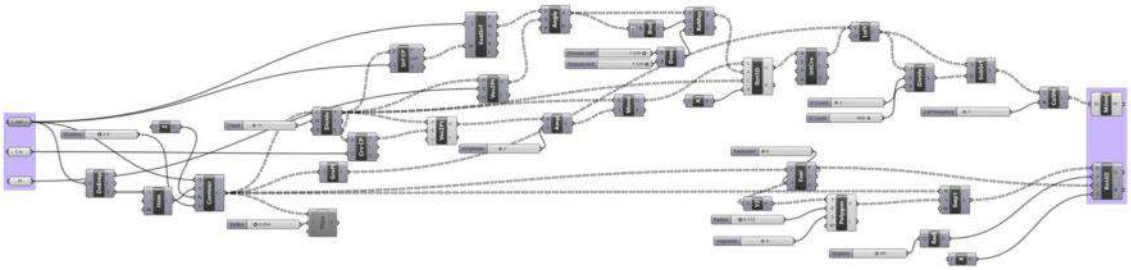
Early concept



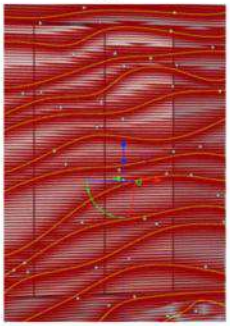
Single floor Grasshopper output

By using the parametric software Grasshopper in combination with Rhinoceros 3D, we developed a definition which is disposing the kinetic panels over the facade planes.

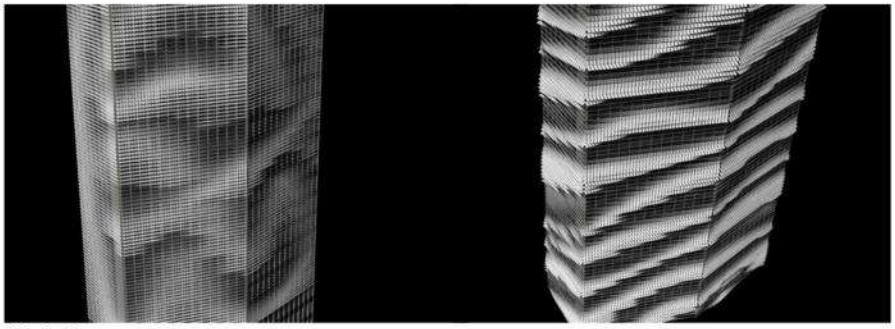
Each of the panels is responsive and reacting to the given curve. In this way we are able to control the aesthetics of the facade and the amount of insolation.



Grasshopper definition



Design process



Variations

"Beogradjanka" with added panels

Retrofitting Office Building: Beogradjanka

Group 7: Miroslav Vulić, Neda Džombić, YorgosSpanodimitriou, Mohataz Hossain

Location

Location:	**Belgrade, Serbia**
Architect:	**Branko Pešić**
Project year:	**1969-1974**
High:	**101 m**
Area:	**40.000 m²**
Story:	**24**

Location

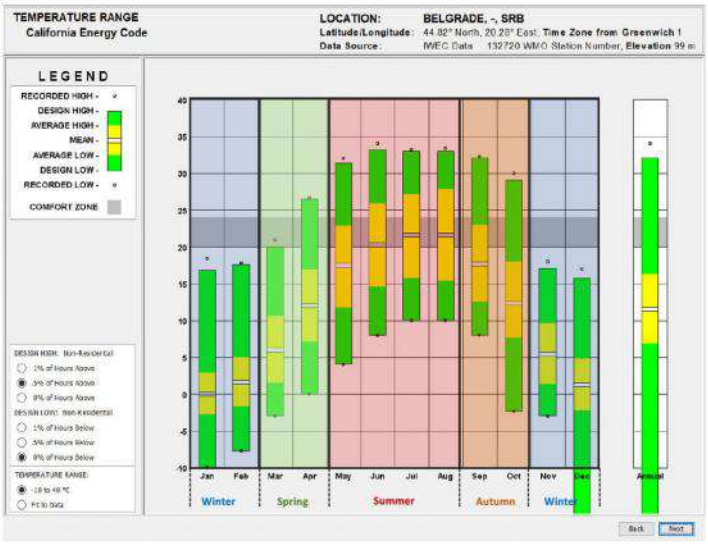
- Beogradjanka Tower is located in the middle of Belgrade, Serbia
- Part of the city with commercial and residential buildings

Context

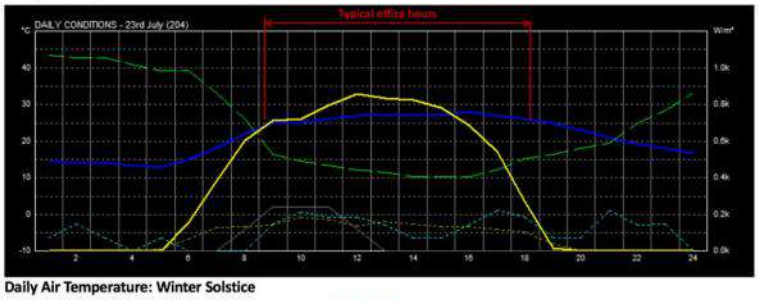
- Modern high-rise building
- 3rd tallest building in Belgrade (1st Usce Tower and 2nd Western City Gate of Belgrade)

Climate and decision

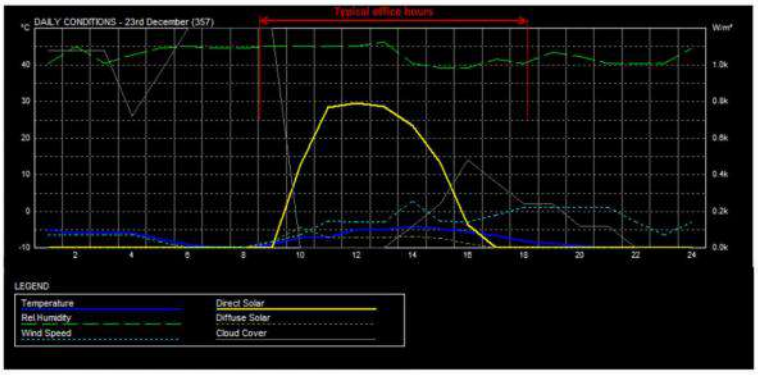
1.



2. Daily Air Temperature: Summer Solstice



Daily Air Temperature: Winter Solstice



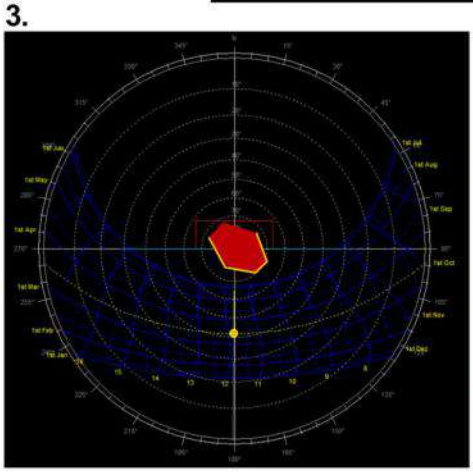
Graph 1: The temperature graph shows that in the summer, daytime temperatures get quite high (almost 35 C° on average),
but also that during night the temperature drops significantly (almost down to 15 C° on average).

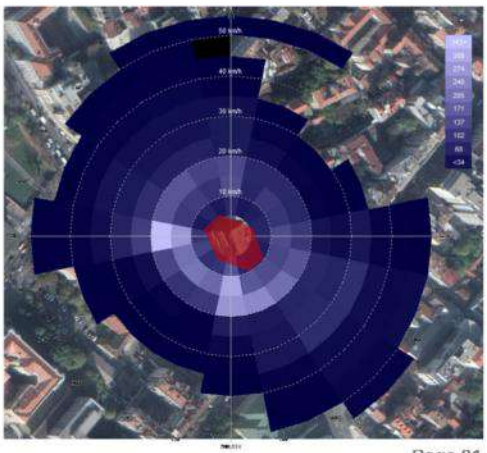
Graph 2: Through a confrontation between temperature and direct solar radiation, both in summer and winter, it's possible to observe how there is constant solar radiation during workhours during the whole year.

Graph 3: The solar and wind geometrical graph show how the building is exposed to solar radiation and natural winds during the whole year on average.

Through the weather analisys, it has been possible to assess a dynamic strategy based on natural ventilation (in summer) and greenhouse effect (in winter).

3.

