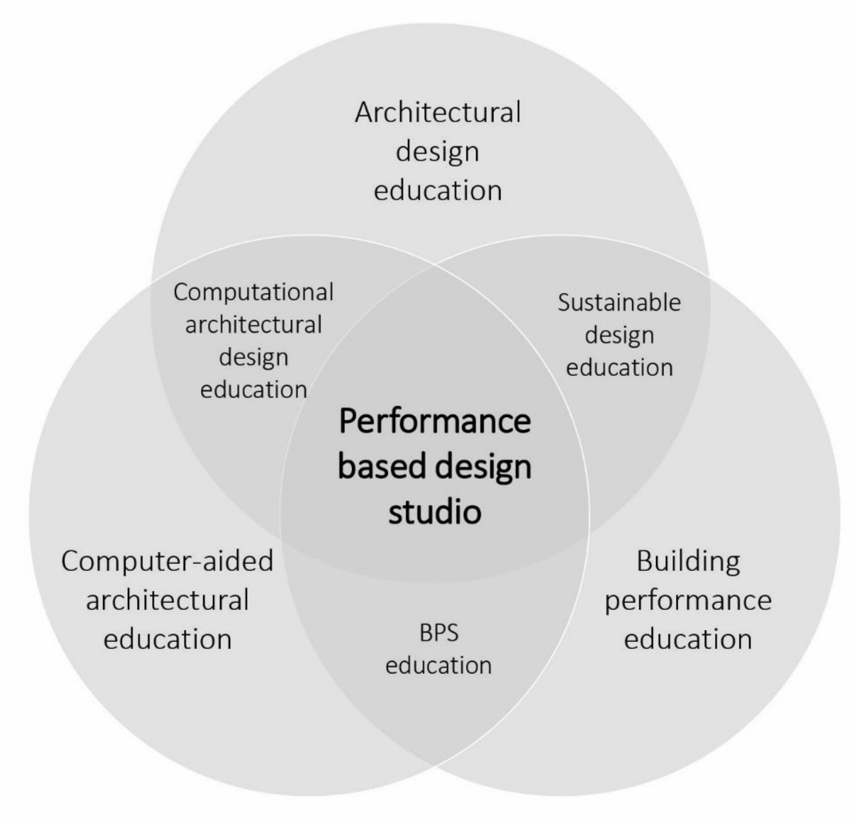
BERGISCHE UNIVERSITÄT WUPPERTAL

Faculty of Architecture and Civil Engineering

# PERFORMANCE BASED EARLY DESIGN IN ARCHITECTURAL EDUCATION

## Framework, Methods and Experiences




IŞIL KALPKIRMAZ RIZAOĞLU

PhD Thesis

Wuppertal 2024

BERGISCHE
UNIVERSITÄT
WUPPERTAL

# PERFORMANCE BASED EARLY DESIGN IN ARCHITECTURAL EDUCATION

## Framework, Methods and Experiences

This thesis is submitted

for the award of a doctoral degree

(Dr.-Ing)

in the

Faculty of Architecture and Civil Engineering of the

University of Wuppertal

by

IŞIL KALPKIRMAZ RIZAOĞLU

(born in Şişli, İstanbul, Türkiye)

Supervisor: Prof. Dr.-Ing. Karsten Voss

Doctoral Committee

Prof. Dr.-Ing. Karsten Voss, First referee

Prof. Dr. Gülsu Ulukavak Harputlugil, Second referee:

Prof. Dr.-Ing. Arndt Goldack, Head of the committee

Prof. Dr.-Ing. Christoph Grafe, Member

Day of submission: 17 January 2024

Day of defense: 14 May 2024

Wuppertal 2024

Published and distributed by: Library of the University of Wuppertal

Universitätsbibliothek Wuppertal

Bergische Universität

Gauss-Strasse 20

Wuppertal-Elberfeld

Germany

Telephone: +49 202 439-2690

Telefax: +49 202 439-2695

Email: elpub@bib.uni-wuppertal.de

Website: https://elpub.bib.uni-wuppertal.de/

urn:nbn:de:hbz:468-2-4621

DOI: 10.25926/BUW/0-533

Keywords: building, design, performance, simulation, architectural education, design studio, early design.

# Acknowledgements

This Ph.D. thesis deals with the problem of how building performance assessment, in particular building performance simulation in architectural education, can be better integrated into design education in order to support future architects in taking a more active role in creating a more sustainable environment. It is conducted between 2020 and 2024 at the Chair of Building Physics and Technical Building Services at the University of Wuppertal under the supervision of Prof. Dr.-Ing. Karsten Voss.

First of all, I would like to express my heartfelt thanks to my family for supporting me at every stage of my life and to my beloved husband Gökhan Rızaoğlu, who was always with me from the very first step.

The names below are just a few of the wonderful people I've gotten to know over the past four years, so before I begin, I'd like to thank everyone for their contributions along the way and apologize in advance for not being able to mention everyone individually.

I cannot thank Prof. Dr.-Ing. Karsten Voss enough, not only for giving me the chance to be a Ph.D. student, but also for always believing in me and motivating me to do better to reach my potential, and always taking his time and being available to me.

I thank everyone who contributed to the warm atmosphere in the chair, where I started working as a research assistant in 2019 and where I felt not only with colleagues but also with real friends. I would especially like to thank Hale Tuğçin Kirant-Mitic, Dr.-Ing. Ghadeer Derbas and Dr.-Ing. Karl Walther. I thank my dear friend Yara Al Manaseer, who just started her PhD study in the chair. And many thanks to Antje Thrams, whose cheerful and curious approach to the nature allowed me to take a real break from the work I was doing at the time during our short chats at work.

And of course, my dear friends in Turkey, Zahide Berna Beycan, Mustafa Eren, Oğuz Meriç, Dr. Seda Hayal Tatlı and Orkun Türkyılmaz, it was unique for me to feel your presence despite the thousands of kilometers and your endless trust and support.

Good friends with whom we crossed paths in Germany, unfortunately it is not possible to name them all, but I would like to highlight Dr. Ioana Caracas, Kristinko Blažun and Dr. Alex Kyriacou, who witnessed my best and worst times, with whom I felt comfortable to laugh wildly, but also always felt free to live my moody moments.

I would also like to extend my gratitude to Doris Krystof, whom I had the honor of having as my mentor during the Selma Meyer Mentoring Qualification Program at Heinrich Heine University Düsseldorf, for the valuable time she spared for me not only as a mentor but also as a friend.

For the direct contributions to the thesis, I would like to thank Univ.-Prof. Dr.-Ing. Anton Maas who, together with Prof. Dr.-Ing. Karsten Voss opened the necessary communication channels for the realization of the first survey “BPS in Teaching” and the members of “Standing Committee of Building Physics and Technical Services” of the university lecturers in German language institutions, with whom I was able to conduct the survey, as well as the participating teams of the Solar decathlon 21/22 Competition for their invaluable contribution to the second survey “BPS in SDE22/22”.

Special thanks to each and every one of my students for their interest and contributions during the winter semesters of 2020 and 2021, when the “performance-based design” course prototypes were implemented and tested in the architecture master's program at the University of Wuppertal.

I owe special thanks to Univ.-Prof. Dipl.-Ing. Dr. Christina Johanna Hopfe, who inspired the content of the survey, which was one of the first steps of my Ph.D. research, and whom I had the opportunity to meet afterwards. Although she could not be my co-supervisor, contributed greatly to enriching the methods of the research through clear and fruitful discussions during my research stay at the Institute of Building Physics, Services and Construction, TU Graz. I would also like to thank the International Office of the University of Wuppertal for supporting me in accessing Erasmus funds to finance the research mobility.

I sincerely acknowledge the Center for Graduate Studies at the University of Wuppertal for granting me access to the German Academic Exchange Service (DAAD) Teaching Assistant Fund during the test phase of the course prototypes and for partially funding my participation in the CESBP 2022 and BAUSIM 2022 conferences, as well as for the great events they organized, such as excursions, theatre and cinema visits, especially for tickets to many of Pina Bausch's works.

I would also like to thank the Gender Equality and Diversity Unit at the Wuppertal University for their support for my participation in the BS202 conference through the fund for women researchers.

Finally, I would like to extend my sincere thanks to Prof. Marilyne Andersen of the École Polytechnique Fédérale de Lausanne, Univ.-Prof. Dr.-Ing. Christoph Nytsch-Geusen of the Berlin University of the Arts, Prof. Christoph Reinhart of the Massachusetts Institute of Technology, Prof. Dr.-Ing. Hans Jürgen Schmitz of the Frankfurt University of Applied Sciences, Prof. Dipl.-Ing. Andreas Wagner of the Karlsruhe Institute of Technology, who took time out of their busy schedules to participate in the interviews and whose highly objective and fruitful evaluations ensured that the research was evaluated by international experts.