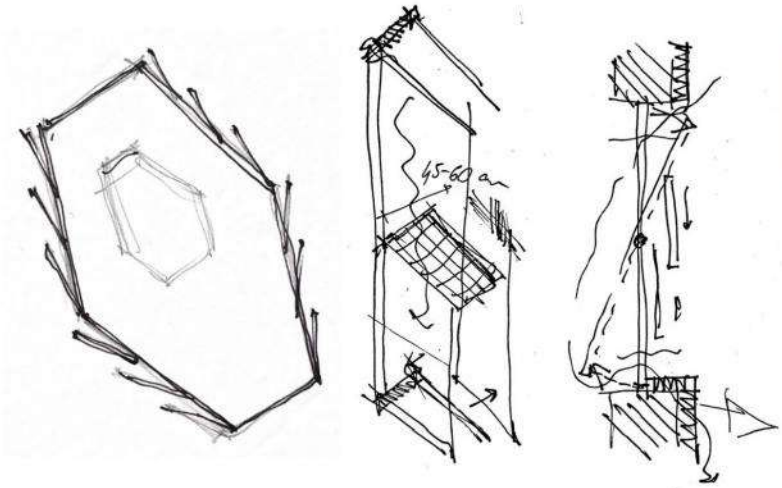




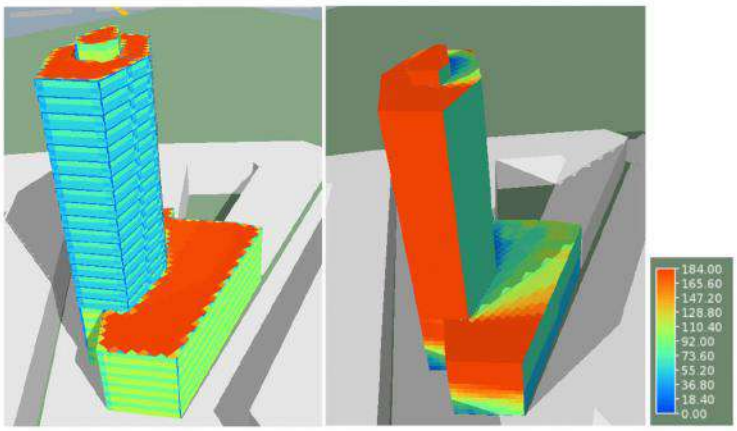
Retrofitting Office Building: Beogradjanka

Group 7: Miroslav Vulić, Neda Džombić, YorgosSpanodimitriou, Mohataz Hossain

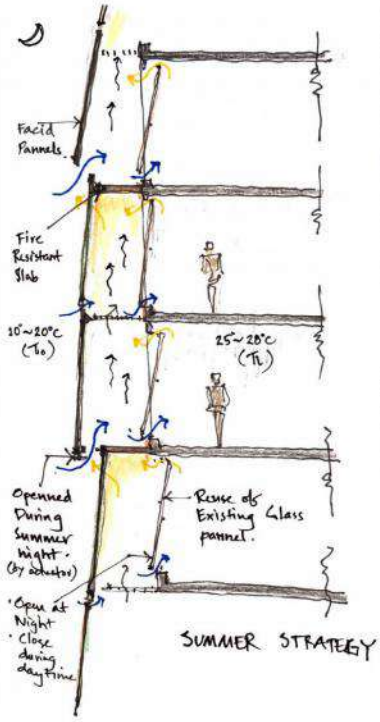
Façade concept

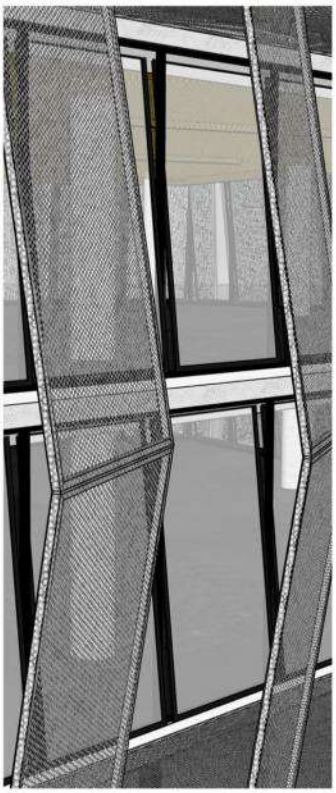


Average Solar Exposition Hours, during Summer (left) and Winter (right)

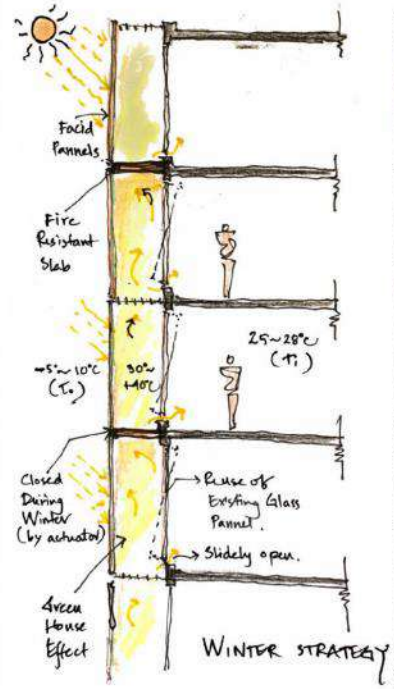


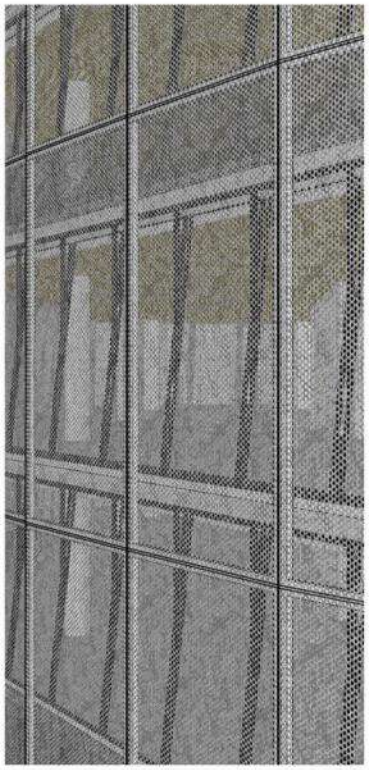
Summer Strategy





Winter Strategy

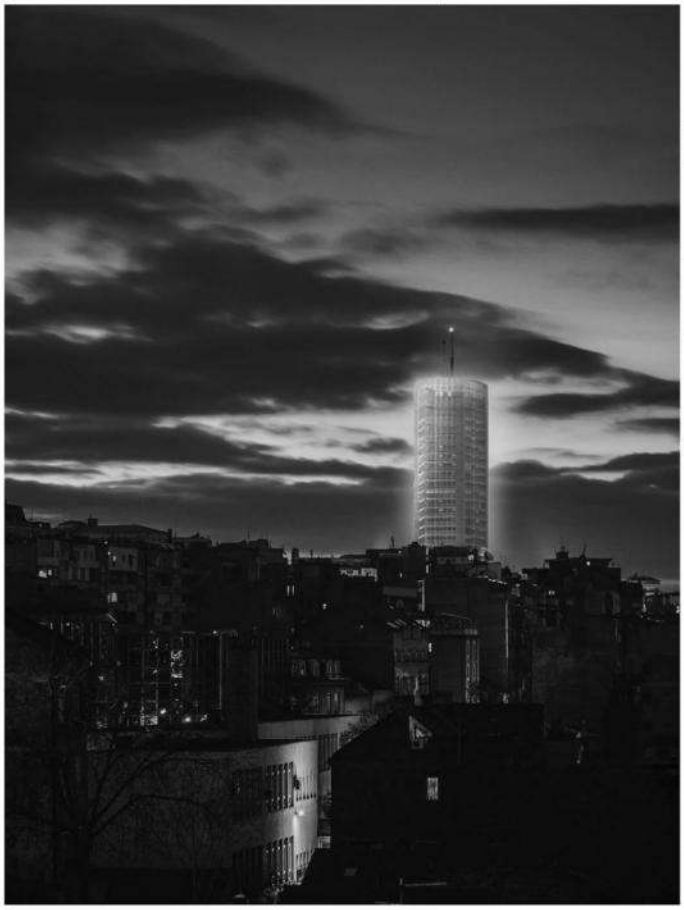




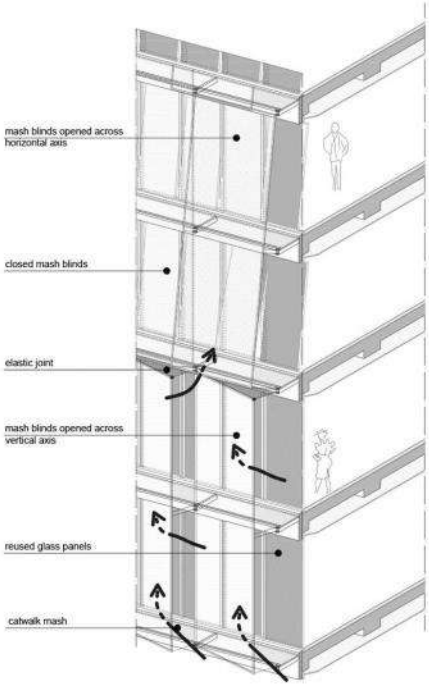
Retrofitting Office Building: Beogradjanka

Group 7: Miroslav Vulić, Neda Džombić, YorgosSpanodimitriou, Mohataz Hossain

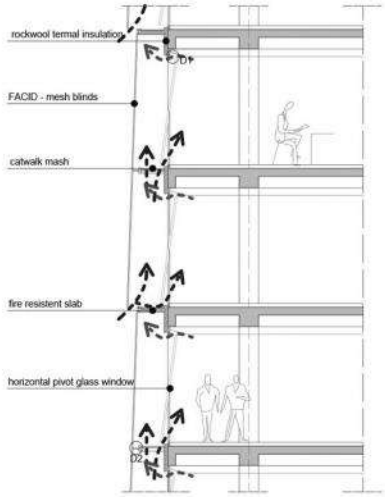
Model visuals



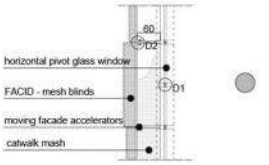
Technical details



ISOMETRIC VIEW. SEGMENT OF FACADE

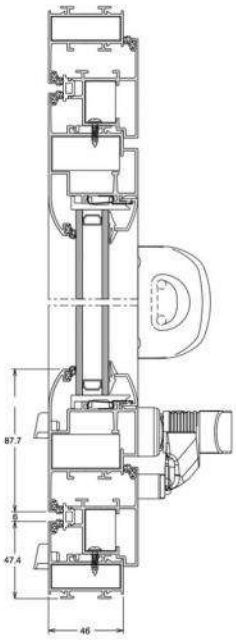


SECTION PLANE. SEGMENT OF FACADE

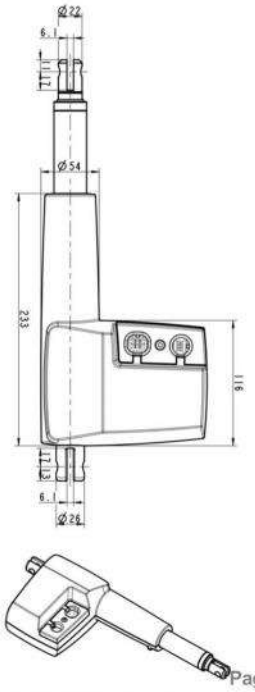


FLOOR PLANE. SEGMENT OF FACADE

Section detail of windows frame



Technical detail of linear actuator

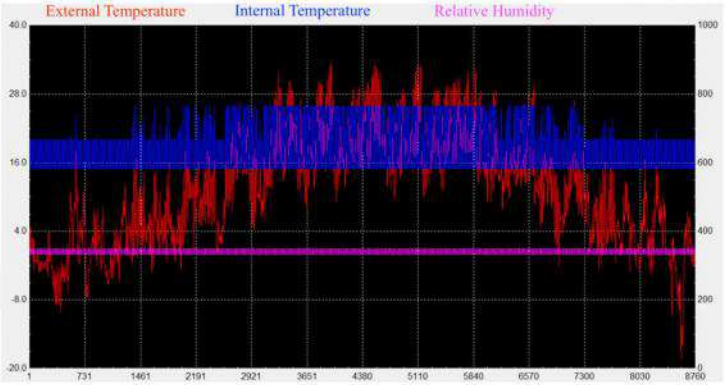


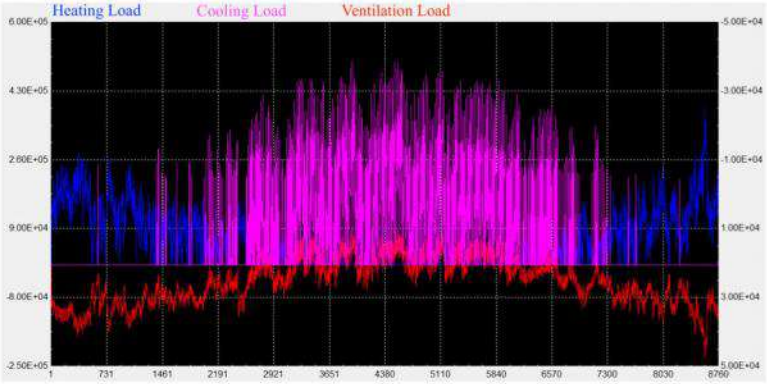
Retrofitting Office Building: Beogradjanka

Group 7: Miroslav Vulić, Neda Džombić, YorgosSpanodimitriou, Mohataz Hossain

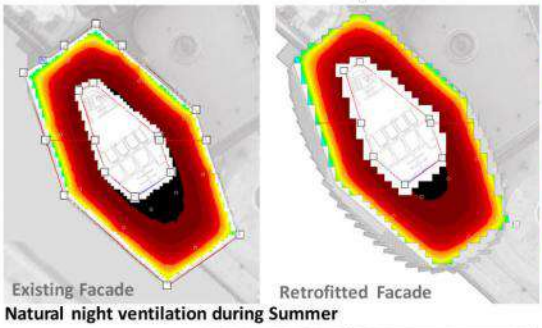
Simulations and results

State-of-the-art conditions

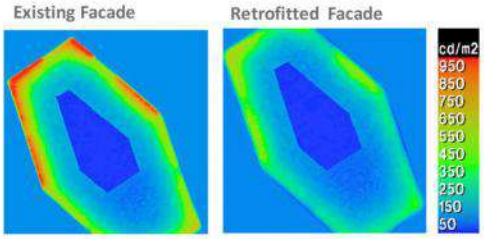




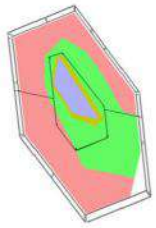
Daylight level analysis (lux)



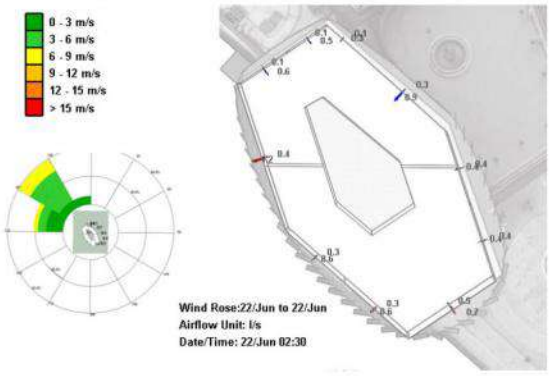
Glare analysis

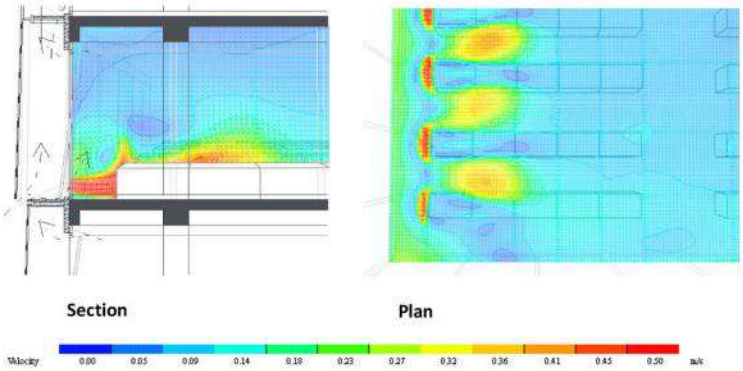


Climate daylight Analysis (UDI: 100-500 lux) :



Natural night ventilation during Summer



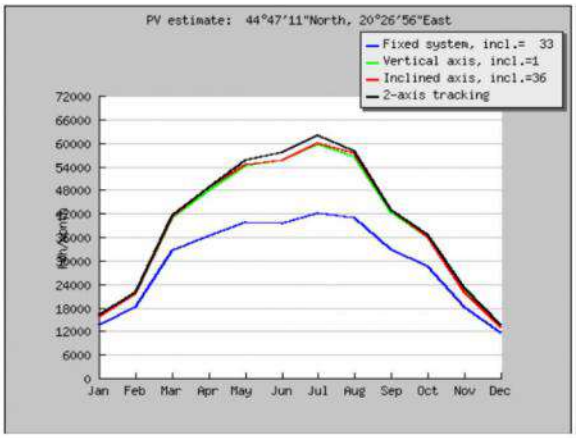


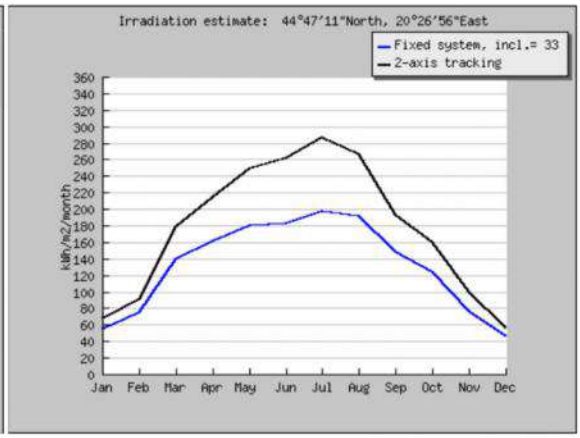
Energy provided by PV panels on the roofs

Solar radiation database used: PVGIS-CMSAF

Nominal power of the PV system: 300.0 kW (crystalline silicon)
Estimated losses due to temperature and low irradiance: 10.0% (
Estimated loss due to angular reflectance effects: 2.9%
Other losses (cables, inverter etc.): 14.0%
Combined PV system losses: 24.9%