# Abstract

This research is concerned with the use of Building Performance Simulation (BPS) integrated with design in architectural education. In the midst of climate change, with time running out to achieve sustainable future goals, it is becoming increasingly difficult to create a built environment with low environmental impact yet high comfort, while achieving energy efficiency and maintaining aesthetic quality. To overcome the multidimensional and highly interactive challenges in the field of architecture and thus realize this multi-purpose built environment, a wider adoption of interdisciplinary approaches that address multiple parameters in an integrated manner is a necessity rather than an option.

The practical application of integrated approaches depends, among other things, to a significant extent on whether practitioners are familiar with integrated approaches and have acquired the necessary knowledge and skills during their higher education. However, BPS is often an add-on rather than a natural part of design education, so new methods are needed to provide design-integrated experiences in education. This research explores how BPS is used in practice and education, and specifically how it is taught in architectural education, and presents a framework for teaching performance-based design in architectural education.

The research is carried out in 4 main steps:

(1) The state of the art in the use of BPS in architectural practice and education is examined through an extensive literature review. The literature review shows that BPS is still underutilized in architectural practice, especially when considering the use of BPS tools in the design phase of architectural projects. It is found that one of the main reasons for this is the lack or low level of knowledge and skills of architects to apply BPS in design workflows, which in turn is due to the fact that BPS education in architectural education is often not provided at all, and when it is, it is often not integrated with design education. The architectural design studio has been identified as the focal point for the potential use of BPS in the design context. However, the review has shown that integrated studio education is very rare and therefore requires more attention.

(2) Two survey studies and interviews are conducted to further investigate the current state in terms of methods and tools of teaching and using BPS in higher education. The results of the "BPS in Teaching" survey show that BPS in higher education in Germany is mainly taught in an interdisciplinary environment in terms of both students' and lecturers' backgrounds, but mostly at the graduate level, through elective courses, separate from design education, case study driven rather than design driven, and using BPS tools that are mostly not integrated or compatible with digital design environments. The results of the "BPS in SDE21/22" survey indicate that the Computer-Aided Design (CAD)-based digital design environments have a high potential for further development of digital platforms that integrate design and BPS tools, thus integrating performance analysis into the design process. Ease of use was identified as the most important feature of a BPS tool to be used in early design. Based on the interviews, which aimed to further explore design-integrated BPS teaching through educators' shared experiences, low level or lack of awareness of environmental issues, students/educators' reluctance to respond to BPS results, educators' level of competency in building science, challenges in interdisciplinary teaching, students' varying levels of building physics knowledge and BPS skills, students' difficulty in understanding BPS results, balancing design and performance content are identified as the main difficulties at student and educator level. At the tool level, the capabilities of tools that can help overcome the uncertainties of the early design phase with templates, exchange data with other design and BPS tools, and be easy to use and learn are mentioned.

(3) Platform prototypes are designed to investigate whether the adoption of a simplified BPS integrated into a design tool supports the integration of BPS in design education. It is aimed to allow students to focus on form and material performance aspects rather than active conditioning and other related building mechanical systems, with tailored simulation workflows didactically structured for architectural early design. These prototypes were tested and evaluated through course observations and student feedback. The students' interaction with the prototypes was positive not only because the prototypes provided predefined workflows, a guiding user interface and were integrated into a design tool they were already using, but also because it reduced the number of simulation inputs by allowing them to work on the architectural form as needed in early design phase. On the other hand, the simulation run time was unfavorable due to the high number of tools used to build the platforms. Overall, the platforms made the BPS experience easier, integrated and attractive at the early phase for the students using them and raised the learning curve of the students at the intersection of design and BPS.

(4) Integrated design studio prototypes are designed to find out how useful a design studio is for integrating the BPS into architectural education and what the main components of an integrated design studio should be. The studio prototypes are tested and evaluated through course observations, student surveys, and educator interviews. The findings indicate that the integrative effectiveness of the design studio is significant. Design project, simultaneous interdisciplinary feedback, supplementary courses, concrete pedagogical methods, coupled BPS and digital design tools, theoretical simplifications are identified as the main components of the integrated design studio.

Based on the overall findings of the thesis research, a framework for performance based early design teaching in architectural education is outlined and presented. The main contribution of this thesis to the research field lies in providing methods within a structured framework for combining design and BPS to better integrate BPS in architectural education. The main motivation is to support today's architecture students, the actors of the future, to take a more proactive role in building a sustainable future. The thesis aims to serve the engagement of the fields of architectural design and performance education by providing concrete future perspectives on the integrated use of BPS in architectural design education for educators and all relevant actors.

# Kurzfassung

Diese Forschungsarbeit befasst sich mit dem Einsatz von Building Performance Simulationen (BPS) in der Architekturausbildung. Inmitten des Klimawandels und angesichts der knappen Zeit zur Erreichung nachhaltiger Zukunftsziele wird es immer schwieriger, eine gebaute Umwelt mit geringen Umweltauswirkungen bei zeitgemäßem Komfort und hoher Gestaltungsqualität zu erreichen. Um die mehrdimensionalen und hochgradig interaktiven Herausforderungen im Bereich der Architektur zu bewältigen, ist eine breitere Anwendung interdisziplinärer Ansätze, die mehrere Parameter auf integrierte Weise berücksichtigen eher eine Notwendigkeit als eine Option.

Die praktische Anwendung integrierter Ansätze hängt unter anderem in erheblichem Maße davon ab, ob die Akteurinnen und Akteure mit integrierten Ansätzen vertraut sind und die erforderlichen Kenntnisse und Fähigkeiten während ihres Studiums erworben haben. BPS ist jedoch häufig eher ein Zusatz als ein regulärer Bestandteil im Studium. Neue Methoden sind erforderlich, um designintegrierte Erfahrungen im Studium zu vermitteln. In der vorliegenden Arbeit wird untersucht, wie BPS in der Praxis und in der Hochschullehre eingesetzt wird, insbesondere wie es im Studium der Architektur gelehrt wird. Darauf aufbauend wird eine experimentelle Plattform für die Vermittlung von „performance based design" vorgestellt und im Einsatz evaluiert.

Die Forschungsarbeit wird in vier Bereichen durchgeführt:

(1) Der Stand der Technik bei der Anwendung von BPS in der architektonischen Praxis und Ausbildung wird anhand einer umfassenden Literaturübersicht untersucht. Die Literaturrecherche zeigt, dass BPS in der architektonischen Praxis immer noch zu wenig genutzt wird, insbesondere wenn es um den Einsatz von BPS-Werkzeugen in der Entwurfsphase von Architekturprojekten geht. Es wird festgestellt, dass einer der Hauptgründe dafür das fehlende oder geringe Wissen und die geringen Fähigkeiten von Architekten zur Anwendung von BPS in Entwurfsabläufen ist. Dies ist darauf zurückzuführen ist, dass die BPS-Ausbildung im Studium der Architektur oft gar nicht angeboten wird, und wenn doch, dann ist sie oft nicht in die Entwurfsstudios integriert. Das architektonische Entwurfsstudio wurde als Brennpunkt für den potenziellen Einsatz von BPS im Entwurfskontext identifiziert. Die Überprüfung hat jedoch gezeigt, dass eine integrierte Studioausbildung sehr selten ist und daher mehr Aufmerksamkeit erfordert.

(2) Zwei Umfragen und Interviews wurden durchgeführt, um den aktuellen Stand der Methoden und Werkzeuge für die Lehre und den Einsatz von BPS in der Hochschulbildung zu untersuchen. Die Ergebnisse der Umfrage "BPS in der Lehre" zeigen, dass BPS in der Hochschulbildung in Deutschland hauptsächlich in einem interdisziplinären Umfeld gelehrt wird, sowohl in Bezug auf den Hintergrund der Studierenden als auch der Dozenten, aber meist auf der Graduiertenebene, in Wahlkursen, getrennt von der Entwurfsausbildung, eher fallstudienorientiert als designorientiert, und unter Verwendung von BPS-Werkzeugen, die meist nicht in digitale Entwurfsumgebungen integriert oder mit diesen kompatibel sind. Die Ergebnisse der Umfrage "BPS in SDE21/22" deuten darauf hin, dass die auf Computer-Aided Design (CAD) basierenden digitalen Entwurfsumgebungen ein hohes Potenzial für die Weiterentwicklung digitaler Plattformen haben, die Entwurfs- und BPS-Werkzeuge integrieren und somit die Performanceanalyse in den Entwurfsprozess einbeziehen. Die Benutzerfreundlichkeit wurde als wichtigstes Merkmal eines BPS-Tools für den Einsatz in der frühen Entwurfsphase genannt. Auf der Grundlage der Interviews, wurden ein geringes oder fehlendes Interesse für Umweltfragen, die Zurückhaltung der Studenten/Pädagogen bei der kritischen Interpretation der BPS-Ergebnisse, das Kompetenzniveau der Lehrenden und der Akteure, die Herausforderungen beim interdisziplinären Unterricht, die unterschiedlichen Niveaus der Studierenden in Bezug auf bauphysikalische Kenntnisse und BPS-Fähigkeiten, die Schwierigkeiten der Studierenden beim Verständnis von BPS-Ergebnissen und

die Ausgewogenheit von Entwurfs- und Leistungsinhalten als die Hauptschwierigkeiten auf der Ebene von Studierenden und Lehrenden identifiziert. Auf der Ebene der Werkzeuge wurden Eigenschaften von Werkzeugen identifiziert die helfen können, die Unsicherheiten der frühen Entwurfsphase mit gezielten Strukturhilfen zu überwinden, die Bedienung vergleichsweise einfach zu halten und Daten mit anderen Entwurfs- und BPS-Werkzeugen auszutauschen.

(3) Mit Hilfe von Plattformprototypen soll untersucht werden, ob die Einführung eines vereinfachten BPS, das in ein Entwurfswerkzeug integriert ist, die Integration von BPS in das Architekturstudium unterstützt. Ziel ist es, den Studierenden vergleichsweise einfache Möglichkeit zu geben, sich auf Performanceaspekte des Entwurfs und der Baukonstruktion zu konzentrieren und nicht auf gebäudetechnische Systeme. Dies wird erreicht durchvorkonfigurierte Simulationsabläufen, die didaktisch für den frühen architektonischen Entwurf strukturiert sind. Diese Prototypen wurden durch Kursbeobachtungen und Studentenfeedback getestet und bewertet. Die Interaktion der Studierenden mit den Prototypen war nicht nur deshalb positiv, weil die Prototypen vordefinierte Abläufe und eine zielführende Benutzeroberfläche boten sowie in ein bereits verwendetes Entwurfswerkzeug integriert waren, sondern auch, weil sie die Anzahl der Simulationseingaben reduzierten. Andererseits war die Simulationslaufzeit aufgrund der großen Anzahl von Werkzeugen, die zur Erstellung der Plattformen verwendet wurden, ungünstig. Insgesamt machten die Plattformen die BPS-Erfahrung einfacher, integrierter und attraktiver in der frühen Phase des Entwurfs und erhöhten die Lernkurve an der Schnittstelle von Design und BPS.

(4) Integrierte Entwurfsstudio-Prototypen wurden entwickelt um herauszufinden, wie nützlich ein Entwurfsstudio für die Integration des BPS in die Architekturausbildung ist und was die Hauptkomponenten eines integrierten Entwurfsstudios sein sollten. Die Studio-Prototypen wurden durch Kursbeobachtungen, Befragungen von Studierenden und Interviews mit Dozenten getestet und evaluiert. Die Ergebnisse zeigen, dass die integrative Wirksamkeit des Entwurfsstudios signifikant ist. Entwurfsprojekte, gleichzeitiges interdisziplinäres Feedback, ergänzende Kurse, konkrete pädagogische Methoden, gekoppelte BPS- und digitale Entwurfstools und theoretische Vereinfachungen werden als die Hauptkomponenten des integrierten Entwurfsstudios identifiziert.

Auf der Grundlage der Ergebnisse der Dissertation wird ein Rahmen für eine performance-orientierte, frühe Entwurfslehre in der Architekturausbildung skizziert und vorgestellt. Der Hauptbeitrag dieser Arbeit zum Forschungsfeld liegt in der Bereitstellung von Methoden innerhalb eines strukturierten Rahmens für die Kombination von Entwurf und BPS, um BPS besser in das Architekturstudium zu integrieren. Die Hauptmotivation besteht darin, die heutigen Studierenden als die Akteure der Zukunft dabei zu unterstützen, eine proaktivere Rolle beim Aufbau einer nachhaltigen Zukunft zu übernehmen. Die Dissertation zielt darauf ab, konkrete Zukunftsperspektiven für den integrierten Einsatz von BPS im Architekturstudium für Lehrende und alle relevanten Akteure aufzuzeigen.

# Nomenclature

| Abbreviation | Description |
|---|---|
| 2D | 2-Dimensional |
| 3D | 3-Dimentional |
| ABK Stuttgart | Stuttgart State Academy of Art and Design |
| AEC | Architecture, Engineering and Construction |
| AIA | American Institute of Architects |
| Bauhaus-Uni Weimar | Bauhaus-University Weimar |
| BC | Building Challenge |
| BEST | Building Energy Software Tool |
| BIM | Building Information Modeling |
| BKU | Bangkok University |
| BPS | Building Performance Simulation |
| BUW | University of Wuppertal |
| CAD | Computer Aided Design |
| CHA | Chalmers Technical University |
| CLC | Continuous Learning Cycle |
| CS | ClimateStudio |
| CTU | Czech Technical University |
| DC | Design Challenge |
| DHW | Domestic Hot Water |
| DIN | German Institute for Standardization (Deutsches Institut für Normung) |
| DOE | Department of Energy |
| DPM | Design Performance Modeling |
| ELT | Experiential Learning Theory |
| EU | European Union |
| EUI | Energy Use Intensity |
| FHA | Aachen University of Applied Sciences |
| gbXML | green building Extensible Markup Language |
| GH | Grasshopper |
| GRE | École Nationale Supérieure d'Architecture de Grenoble |
| GUI | Graphical User Interface |
| HBC | Biberach University of Applied Sciences |
| HDU | House Demonstration Unit |
| HFT | Stuttgart University of Applied Sciences |
| HOAI | German Honorarium Regulations for Architects |
| HSD | Dusseldorf University of Applied Sciences |
| HVAC | Heating, Ventilation, Air Conditioning |
| ION | Ion Mincu, University of Architecture and Urbanism Bucharest |
| IPCC | Intergovernmental Panel on Climate Change |
| ITU | Istanbul Technical University |
| KIT | Karlsruhe Institute of Technology |
| KMU | King Mongkut’s University of Technology Thonburi |
| LCA | Life Cycle Assessment |
| M | Method |
| MOO | Multi-Objective Optimization |
| n/a | not applicable |
| n/d | not defined |
| NA | not available |
| NB | Sustainable Building (Nachhaltiges Bauen) |
| NCT | National Yang Ming Chiao Tung University |
| OAT | One-at-a time |
| Obj | Objective |
| PBD | Performance Based Design |
| PM | Parametric Modeling |

| | |
|---|---|
| PV | Photovoltaic |
| PVT | Photovoltaic Thermal |
| Q | Question |
| RIBA | Royal Institute of British Architects |
| ROS | Rosenheim Technical University of Applied Sciences |
| SCBUTA | Standing Committee of Building Physics and Technical Services |
| SD | Solar Decathlon |
| SDE21/22 | Solar Decathlon Europe 2021/2022 |
| SOLO | taxonomy of the Structure of the Observed Learning Outcomes |
| SOO | Single-Objective Optimization |
| TH Köln | University of Applied Sciences Köln |
| TH OWL | Ostwestfalen-Lippe University of Applied Sciences |
| THL | Technical University of Applied Sciences Lübeck |
| TU Berlin | Technical University of Berlin |
| TU Dresden | Technical University of Dresden |
| TU Kaiserslautern | Technical University Kaiserslautern |
| TU Munich: | Technical University of Munich |
| TUD | Delft University of Technology |
| TUE | Eindhoven University of Technology |
| Uni Kassel | University of Kassel |
| UPH | University of Pécs |
| UPV | Polytechnic University of Valencia |
| US | United States |
| VPL | Visual Programming Language |

| Notation | Description | Unit |
|---|---|---|
| ASE | Annual sunlight exposure | % |
| avgUDIa | Average useful daylight illuminance - autonomous | % |
| DF | Daylight factor | % |
| g-value | Solar energy transmittance | % |
| sDA | Spatial daylight autonomy | % |
| sDG | Spatial daylight glare | % |
| SHGC | Solar heat gain coefficient | % |
| Top | Operative temperature | °C |
| Tvis | Visible light transmittance | % |
| Ug | Glazing thermal transmittance | $W/m^2K$ |
| U-value | Thermal transmittance | $W/m^2K$ |

# Contents

# Chapter 1

## INTRODUCTION

As time is running out to achieve sustainable future goals, it is becoming increasingly difficult to create a built environment with low environmental impact yet high comfort, while achieving energy efficiency and maintaining aesthetic quality. The increasing demand for energy efficiency to reduce greenhouse gas emissions as part of climate change mitigation strategies has set a higher standard for Architecture, Engineering and Construction (AEC). The European Union has announced a number of new policies in recent years [1]: In December 2019, EU leaders meeting in the European Council agreed that the EU should achieve climate neutrality by 2050, meaning that EU countries must dramatically reduce their greenhouse gas emissions and find ways to compensate for remaining and unavoidable emissions to achieve a net-zero emissions balance; As an interim step towards the 2050 goal, they agreed to more than halve the EU's greenhouse gas emissions by 2030 (compared to 1990 levels); and in June 2021, the Council adopted the European Climate Law - a key element of the European Green Deal, legally committing EU countries to meet both the 2030 and 2050 climate goals.