Fixed system: inclination=33°, orientation=0° (optimum)				
Month	E_d	E_m	H_d	H_m
Jan	437.00	13500	1.78	55.2
Feb	643.00	18000	2.65	74.2
Mar	1050.00	32700	4.53	140
Apr	1210.00	36300	5.37	161
May	1280.00	39800	5.80	180
Jun	1320.00	39600	6.08	183
Jul	1360.00	42100	6.35	197
Aug	1320.00	41000	6.16	191
Sep	1100.00	32900	4.95	148
Oct	922.00	28600	4.00	124
Nov	606.00	18200	2.56	76.8
Dec	369.00	11400	1.51	46.7
Yearly average	**970**	**29500**	**4.32**	**131**
Total for year		**354000**		**1580**





Case Study: Belgrade Istocna Kapija

▶ Federico Bertagna, Ariadna Carrobé, Juanma Cruz, Nikola Macut, Mirjana Miletić

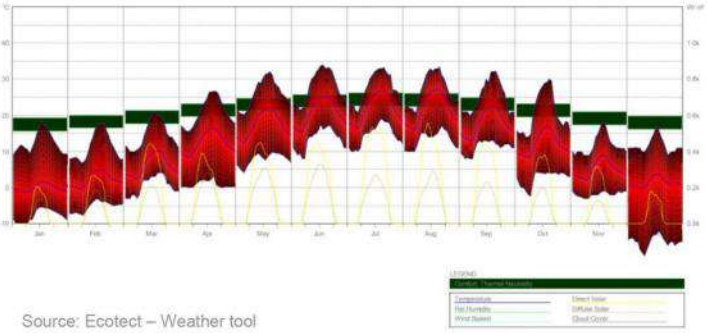
PROJECT DEVELOPMENT PROCESS

Location

The case study building is called Eastern City Gate and it is located in the Konjarnik district in Belgrade, Serbia.

The complex is composed of three residential buildings. For this case study, the south facing building was investigated.

Climate and decision



Source: Ecotect – Weather tool

As shown in the graph above, during winter the temperature in Belgrade decreases up to -10ºC. Since the thermal insulation properties of the external walls in the current condition proved to be rather poor, in order to prevent excessive thermal losses through the envelope, there is the need to implement some passive systems. On the contrary, during summer, the uncontrolled solar radiation that enters the building is possibly the main cause of overheating issues. An external shading system can represent a simple yet effective solution to this problem.

According to the climate data, solar and wind analysis, two solutions are proposed in order to improve the current situation in terms of energy performances and user comfort.
The first is based on the improvement of the thermal insulation properties of the building envelope; the second one is the inclusion of an adaptive façade system where simple rectangular louvers can slide and rotate along the windows depending on the sun position during the day.

Façade concept

Current situation

The window to wall ratio in the building is about 50%. The external layer is made of concrete and only 5 cm of polystyrene is installed is some parts of the external wall as an insulating layer. Most of the windows have wooden frames and a double glass layer.

Type	Composition	Total Thickness (cm)	U value (W/m2*K)	Gas
Window	Outer Pane / Cavity / Inner Pane	24	1,9326	Air
WALL Type 2	Reinforced Concrete / Polystyrene / Reinforced Concrete	12	3,8917	-
WALL Type 2	Reinforced Concrete	200	0,5294	-

Proposed solution

Description	Serbian Law U [W/m²K]/ ACH	EnerPHit/EnerPHit[+] U [W/m²K]
External wall	≤ 0,4	≤ 0,15
Ground floor	≤ 0,4	≤ 0,15
Roof	≤ 0,2	≤ 0,15
Windows	≤ 1,5	≤ 0,85
Internal walls and floor construction	≤ 0,9	≤ 1,0

According to the Serbian regulations, all renovated buildings must improve their energy efficiency by a minimum of one degree. In addition, an upper threshold for the U-value of each constructive element is prescribed.

Type	Composition	Total Thickness (cm)	U value (W/m2*K)	Gas
Window	Three glass	8	0,789	Argon
WALL Type 1	Reinforced Concrete / Polystyrene / Mineral Fibre slab	230	0,2942	-
WALL Type 2	Reinforced Concrete / Polystyrene / Cellular polyurethane	270	0,1667	-
WALL Type 3	Rock wool / Concrete Cast	150	0,288	

One type of window is proposed, whose U-value meets the requirements of both Serbian and EnerPHit parameters. As for the walls, three different types have been tested. As shown in the table, the best insulation material is the Polystyrene, but taking into account the properties in terms of sustainability, rock wool will be used instead.

Case Study: Belgrade Istocna Kapija

▶ Federico Bertagna, Ariadna Carrobé, Juanma Cruz, Nikola Macut, Mirjiana Miletec

Façade adaptivity

Adaptive Element: vertical louvers

Materials: steel frame + PVC mesh

Width: 0.3m | Angle of rotation: various (±90°)

Mechanism of Adaptation: rotation along axis

Softwares: Rhinoceros 3D, Grasshopper, Ladybug

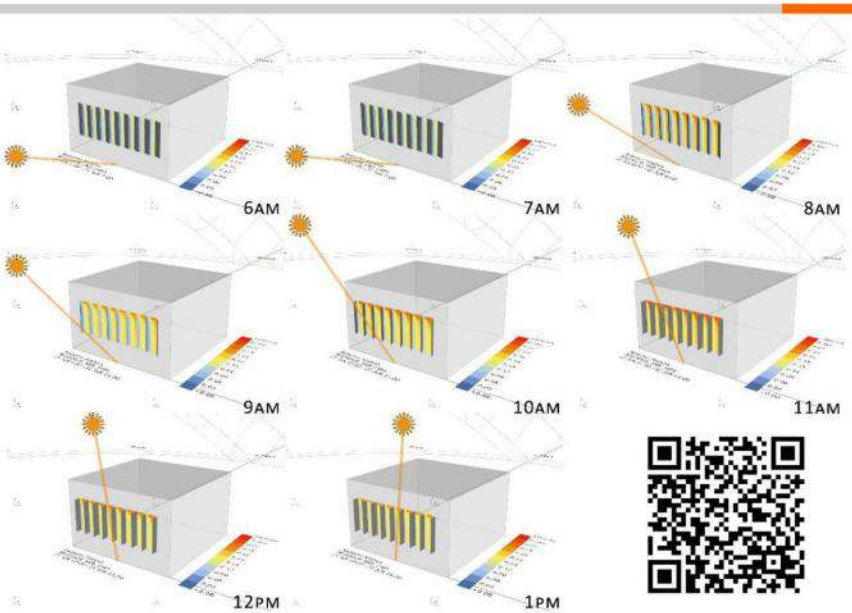


Fig.1: Radiation Analysis, West window | June 21st, 6AM-1PM

Model

For this simulation a simplified parametric model of a single window protected by a set of vertical rectangular louvers has been used (Fig.2). The analysis have been carried out for an East-facing windows as well as for an West-facing window.

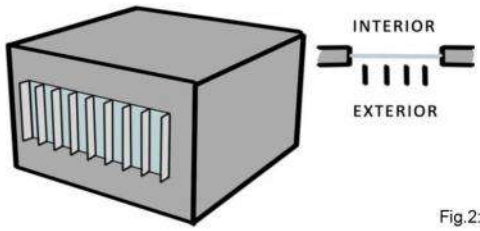


Fig.2: View of the model

Simulation

Analysis Period: June 21st, 6AM-10PM
Time step: 1 hour

Adaptation

The objective is to prevent uncontrolled solar radiation to enter the building through the windows. The system adapts its shape according to the position of the sun, more specifically, the angle of rotation of the louvers depends on the sun azimuth. This was achieved through a Grasshopper definition (Fig.3).

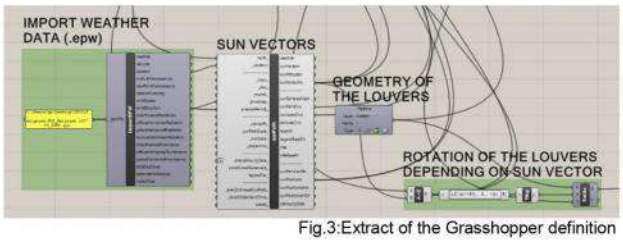
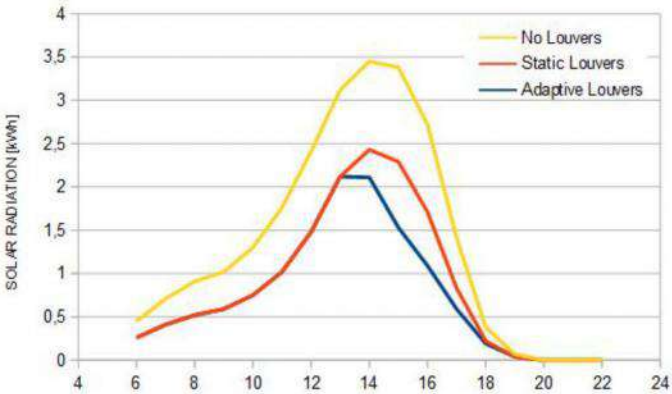


Fig.3:Extract of the Grasshopper definition

Results

Three cases have been investigated for each window orientation:
CASE 1: no louvers
CASE 2: static louvers, normal to the facade (Fig.2)
CASE 3: adaptive louvers
For the analysis period investigated, compared to Case 1, the solar radiation on the west-facing window is reduced by 36% in the case of static louvers while the reduction reaches 45% when an adaptive system is applied.