The complexity of the multi-objective process of meeting comfort needs while achieving energy efficiency, minimizing environmental impact, and ensuring aesthetic quality is becoming increasingly challenging. To achieve the desired sustainability goals, optimum solutions are sought that take into account multiple performance criteria, rather than focusing on a single objective. At this point, Building Performance Simulation (BPS) tools stand out by enabling these complex analyses to be performed more quickly and effectively in a multi-layered, interdisciplinary and evidence-based manner [2–4]. It is argued that the need for sustainability further increases the complexity of buildings and that it is almost impossible to achieve this through individual approaches and that integrated multidisciplinary work is an imperative[5].

The initial steps in building design are particularly important for the performance of a building in terms of environmental, comfort, energy and, of course, aesthetic considerations. [6–12]. On the flipside, while a great deal of research and tools have been developed over the last half-century, only a few BPS tools have become widespread among architects, and few of these can actually be used in the early design phase [13–16]. This is due, on the one hand, to the fact that most of the tools, that claim to provide an integrated design and BPS workflow, mainly serve to evaluate projects that are already in an advanced phase or almost completed design stage, and have not really been used for "design" [17–23].; and, on the other hand, to the fact that architects are often not introduced to BPS during their higher education, or learn BPS separately from their design education, thus lacking the opportunity and skills to carry out a design workflow in an integrated approach [16,24–26]. In this situation, it is essential to develop interdisciplinary and design-integrated teaching and learning methods. Architects are not the only actors responsible for overall performance, but given that they are the main actors in the design process, and given the importance of the impact of architectural design decisions on overall performance, it is clear that they have a key role to play in incorporating baseline performance assessments into the design process.

Previous studies [16,26–34] investigating the relevance of BPS education in higher education show that the experience gained during education plays a significant role in the adoption of BPS tools by architects and engineers in their professional life. As argued by many before [29,30,34–37] , the first and foremost requirement for the integrated approach is to have sufficient domain knowledge and then the necessary experience to be able to apply this knowledge. Yet many other studies point to the gap between the knowledge and skills of graduates in BPS and the expectations of the AEC industry

[16,22,24,38–40], indicating an urgent need for action towards more integrated, knowledge-based and scientific methods in architectural education that can act as a catalyst for more interdisciplinary and integrated design teaching.

The contribution of this thesis is to outline a framework for a better adoption of BPS in architectural education by providing methods for combining design and BPS, thereby revealing the components for the action needed in current architectural education and supporting today's architecture students as future actors to take a more proactive role in building the envisioned sustainable future.

## 1.1. Motivation

The adoption of integrated teaching and learning methods, especially the integration of BPS in design teaching, is important to ensure an interdisciplinary and multidimensional architectural education, thus equipping future actors to manage the complex tasks of AEC. Nevertheless, BPS has not yet been fully integrated into design education. A thorough identification of the challenges for the integrated teaching of BPS in design would be the first step towards a solution.

Second, educational BPS tools that are easy to use, easy to learn, and integrated into a design tool that allows architecture students to analyze multiple performances in their own design environments can promote targeted integration. However, there are still gaps in this regard and more research is needed to develop such BPS tools.

The design studio, as the core of architectural education, can provide a useful ground for integrated BPS teaching. But only a few studies have explored this potential. The existing ones have either addressed the teaching of BPS in a course that is not part of the design studio or have examined the design studio but excluded BPS. Therefore, more comprehensive and systematic research is needed to determine how useful the design studio can be in this regard and what the key components of integrated design studio teaching should be on the move to a performance-based early design teaching.

## 1.2. Problem and Methodology

The broader adoption of interdisciplinary approaches in architectural education that address multiple parameters in an integrated manner is a necessity rather than an option. Integrating performance into design education at an early stage of the architectural design process is a potential way to make relevant assessments a natural part of the process and a means of informing and motivating the design, rather than merely an additional instrument to evaluate the designs already developed. However, early design integration is very limited, so even if students are familiar with BPS, they often lack the knowledge and skills for design-integrated performance evaluation because BPS is often not taught as part of their design education.

In response, this research aims to characterize the challenges and potential solutions for the integrated teaching of BPS in design in order to outline a framework for performance-based early design teaching in architectural education.

The research has 3 main objectives: (1) to investigate the use of BPS in practice and in architectural education; (2) to explore if the adoption of simplified BPS in a design tool supports integration; and (3) to find out how integration can be improved with the help of design studio teaching. The research used literature review, questionnaires, interviews, and prototyping methods to achieve these objectives. The problem, purpose, objectives, methods and research questions are illustrated in Figure 1. 1, showing the relationships between them.

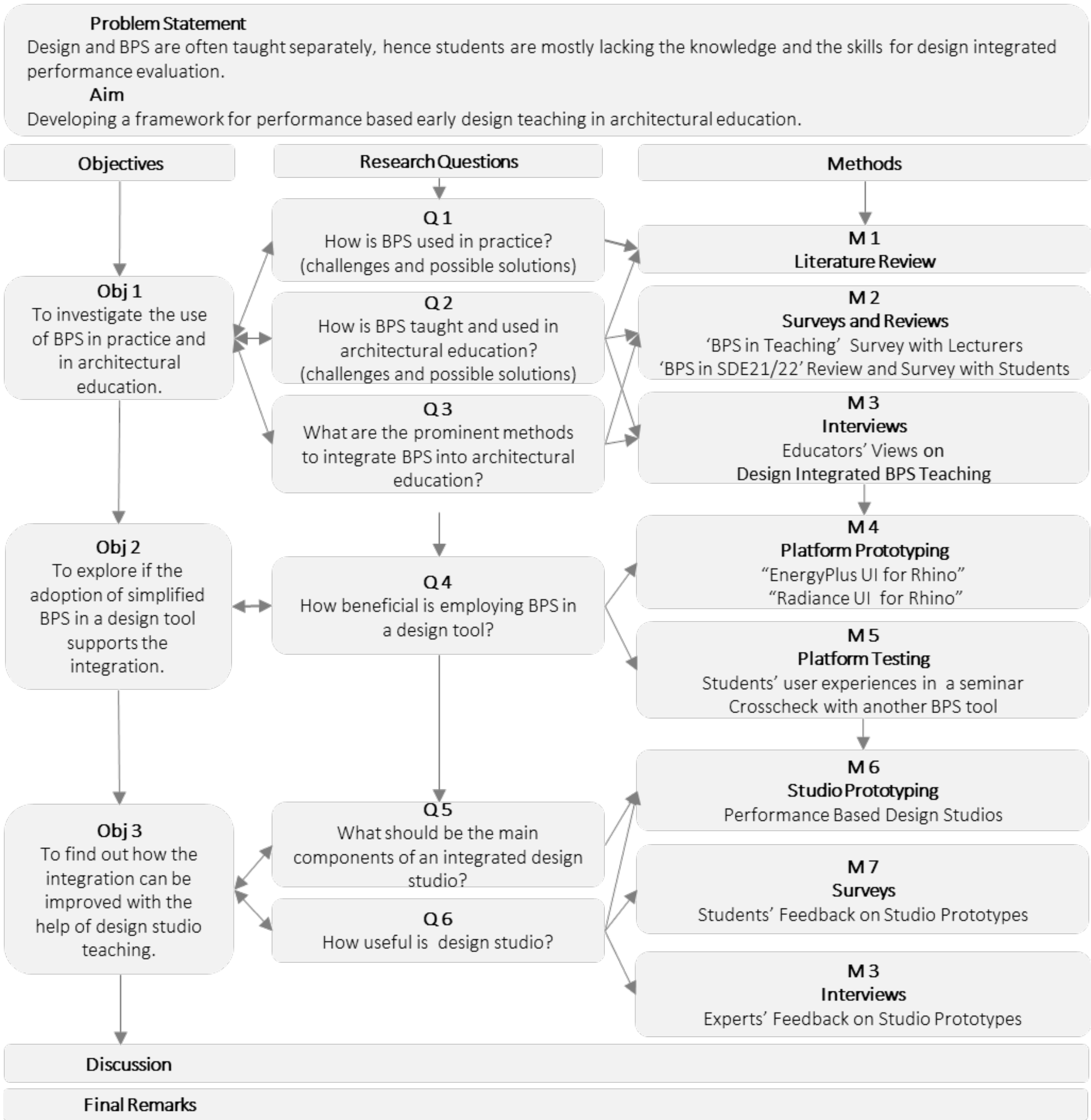



Figure 1. 1: Illustration of the aim, objectives, research questions and methods of the thesis.

## 1.3. Structure and Main Content

The thesis consists of 6 chapters, structured as follows (Figure 1. 2):

**In Chapter 1**, following a brief introduction on the background and motivation of the research, the main problem area that the thesis focuses on, the aim, objectives, research questions and methodology of the research are explained. Also, the structure of the thesis is presented by describing the main content of the chapters.

**In Chapter 2**, the state of the art in BPS use in architectural practice and education is presented. First, the conceptual framework of the terminology is outlined by defining the terms that are frequently referred to in the thesis. Secondly, the adoption of BPS in practice is explained by elaborating the historical background, the necessity of BPS in practice, the role of architects in BPS, the role of BPS in early design. Next, the relationship between performance and form is analyzed through the review of prominent projects where BPS has been incorporated into the project design process, starting from the early design phase. Finally, how BPS is taught and used in architectural education is explored, focusing on the relevance of BPS, challenges and possible solutions for its integration into design education. The chapter concludes with a review of selected design studio experiences around the world.

In Chapter 3, two survey studies, namely "BPS in Teaching" and "BPS in SDE/22", which aim to further investigate the use of BPS in higher education, are presented and the results of the surveys are evaluated. First, based on the results of the "BPS in Teaching" survey with the participation of 18 lecturers who teach BPS tools in higher education institutions in Germany, the courses in which BPS is taught and BPS tools used are discussed. Second, the integrated effectiveness of the BPS tools and related methods used in the Solar Decathlon Europe 21/22 competition is investigated through the results of the "BPS in SDE21/22" review and survey with the participation of the competition teams. Following this, interviews with educators to further explore design-integrated BPS teaching are presented and evaluated. Within the scope of the study, the courses taught by the interview participants were discussed in terms of performance content, level, type, format, ratio of design content, number of students, design scales, activities, tools, and assessment methods. Moreover, the main difficulties in integrating building performance - in particular BPS - into the design process in architectural education in general and possible solutions are elaborated through the interview.

In Chapter 4, platform prototypes designed and tested to investigate whether the employment of design tool-integrated and simplified BPS tools, with a reduced level of simulation input that allows the user to focus more on form and material related issues rather than technical engineering aspects, supports the integration of BPS in design education are presented. The evaluation of the prototypes through classroom observations and student feedback is shared.

In Chapter 5, integrated design studio prototypes are presented that were designed and tested to find out how useful a design studio is for integrating BPS into architectural education and what the main components of an integrated design studio should be. Evaluations of the prototypes made through course observations, student surveys, and educator interviews are shared. Based on the overall findings of the thesis research, a framework for performance-based early design teaching in architectural education is outlined and presented.

In Chapter 6, an overview of the main work and the main findings the research is presented. In conclusion, the limitations and major contributions of the thesis, including future perspectives, are shared.

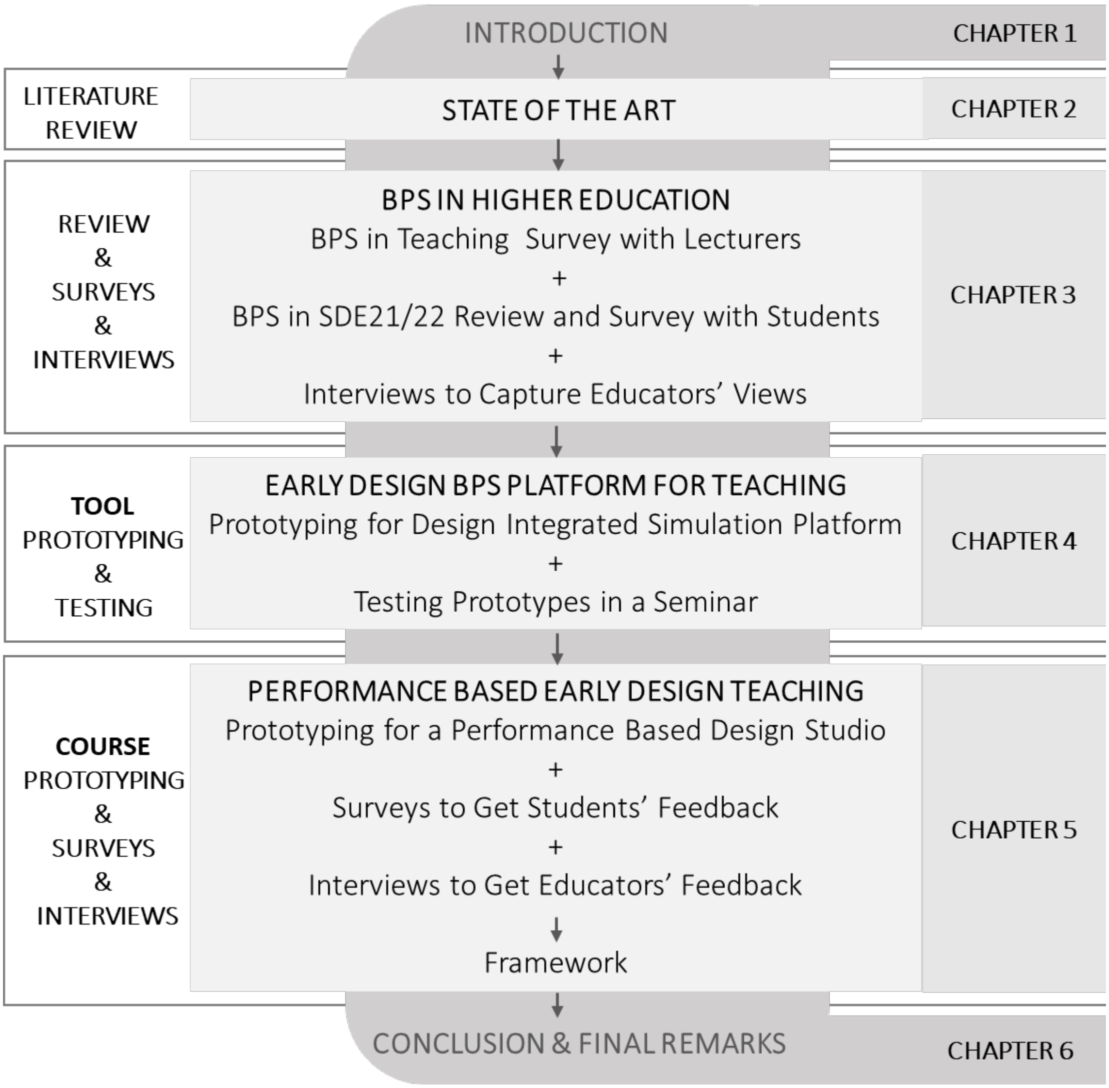



Figure 1. 2: Structure of the thesis and framework of the methods.

# Chapter 2

## THE STATE OF THE ART OF BPS IN ARCHITECTURAL PRACTICE AND EDUCATION

This chapter presents the current state of knowledge on the use of BPS in architectural practice and architectural design education.

**Section 2.1** outlines the conceptual framework of the terminology by explaining the terms of BPS, design process, design stages and phases, design evaluation, performance-based design, design and performance evaluation tools, CAD, Building Information Modeling (BIM), etc., which are the main components of this research and are frequently referred to in this context.

**Section 2.2** investigates the use of BPS in architectural practice. It discusses the historical background and evolution of the BPS tools (in section 2.2.1), the necessity of BPS in practice (in section 2.2.2), the role of architects as performer in BPS (in section 2.2.3), and the use of BPS in early design (in section 2.2.4) by elaborating on the efficiency of BPS use in relation to design phases (in Section 2.2.4.1), the suitability of BPS tools for early design (in Section 2.2.4.2), and the ability of BPS as a design stimulator (in Section 2.2.4.3).

**Section 2.3** investigates the use of BPS in architectural education. It discusses the relevance of the use of BPS in architectural education (in section 2.3.1), the current use by elaborating on the challenges and possible solutions (in section 2.3.2), the integrated architectural education in terms of creativity and science (in section 2.3.3), and the relationship between BPS and design studio (in section 2.3.4) by elaborating on the role of BPS in design studio teaching (in section 2.3.4.1) and by evaluating the design studio examples in the literature (in section 2.3.4.2).

**Section 2.4** concludes with the summary of the main findings and the description of an explicit gap in the knowledge that the PhD research aims fill.

The objective (**Obj1**), research questions (**Q1, Q2** and **Q3**) and method (**M1**) of the thesis studied in this chapter are demonstrated in Figure 2. 1.

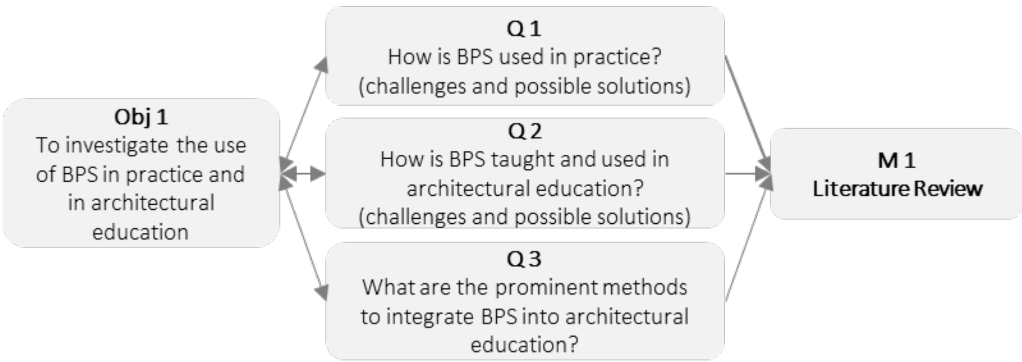



Figure 2. 1: Literature review - the objective (Obj1), research questions (Q1, Q2 and Q3) and method (M1) of the chapter.