	WEST WINDOW		
	No Louvers	Static Louvers	Adaptive Louvers
TOTAL [kWh]	23,09	14,67	12,7
REDUCTION [%]	-	36%	45%

Critical aspects

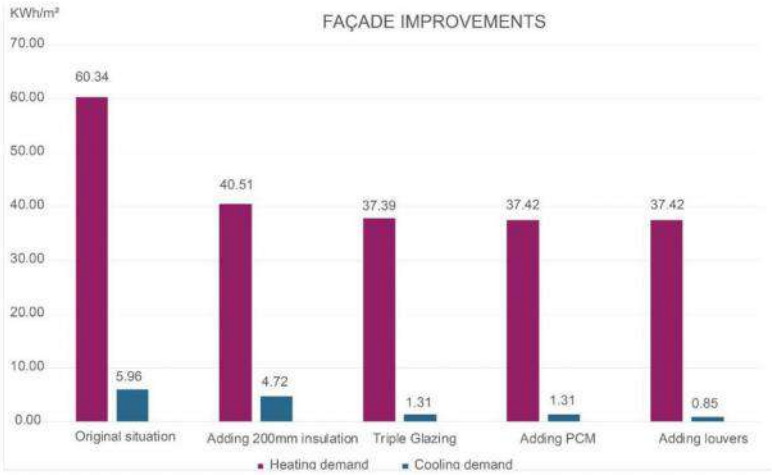
- Radiation reduction during summer is not the only requirement in order to achieve a suitable comfort level and good energy performances. More detailed investigations are needed.
- How to evaluate to what extent an adaptive facade is a better solution compared to traditional shading systems?

Case Study: Belgrade Istocna Kapija

▶ Federico Bertagna, Ariadna Carrobé, Juanma Cruz, Nikola Macut, Mirjiana Miletec,

Simulation

The measures used for the retrofitting have been decided through an energy analysis in EnergyPlus 8.9 in order to find the most optimal results.



Model sketch

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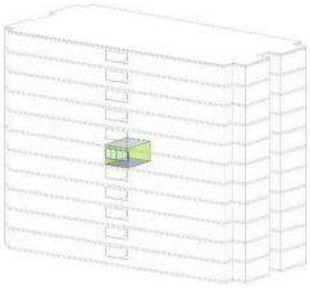
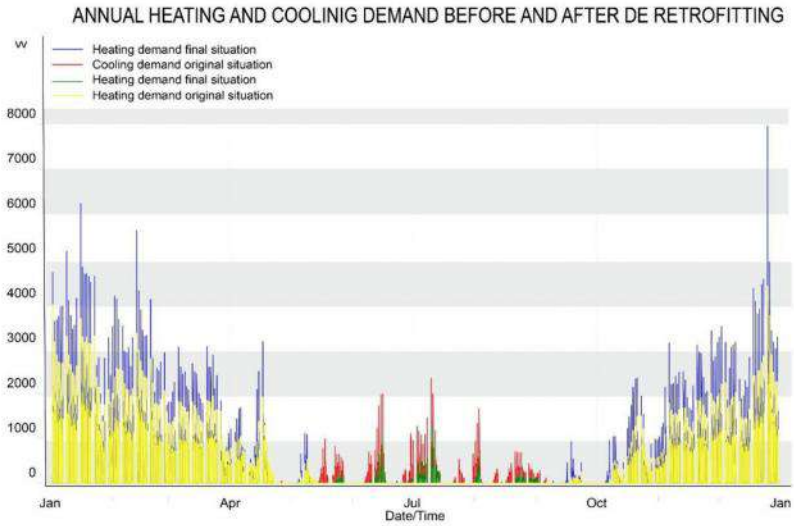
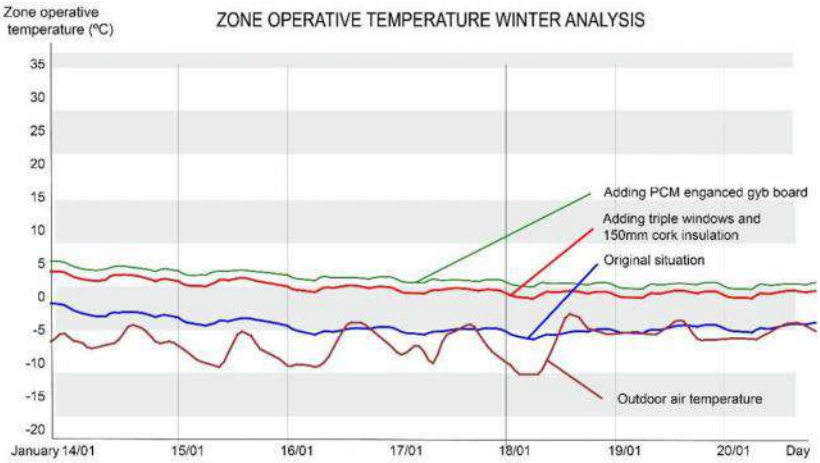




Simulations and results

The first graph shows how the energy demand used in the analyzed room for heating and cooling. The adaptation reduced 36% the heating demand and 86% the cooling.

The second figure shows the annual energy demand before and after the retrofitting, decreasing significantly in both of them. As we can see, Belgrade has a high heating demand winter, and our concept is not only to reduce the cooling demand through



Conclusion

Having a compact envelope using a continuous insulation layer and high insulated windows are the most effective measures in order to reduce the heating demand.
Also, adding PCM embedded on gypsum boards, in this case on the wall (melting temperature 25ºC) taking advantage of thermal mass effect, stabilize interior temperatures helping the thermal comfort to be more steady.
For reducing the cooling demand, the solar protection has been the most effective measure.

cost EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY
European COST Action TU1403
Adaptive Facades Network
UNIVERSITY OF BELGRADE FACULTY OF ARCHITECTURE

▶ Federico Bertagna, Ariadna Carrobé, Juanma Cruz, Nikola Macut, Mirjiana Miletec

Technical Details

Thermal Insulation and Cladding System

The proposed solution consists of cork insulationpanels on the outer side of the building enveolpe. The main properties of this material are the following:

- Density: 120 kg/m3
- Specific Heat: 1670 J/kg*K
- Thermal Conductivity: 0,041 W/m*K

PCM (Phase Changing Material) is installed on the inner side of the external walls, embedded in a 13 mm thick gypsum board.
KLP facade panels (140mm width, 30mm thick) are applied as a cladding system (Fig.1). They are made of recycled polyolefin polymers (fire class B according to the EN 13501-1 standard).

Fig.1: Cladding system

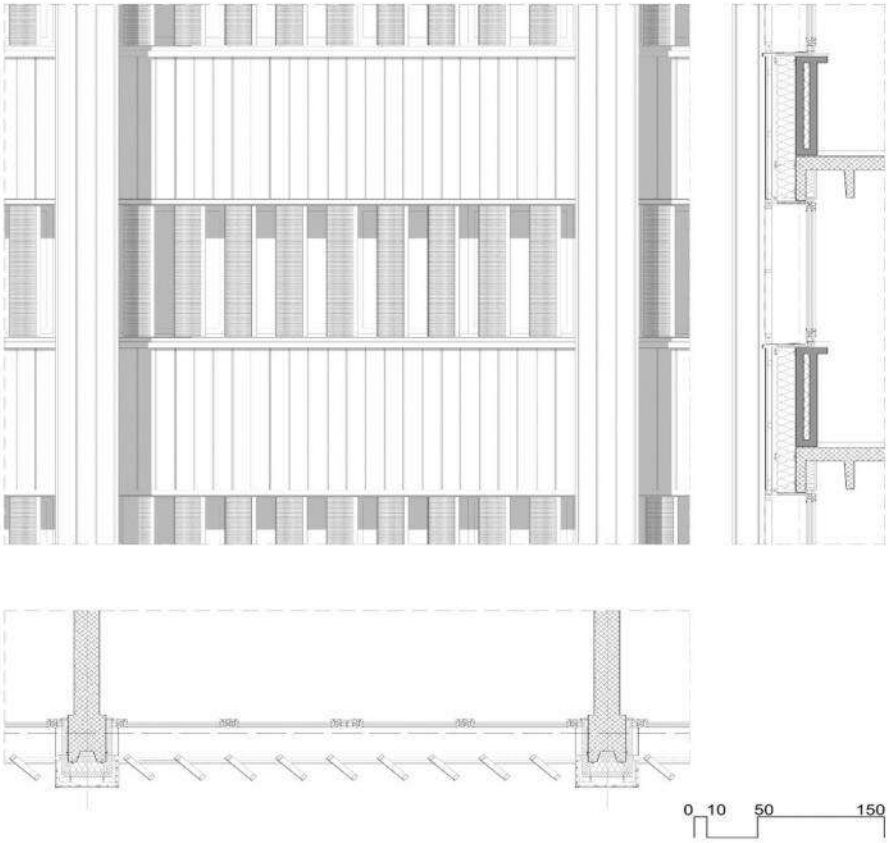


Fig.2: Facade system

Adaptive Shading Elements

The adaptive shading elements are made of a steel frame that supports a PVC mesh sheet (Fig.3). Thanks to its air permeability, the effect of the wind force on the elements can be considered negligible. On the contrary, sunlight is blocked, preventing the solar radiation to enter the building and to cause overheating.
The durability of the whole system has to be carefully investigated, however, thanks to their simplicity, the single elements can be replaced quite easily.