### 2.1. Framework of the Terminology

The definition section is presented to set the conceptual framework of the terminology and to define the terms and concepts that are frequently used in this research and fundamental to this thesis, in particular "performance-based design".

### 2.1.1. Building design

The very word "**design**" refers to both an end product (noun) and a process (verb), which has been intentionally created by a thinking agent. Simon [41] states that "**Designing** is an activity to transform an existing state into a desired state.". In the context of this study, "**designers**" refers to professionals in the field of AEC and students of this field, who conceptualize and create new concepts, ideas, products of the built environment. Accordingly, "**building design**", also here it refers to "**architectural design**", means the application of a broad range of architectural, engineering and technical, as well as phycological and emotional, features to the design of buildings. Lawson [42] defines "**design process**" as an iterative cycle of analysis, synthesis and evaluation. In AEC, the design process constitutes a very large portion of design projects, accounting for at least two-thirds of the entire project process.

In this study, design phases are defined based on the stages of a building project according to the Royal Institute of British Architects (RIBA) [43] and the German Honorarium Regulations for Architects and Engineers (HOAI) [44], (Figure 2. 2): (I) **Early design phase**: Conceptual investigations, schematic design, form finding, massing studies etc. for the exploration of design options; (II) **Design development phase**: Layout of the floor plans is decided on; exactly what is needed in each part of the building and some rough designs for facades, details such as windows, comparison, evaluation and selection of prominent design alternatives are amongst the first alternatives to be developed.; (III) **Advanced design phase:** More detailed drawings are produced. Input from external consultants such as surveyors, engineers, fire officers etc. may be sought. An application for approval is made to the planning authority. At this stage all specifications and tender drawings for the project are completed.

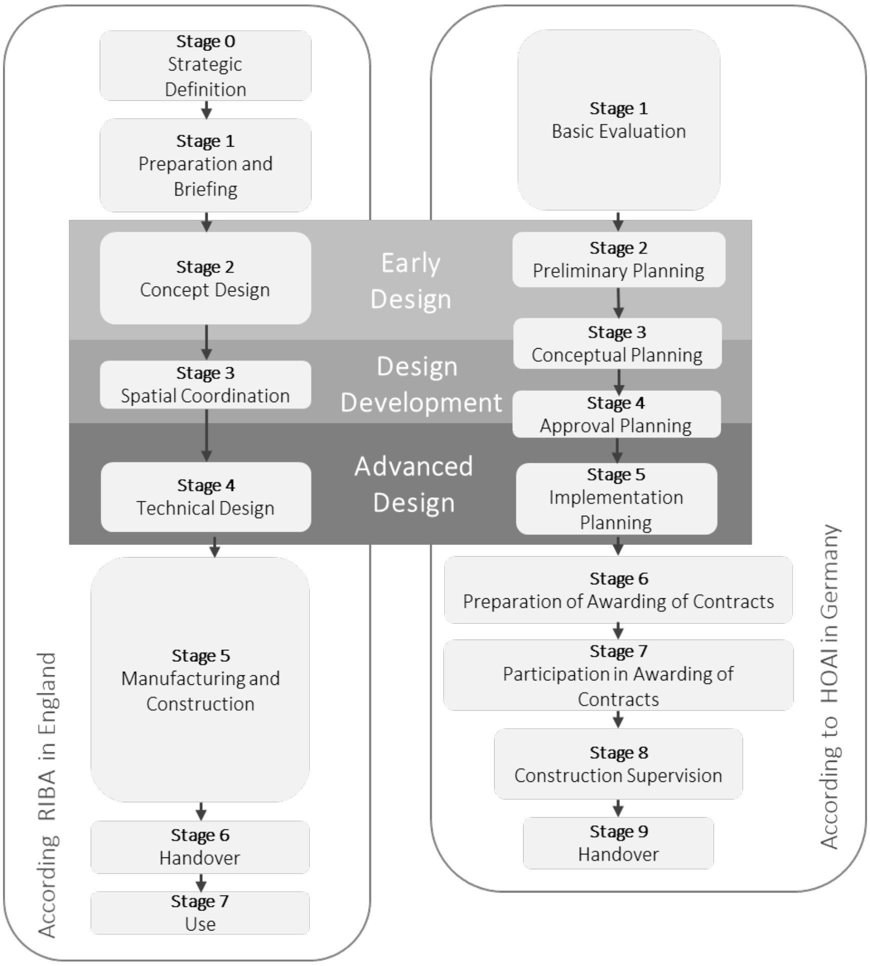



Figure 2. 2: Early, design development and advanced design phases through the stages of a building project according to RIBA [43] and HOAI [44].

### 2.1.2. Building performance

The dictionary definition of “**performance**” [45], speaking of a non-human entity, refers first to “how well or badly something works”, second to “the act or process of performing a task, an action”, and third to “the ability to perform”. Therefore, “building performance” refers to the ability of a building to perform its tasks and functions, the degree of construction control over the delivery process, and its success as a presentation or entertainment [8].

The concept of **building performance** can be tracked far back to 18th Century BC in Hammurabi’s Code, where is stated that "a house should not collapse and kill anybody". It was also often referred to in the “Ten Books of Architecture”, which is written by the Roman architect and military engineer Vitruvius (c. 80–70 BC – after c. 15 BC) and explaining the three elements necessary for a well-designed building as Firmitas (firmness, durability), Utilitas (commodity, utility, usefulness), Venustas (delight, beauty) [46].

The concept of building performance, as we understand it today, emerged in the late twentieth century, where building performance is assessed not only on structural integrity but also by adding domains such as energy use and balance, hygrothermal, acoustic, lighting, visual comfort, life cycle assessment (LCA), fire safety, urban microclimate, and also, in larger scale, environmental impact and urban building energy modeling. Gibson [47] defines the **building performance as** "the practice of thinking and working in terms of ends rather than means. [ …] It is concerned with what a building or building product is required to do, and not with prescribing how it is to be constructed. […] therefore, the performance approach is nothing more than the application of rigorous analysis and scientific method to the study of the functioning of buildings and their parts.".

De Wilde [48] states that building performance is based on expectations; for example, while the engineering view is concerned with how well a building performs its tasks and functions, the aesthetic view is concerned with the success of buildings as a form of presentation or appreciation. The concept of performance has been discussed not only in terms of the physical effects of building function and use, but also in terms of the psychological and emotional effects on occupants [49,50].

### 2.1.3. Performance based design

**Performance Based Design** (PBD), in contemporary sense, refers to a design process aiming a final product (building and/or building elements) that meets certain measurable or predictable performance requirements. Along with the new understanding of building performance, the PBD emerged as a reaction against the static concept of performance, the so called “prescriptive design”, which implies specifying exactly what steps to take [51], whereas in PBD any solution and/or method can be adopted as long as it meets the objectives of a design project.

Performance Based Building Network [52] states that “PBD is a process in which performance requirements are translated and integrated into a building design.”. Accordingly, Oxman [53] defines it as a process that includes the consideration of all guiding factors for the fulfillment of performance expectations, and uses another term “**performative design**” to point out that the process is an exploitation of BPS for the generation of design forms. Shi [54] defines PBD as a methodology in which the designers emphasize the performance of the building. Referring to Oxman's idea, he mentions “performance-driven design”, which is not only an evaluation-oriented but also an iterative process to find design alternatives and arrive at the optimal design based on multiple performance criteria by making use of intelligent parametrization and optimization techniques. And one recent study by Ampanavos and Malkawi [55] defines “**performance-driven design**” as a methodology that assists design in meeting measurable objectives related to the performance of a building. But they also highlight the time intensity and cognitive load associated with optimization and form parameterization and suggest the use of machine learning techniques. Bucher et al. [56] argue that a more goal-oriented design process is possible with an inverse formulation that starts with performance attributes rather than design parameters, i.e. by conditioning the design generation process by certain performance targets instead of checking performance of a design feature. And so, going back to the term PBD and adding the word “generative”, they redefine PBD as “a paradigm that combines both the automated form generation process and a performance-based perspective on the design workflow”.

As can be seen from the extensive definitions, PBD has also been referred to by other terms such as performative and/or performance-oriented as the level of integration into design and the necessary auxiliary methods it includes, but it still predominates as the main term to describe the subject due to its inclusiveness. Therefore, in the context of this thesis the term PBD is retained.

### 2.1.4. Building performance simulation

Quoting Becker and Parker [57]: “[…] a **simulation** enacts, or implements, or instantiates a model, which is a description of some system that is to be simulated, and often a mathematical one.” Hensen [3] describes the **simulation modeling** as creating a computer-based simplified representation of a real system that allows to concentrate on the essentials of a (complex) problem while leaving out details that are not relevant for the issues at hand; and simulation as a using a model for predicting the behavior of a real system in the future.

Schmitz [58] points out what an architect understands by a model and explains it as follows: "In architects' terminology, a 'model' is something three-dimensional, and as soon as the software presents a geometric interface, it is almost impossible to separate a 'simulation model' from the 3D representation on the screen. But the model concept of simulation encompasses much more than geometry."

De Wilde [59] explains the objective of BPS as the quantification of aspects of building performance that are relevant to the design, construction, operation and control of buildings, and defines it as “the reproduction of the physical behavior of a system”, and accordingly [60] defines the **building simulation** as “the domain of simulation that studies building or building-sub systems”.

BPS has various “**simulation domains**”; the most prominent are energy, thermal, lighting, acoustics and air flow simulations. According to United States (US) Department of Energy (DOE) [61], indication of a performance for the domains is called as a “**performance indictor**”, performance indicator is “operational information indicative of the performance or condition of a facility, group of facilities, or site, which is a parameter, or a value derived from a set of parameters”. Accordingly, “**performance metric**” [61] is a more specified and standardized version of an indicator, such as “daylight factor”, “energy use intensity”, etc.

BPS comes to the forefront when considering the methods of building performance appraisal, alongside the full-scale experiments and in-situ tests and measurements (if a building is built), which are mostly expensive and onerous [2]. Also, as mentioned by Hensen and Lambert [62], the assessment of a future building behavior/performance in advance is more efficient and economical than fixing problems when the building is in use.

### 2.1.5. Design and performance assessment tools

In the context of the thesis, “**tool**” refers to an instrument/ apparatus used in performing an operation or necessary in the practice of a vocation or profession, and “**digital tool**” is used to refer to the software applications or computer programs. For example, considering the tools of design, while "design guides" and "rule of thumbs" stay in the "tools" category, digital design programs, i.e. Sketch-up, AutoCAD, Revit, are in the "digital tools" category.

Digital - design - tools also have their sub-categories. Looking at architectural project drawings, they can be categorized as Computer Aided Design (CAD) and Building Information Modeling (BIM) tools. CAD involves the use of computers to aid in the design process of a building. In the early 1980s it was basically just the replacement of the traditional hand-drawing processes with the use of digital tools, so called CAD tools, which were initially used only for two-dimensional (2D) drawings to save working time by freeing the architect from the burden of technical drawings by hand [63]. Today, CAD tools offer wide variety of options, not only for architects, but also for anyone interested in creating 2D or 3D plans and models of design objects [64]. On the other hand, BIM tools, again with 2D and 3D design options, are more focused on the definition and documentation of building, in addition to designing it [65]. Although the concept of BIM has been in development since the 1970s, it only became an agreed term in the early 2000s.

## 2.2. BPS in Architectural Practice

### 2.2.1. Historical background

Research and practice in BPS simulation dates back to the late 1950s, approximately as long as the history of computers, and the very first reported simulation tool for buildings was BRIS, introduced in 1963 by the Royal Institute of Technology in Stockholm [66].

Kusuda [67], reporting on the early history of building system simulation, mentions that until the late 1960s, several models with hourly resolution had been developed focusing on energy assessments and heating/cooling load calculations. The energy crises in the 1970s accelerated the efforts to reduce the energy consumption of buildings, which resulted in the release of more powerful simulation engines in the early 1970s, among those were BLAST, DOE-2, ESP-r, HVACSIM+ and TRNSYS [68]. At that time computers were large in physical size, but tiny in memory, slow in speed, and difficult to approach [67–69]. In the late 1990s and early 2000s, the technological advancement in both hardware and software supported the uptake in dynamic simulation, i.e. COMFIE, IDA (based on IDA later IDA-ICE), MODELICA, EnergyPlus [16,19,70–72].

Explaining the evolution of the BPS, Clarke [73] classifies the four generations: a first generation, consisting mainly of manual methods based on analytical formulas and many simplifying assumptions (until the mid-1970s); a second generation with increased accountability for temporal aspects (mid-1970s – mid-1980s); a third generation based on numerical methods that can run on personal computers and allow for coupled simulation (mid-1970s - mid-1980s); and a fourth generation that adds program interoperability (mid 1990s – 2001). This classification reveals the high advancement of tools in less than a half century, by showing that the capabilities of building performance assessment tools increase with each new generation; on the other hand, it also reveals the complexity of these tools increases accordingly [60].

Today, BPS is applied in a wide area ranging from material scale to urban scale. The Building Energy Software Tool (BEST) directory [74] lists 288 tools for evaluating energy efficiency, renewable energy, and sustainability in buildings.

A comprehensive study [71], demonstrating the most prominent trends (from 2011 to 2022) in the literature related to BPS, points to five application areas: (1) performance-driven or -based design, (2) optimization, (3) building-to-grid interaction, (4) urban modeling and (5) digital twin (a virtual representation of an object or system, which is updated from real-time data, and uses simulation, machine learning and reasoning to help decision making in AEC).

### 2.2.2. BPS in architecture

To answer the question of whether BPS is needed in architecture, one must look at the tasks that need to be performed within the scope of architecture discipline. Even a simple search of the dictionary meaning of the word "architecture" reveals high interdisciplinary requirements: "**architecture**" – "the art or science of building or constructing edifices of any kind for human use" and (II) "knowledge of art, science, technology, and humanity" [75].

Rittel and Weber [76], referring to the planning/governing system but also fitting the context of architectural design for being at the intersection of the natural and social sciences, define the "**design problem**" as "wicked", [… ] in a sense similar to "malignant" (in contrast to "benign") or "vicious" (like a circle) or "tricky" (like a leprechaun) or "aggressive" (like a lion, in contrast to the docility of a lamb)." They state that "[…] in order to describe a wicked problem in sufficient detail, one has to develop an exhaustive inventory of all conceivable solutions in advance. Thus, in order to anticipate all questions (in order to anticipate all information required for resolution ahead of time), knowledge of all conceivable solutions is required.".

Hensen [3], in one of his most recent lectures, refers to the subsequent demand for energy saving in the view of climate change mitigation, adding that the ultimate goal is a zero-carbon sustainable built environment where the indoor environment is optimized for health, comfort and/or productivity. Voss [77,78] states that in order to achieve climate neutrality goals, fossil energy-based systems should be replaced with renewable energy, especially with Photovoltaic (PV)/Photovoltaic Thermal (PVT) systems, so that energy positive buildings can be achieved by going one step further than zero-energy buildings. At this point, computational modeling and simulation of building performance comes forward as a useful method to bring together the knowledge from many fields and enable collaboration for multidisciplinary work [3].

Lechner and Andrasik [5] argue that the need for sustainability further increases the complexity of buildings and that it is almost impossible to achieve this through individual approaches and that integrated multidisciplinary work is imperative. They emphasize the need to move from the traditional sequential design process by profession to an integrated design process by function, where performance requirements/expected functions are considered from the very beginning of the design process for high performance buildings through interdisciplinary work of all AEC actors.

Beyond that, the use of BPS in commissioning and operation also has high potential to detect possible gaps between simulated and measured and additionally support performance appraisal and monitoring models, e.g., digital twin, which uses data streams to create a digital representation of a real-world asset to improve collaboration, information access, and decision making [79].

### 2.2.3. Architect as a performer

As the initial shapers of the built environment, architects are among the most important actors. In particular, the very first steps in building design, such as deciding on the location, orientation and footprint of a building, shaping its volume and spaces, and sizing its openings, as well as early exploration of on-site energy use considering climate and site context, are very important in terms of building performance [6–11]. One study [12] arguing that energy performance related to a site should be considered in early design; e.g. solar gains of the site, shows that 10-20% of heating and cooling demand can be saved by an energy-aware site structure. The three-tier approach of Lechner [11] categorizes the design phases for sustainable design of heating, cooling, and lighting as (I) building design, (2) passive design and (3) mechanical system design. According to this approach, categories one and two should be the domain of architecture, and the proper decision at these two levels can reduce the energy consumption of buildings by up to 80 percent.

Moreover, for better communication for interdisciplinary workflow, thus for integrated design process with adoption of BPS is a must rather than an option [26,79]. This requires architects to have the basic skills and knowledge in BPS. But what is the required level of knowledge and expertise? Reinhart et.al. [80] state that the first step for architects is to have a basic understanding of the field in order to be able to interpret the BPS results and validate their designs accordingly. Alsaadani & Bleil de Souza [24], discussing the methods for teaching BPS to architects, present a concept of “consumer, performer and expert” to define the level of skills and knowledge of architects for using BPS: (1) “**consumer**”, who is limited to the basic knowledge of simulation processes and can define the questions for the simulation in dialogue with an expert and interpret the results in order to then integrate them into the design process, but mostly not the one capable of running simulation by themselves (II) “**performer**” who can carry out the basic simulations themselves in order to support early design decisions. (III) The "**expert**", who has mastered the theory and methods in detail, can model complex simulation tasks, interpret the results and safely validate them with confidence. Schmitz [58], who adopts and applies this approach in teaching, emphasizes that at least "performers" are needed to integrate BPS into early design, and that BPS with only "consumers" is destined for late integration.