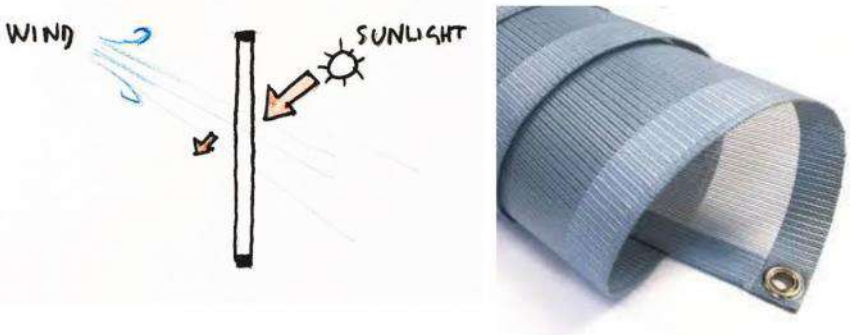


Fig.3:PVC mesh sheet

Case Study: Residential Building “Rudo”

▶ **Jorge Luis Aquilar-Santana, Anka Mirkovic, Berk Ekici**
Milica Petrovic, Ashal Tyurkay

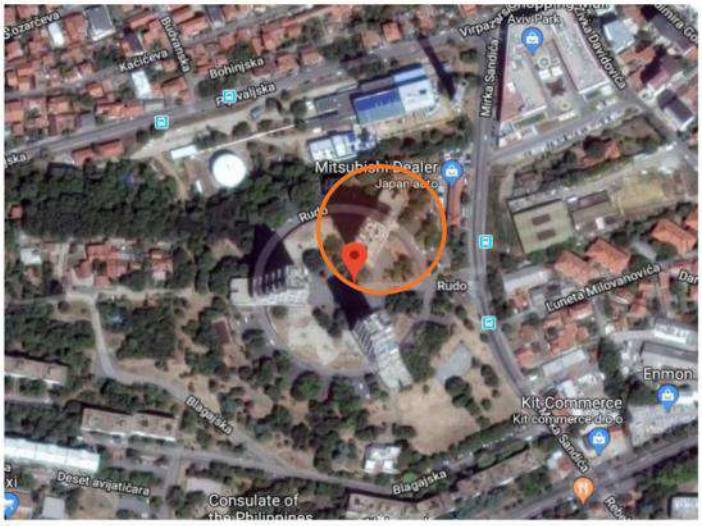
General information

Location

“Rudo”, East Gate of Belgrade

Latitude: 44.786568
Longitude: 20.448921
Constructed: 1973-1976.
Height: 85 m
Number of floors: 28

Location of the building is the residential part of Belgrade - Konjarnik, in the southeastern part of the city. The buildings are considered a landmark for the city of Belgrade due to their position and height.
It is a very populated area, with around 500 people living in each building. Middle-class residents live in the building, with medium or low level of income.

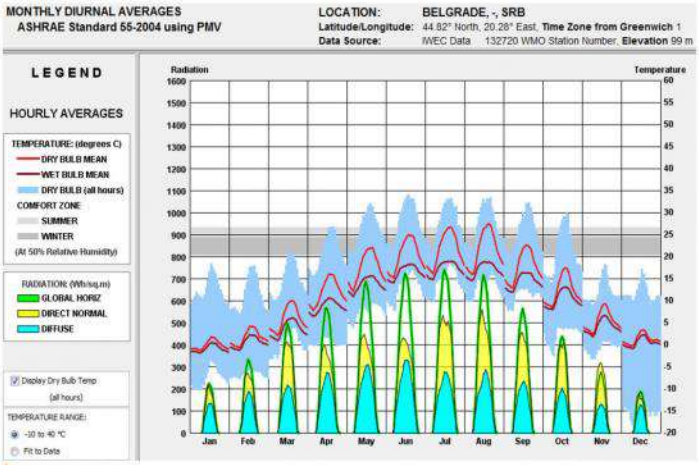


▶ **Fig. 1:** Geographical location of the building (Source: Google Maps)

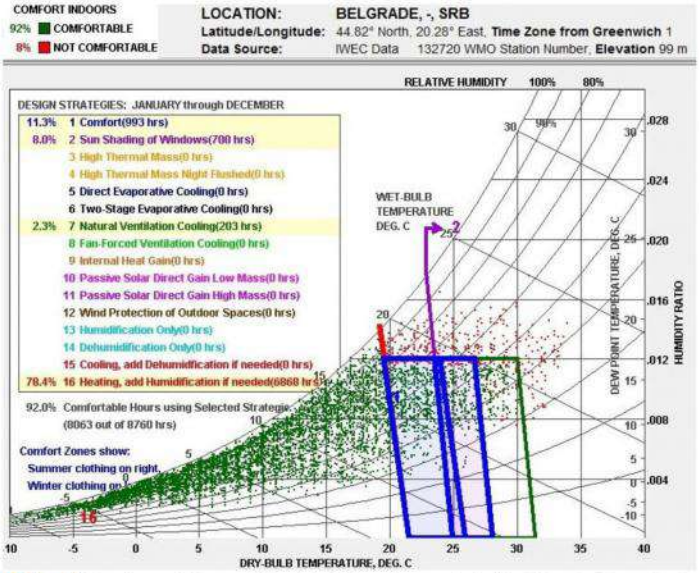
▶ **Fig. 2:** Site model of the building (Source: 3D Warehouse / SketchUp)

Climate and decision

From the analysis of climate conditions in Belgrade, Serbia using @WeatherSpark, the conclusion is that Belgrade has more cold days than very hot summer ones, but the number of sunny days is very high - 300 sunny days during the year. The decision was to provide heating during winter using solar panel collectors to heat the water for the radiators and to add sun shading movable textile elements, so that overall thermal comfort can be improved. Simple analysis of the proposal was carried out using @ClimateConsultant software. The results show users' thermal comfort increases to 92%.



▶ **Fig. 3:** Average temperatures for Belgrade (Source: https://weatherspark.com/)



▶ **Fig. 4:** Psychrometric conditions for Belgrade, created with Climate Consultant software

Case Study: Residential Building “Rudo”

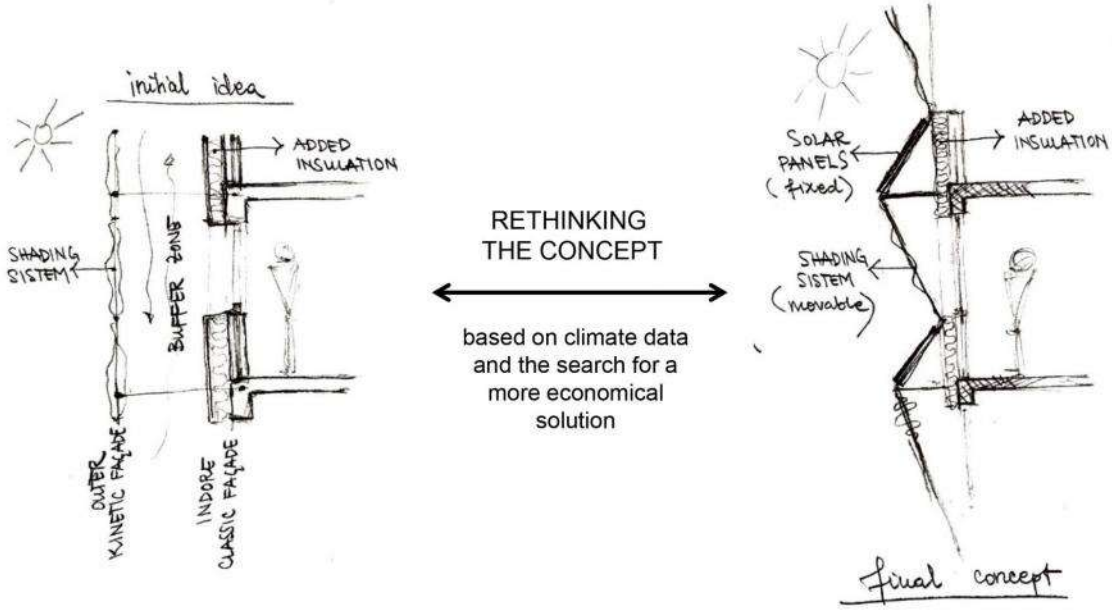
▶ Jorge Luis Aquilar-Santana, Anka Mirkovic, Berk Ekici
Milica Petrovic, Ashal Tyurkay

Architectural design concept

Façade concept

The façade concept is developed with the performance approach which takes user requirements into consideration based on building typology and climatic conditions of the site. Design solutions are proposed with this point of view after the existing building façade problems have been identified.

As the building façade lacks of thermal insulation, in winter time interior spaces are over-heated, and in summer time unwanted thermal gains are too high, thus, energy efficiency of the building is low. Since the window systems are replaced individually by tenants, most of the apartments experience weathertightness problems which also decreases the energy efficiency considerably. In parallel to this, users have to spend a lot on space heating and cooling which is not economical in the long term. Moreover, exposed prefabricated concrete panels have remained unmaintained and pose structural risks. Another factor in choosing the façade systems and developing the solutions is the affordability that matches the users' economic conditions.



Problems / Challenges

- Prefabricated concrete panels
- No insulation in facade elements
- Poor window conditions /weathertightness
- Absence of shading
- Uncomfortable interior temperatures

Prioritized Requirements

RESIDENTS' HAPPINESS ☺

- Thermal comfort
- Energy efficiency
- Affordability

Solutions

- Repair and maintenance
- Adding thermal insulation
- Changing the windows
- Providing solar control
- Adding solar panels

Case Study: Residential Building "Rudo"

Jorge Luis Aquilar-Santana, Anka Mirkovic, Berk Ekici
Milica Petrovic, Ashal Tyurkay

Architectural design concept

Technical details + Materials

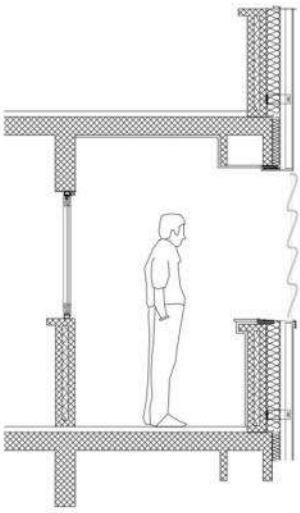


Fig. 5: Detailed section - balcony

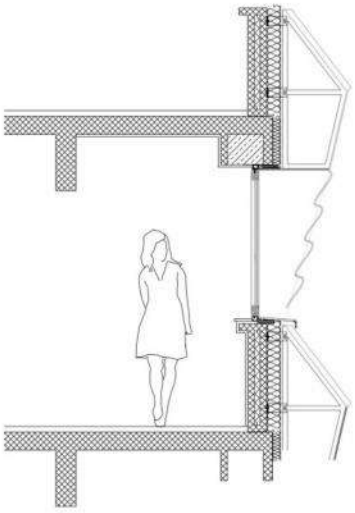


Fig. 6: Detailed section

Fig. 7: Cladding material - IRIS Fabbrica Marmi e Graniti

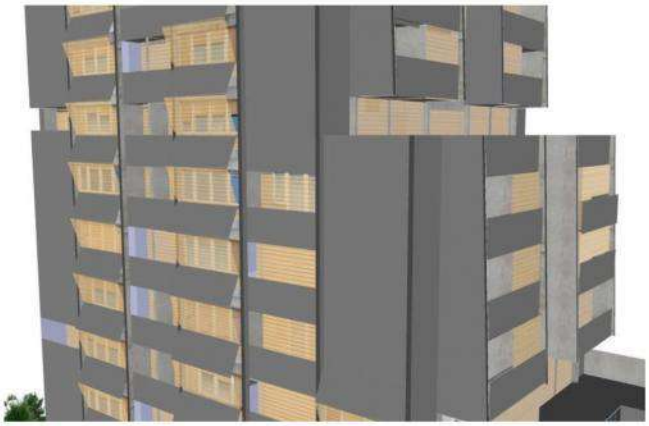
Fig. 8: Fabric PTFE - Koch Membrane

Fig. 9: Solar pannel collector -

Fig. 10: HDPE (vapor diffusive) waterproofing membrane (Dupont Tyvek)

Fig. 11: Mineral wool thermal insulation (Knauf thermo roll)

3D model



Case Study: Residential Building “Rudo”

▶ Jorge Luis Aquilar-Santana, Anka Mirkovic, Berk Ekici
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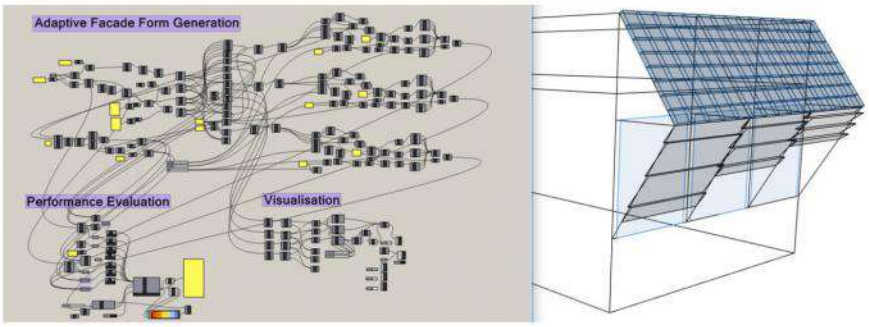
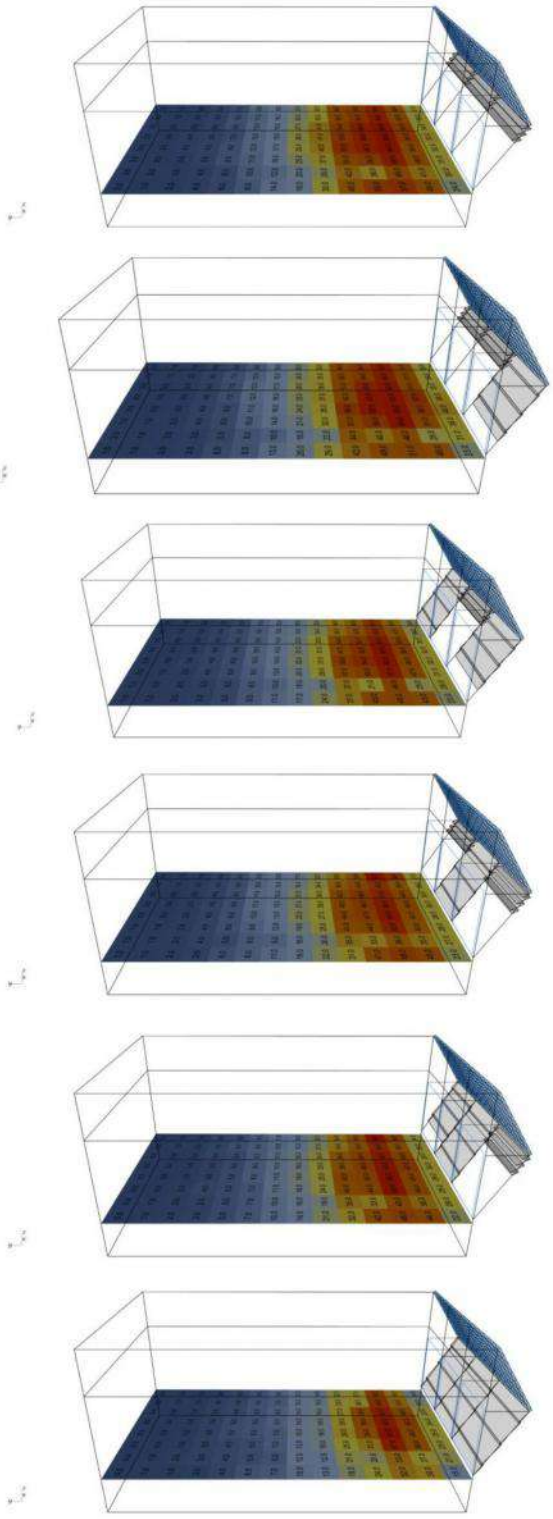
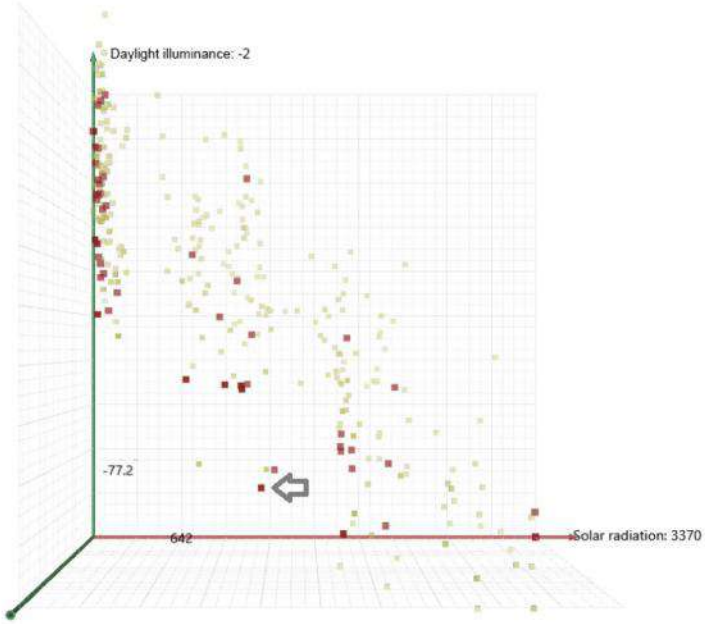
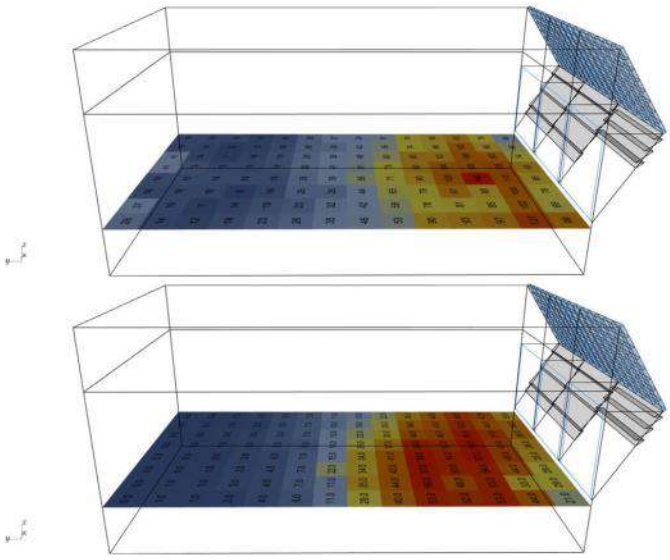
Parametric façade model





▶ **Fig. 11:** Variations of the adaptive facade





▶ **Fig. 12:** Optimized design solution

Case Study: Residential Building "Rudo"

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Milica Petrovic, Ashal Tyurkay

Simulation and conclusions

Program Version:**EnergyPlus, Version 8.8.0-7c3bbe4830, YMD=2018.09.06 16:23**

Tabular Output Report in Format: **HTML**

Building: **Building 1**

Environment: **RUN PERIOD 1 ** BELGRADE - SRB IWEC Data WMO#=132720**

Simulation Timestamp: **2018-09-06 16:23:09**

Report: **Annual Building Utility Performance Summary**

For: **Entire Facility**

Timestamp: **2018-09-06 16:23:09**

Values gathered over 8760.00 hours

Site and Source Energy

	Total Energy [GJ]	Energy Per Total Building Area [MJ/m2]	Energy Per Conditioned Building Ar
Total Site Energy	25.64	993.91	
Net Site Energy	25.64	993.91	
Total Source Energy	57.30	2221.10	
Net Source Energy	57.30	2221.10	

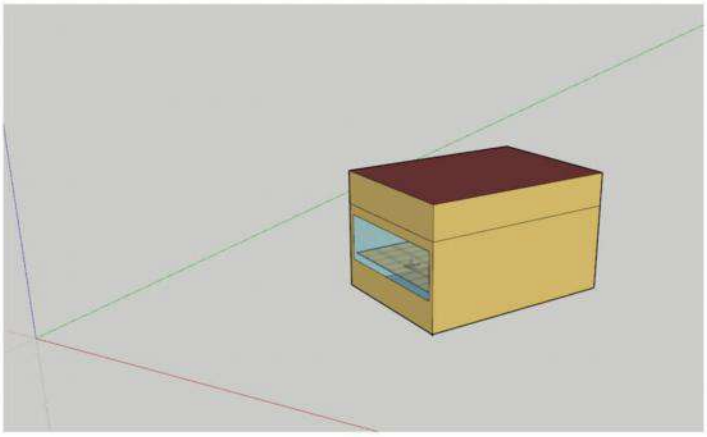
Report: **Demand End Use Components Summary**

For: **Entire Facility**

Timestamp: **2018-09-06 16:23:09**

End Uses

	Electricity [W]	Natural Gas [W]	Propane [W]	District Cooling [W]	District Heating [W]	Water [m3/s]
Time of Peak	02-JAN-16:10	-	-	02-AUG-15:30	25-DEC-08:09	-
Heating	0.00	0.00	0.00	0.00	6118.85	0.00
Cooling	0.00	0.00	0.00	5136.43	0.00	0.00
Interior Lighting	247.44	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	177.46	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	0.00	0.00	0.00	0.00	0.00	0.00
Pumps	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	424.89	0.00	0.00	5136.43	6118.85	0.00



OLD

Heating → (25 DEC 08:09)

6118.85 W x 0.20 = 1.22t CO_2 / kWh

Cooling → (02 AUG 15:30)

5136.43 x 2.5 = 12.84t CO_2 / kWh

NEW PROPOSITION

Heating → (25 DEC 08:09)

6084.44 W x 0.20 = 1.21t CO_2 / kWh

Cooling → (02 AUG 15:30)

4444.51 x 2.5 = 11.11t CO_2 / kWh

Program Version:**EnergyPlus, Version 8.8.0-7c3bbe4830, YMD=2018.09.07 11:12**

Tabular Output Report in Format: **HTML**

Building: **Building 1**

Environment: **RUN PERIOD 1 ** BELGRADE - SRB IWEC Data WMO#=132720**

Simulation Timestamp: **2018-09-07 11:12:43**

Report: **Annual Building Utility Performance Summary**

For: **Entire Facility**

Timestamp: **2018-09-07 11:12:43**

Values gathered over 8760.00 hours

Site and Source Energy

	Total Energy [GJ]	Energy Per Total Building Area [MJ/m2]	Energy Per Conditioned Building Area [MJ/m2]
Total Site Energy	23.05	893.37	893.37
Net Site Energy	23.05	893.37	893.37
Total Source Energy	59.43	2303.49	2303.49
Net Source Energy	59.43	2303.49	2303.49

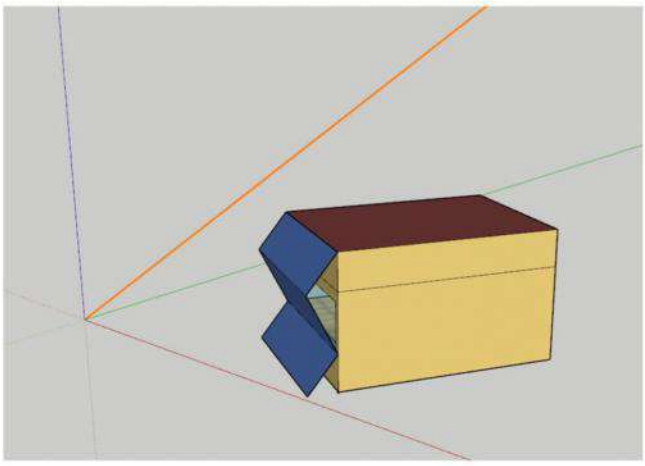
Report: **Demand End Use Components Summary**

For: **Entire Facility**

Timestamp: **2018-09-07 11:12:43**

End Uses

	Electricity [W]	Natural Gas [W]	Propane [W]	District Cooling [W]	District Heating [W]	Water [m3/s]
Time of Peak	02-JAN-16:10	-	-	15-JUN-13:00	25-DEC-08:09	-
Heating	0.00	0.00	0.00	0.00	6085.44	0.00
Cooling	0.00	0.00	0.00	4444.51	0.00	0.00
Interior Lighting	247.44	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	177.46	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	0.00	0.00	0.00	0.00	0.00	0.00
Pumps	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	424.89	0.00	0.00	4444.51	6085.44	0.00



3.4. Awarded workgroups and photos of all teams

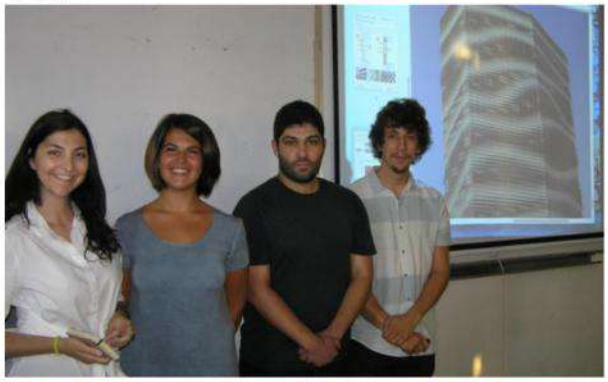
Team 1

Team 2

Team 3

Team 4

Team 5



Team 6

Team 7

Awarded workgroups - teams:

Team 7 – Retrofitting the façade of the office building

Team 1 – Retrofitting the façade of the office building

Team 4 – Retrofitting the façade of the residential building

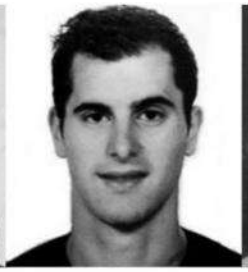
(Photos: A. Krstić-Furundžić)

3.5. Workshop Expert Committee

Trainers during the workshop

Ass.Prof.Dr. Marcin Brzezicki
Wroclaw University of Science and Technology, Poland

Riccardo Pinotti
UNIBZ Free University of Bolzano / EURAC Institute of Renewable Energy, Italy



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Critics

Prof. Dr. Jelena Ivanović-Šekularac
University of Belgrade, Serbia

Teach.Ass. Anica Dragutinović
Hochschule Ostwestfalen-Lippe, University of Applied Sciences, Germany

Photo documentation of the Social events, Lunches and Welcome dinner

(Photos: A. Krstić-Furundžić)

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