### 2.2.4. BPS in early design

#### 2.2.4.1. Efficiency of BPS use in relation to design phase

Almost 20 years ago, Hensen [23] saw the potential for more effective use of BPS in its integration into early design processes, noting that simulation can be much more effective when used to compare the predicted performance of design alternatives rather than to predict the performance of a single design solution in absolute terms. Painting a picture of the state of BPS use in the early 2000s, he noted that BPS had been around for almost half a century, but had not really been used for "design". Today, BPS is still rarely used during early design [17–22]. It is mostly executed after the design stage or in a late design stage; so that feedback from analysis cannot be usefully incorporated into early modifications of the project [6,81]. The main reasons behind the low adoption rate are often cited as lack of ease of use, ease of learning, integration (or at least interaction/exchange) with design tools, rapid feedback and affordability [15,22,35,82,83]. One analytical review [84] on the use of BPS tools in informing architectural decisions in early design stages, from 2019, reveals that out of 55 tools reviewed, although 55% of the tools claimed to target both architects and engineers, only 4 tools were found to - almost - meet the expectations for early architectural design use.

Late integration of BPS tends to result in designs that are largely unsuccessful in terms of performance and require major revisions. A survey, with 306 building professionals, from 2012 [85] showed that energy modeling results directly change design, as confirmed by 80% of respondents In another survey with architects [15], which included 118 architects from India (20%), Australia (8%) and the UK (4%), with the majority from the US (68%), the almost all of the respondents agreed that the current focus on building performance has to be brought to earlier stages arguing that the late integration is more likely to result in less integrated and insufficient design solutions. According to the study, ease of use, the ability to represent complex problems and the validity of the tool were emphasized to ensure early integration. Another survey [86], conducted by IBPSA-USA in 2021 with 120 respondents (58% energy modelers and simulation specialists, 27% architects and 15% other professions), in which the thesis author participated in the analysis and visualization of the survey results, investigated the current state of early design analysis. It reveals that these possible major revisions can lead to time and cost problems. it also shows that as the design phase nears completion, architects become more committed to their designs and less willing to change them. Some other findings from this survey are also significant, such as more than 87% of respondents agreeing that early design analyses help create high performance buildings, and almost 70% agreeing that early design analyses save time and money. On the other hand, over 15% of respondents said that it can be difficult to translate analyses into meaningful results/visuals, and there were also some concerns about the complexity and cost of early design analyses. Time was the biggest barrier at 34%, followed by budget at nearly 27%, and company attitudes toward building performance at just under 17% [86].

"Architect's Guide to Building Performance" from the American Institute of Architects (AIA) [87] uses the term Design Performance Modeling (DPM) for early design, which BPS is adopted, and explains it as "*typically prepared during the early stages of design, before engineering systems are incorporated. The analysis is less complex and less time consuming, in order to allow for more rapid exploration of a greater number of parameters.*" The guide lists the analyses and simulation work in three categories: "early investigations", "single aspect simulation" and "whole building simulation". And it explains the correlation between the cost and effectiveness of changes in relation to the design phases (Figure 2. 3), which clearly demonstrates the importance of the role of architects, how effective their contribution can be and how this can reduce the cost of changes and lead to a more efficient design process.

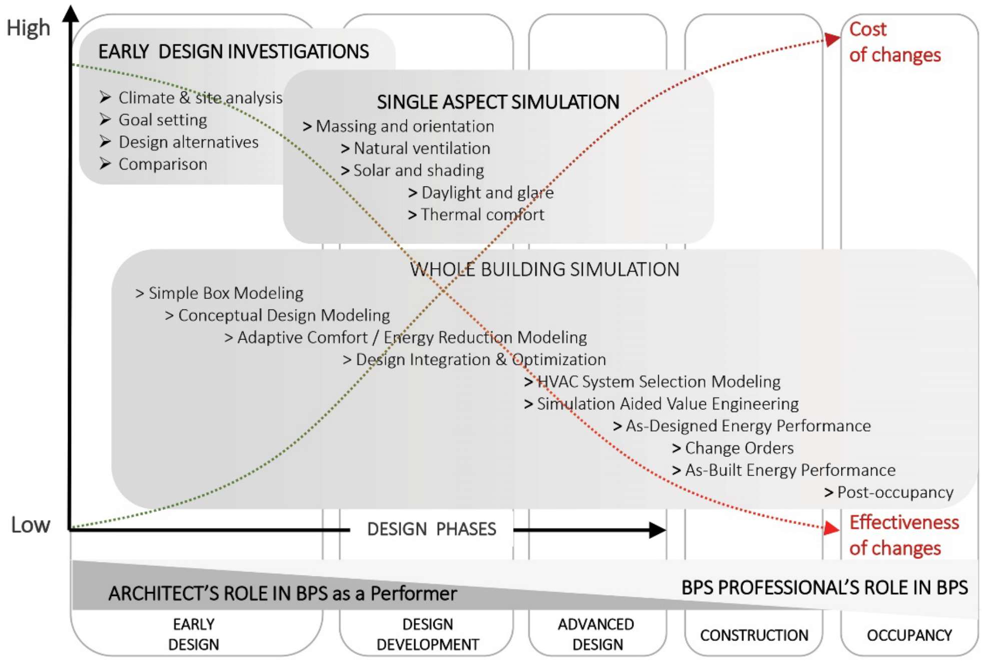



Figure 2. 3: Architect's role in BPS and changes' cost and effectiveness (Adapted from [87]).

### 2.2.4.2. Suitability of BPS tools for early design

Many authors have reported that although a considerable amount of BPS tools have been developed over 30 years to assist architects in the design process, very few of them have actually been adopted by architects and unfortunately BPS is still not inherent in the practice of architecture [13–16].

To understand how suitable and useful a BPS tool is for a particular design phase, it is necessary to understand the needs of different design phases and the features and suitability of BPS tools in comparison. Early design seeks for the detection and quick evaluation of possible design alternatives in a relatively short time and with relatively less input, thus less complex and less time-consuming design integrated BPS have a higher potential to be adopted in early design investigations [26]. Informative performance assessments [88], providing proactive support in decision-making and an ability to manipulate geometric features rather than merely analyzing performance [89], are stated among the most necessary features of early design BPS use. Architects are interested in obtaining rapid and iterative performance feedback during design, rather than analyzing whether a pre-determined building design surpasses or fails a compliance requirement in a late stage of design [90]. In early design, before the design and sizing of mechanical systems with expert consultants, BPS tools should ideally be used to inform architectural decisions about building orientation, form, material, envelope, glazing, and passive strategies [91].

However, traditional simulation tools are premised upon the ability to simulate and evaluate the performance of an object itself, once it has been defined at an appropriate level. As a result, they are rarely employed in the early conceptual stages of design [89]. A study [82] comparing ten early design BPS tools reveals that the far majority of the tools only allow the evaluation of the performance in terms of energy efficiency and energy demand, but only a few support the investigation of active solar energy utilization, such as the applications of photovoltaic panels or solar thermal collectors, which are essential to be included in early design investigation in order to be naturally integrated with architectural design. The study states that there is a need to improve existing tools to become more informative rather than evaluative. Also results of two surveys conducted among 445 architects in the USA [19] show that intelligence, which refers to support for decision making through the use of techniques such as parametric design and design optimization, and a user-friendly GUI are ranked higher than interoperability and accuracy of a BPS tool for early design use.

The first attempts for the adoption of BPS by architects were creating architect-friendly GUIs for building simulation engines [15,92], e.g. DesignBuilder (first released in 2003), Open studio (first released in 2008) and Simergy (first released in 2013) are GUIs for EnergyPlus, but difficulty of data input, lack of default values & templates, limitations on building geometry representation, and using number of simulation tools separately for different tasks were basic problems [19,82].

Meanwhile, as 3D modeling tools evolved, approaches went in two different directions: one group focused on BIM-based and the other on CAD-based environments. In general BIM was considered to be too detailed and complex for the early design. Many studies [15,70,82,85,88,89,93–96] report that interoperability of BPS and BIM tools is still an issue. The universal file formats such as green building Extensible Markup Language (gbXML) and Industry Foundation Classes (IFC) are available, but transfer workflows are still troublesome. Addition to that BIM is not as flexible as design explorations require especially in early design, due to its high-level-of-detail-demanding structure.

Distributed, run-time linked, open-source environments (e.g., Pollination by Ladybug Tools) seem to have a high potential compared to others, i.e. "combined" (e.g., IESVE) and "central" (e.g., data is shared via IFC and/or gbXML between design tool and – here it is mostly BIM - and BPS tool). Hensen [23] calls it as a "distributed integrated simulation environment", while Negendahl [70] as a "distributed model method", which is a model developed as an opposition for the central models, disengaging itself from a top-down control and one directional model operation. Distributed models of geometry (here, the "geometry" refers to an architectural design model) and simulation are characterized by integration at the model level by utilizing a middleware component (usually a software or a-self tailored/custom script) to translate data between design tools and BPS tools. A middle software, which is connecting the tools, consists of a Visual Programming Language (VPL), i.e., such as Grasshopper [97] and Dynamo [98]. Figure 2. 4 illustrates the models of design and simulation environments: (I) Combined model, which is typically operated in a simulation package; (II) Central Model, which uses a central database/file format/schema; and (III) Distributed Model, which uses a middleware to couple design and BPS tools.

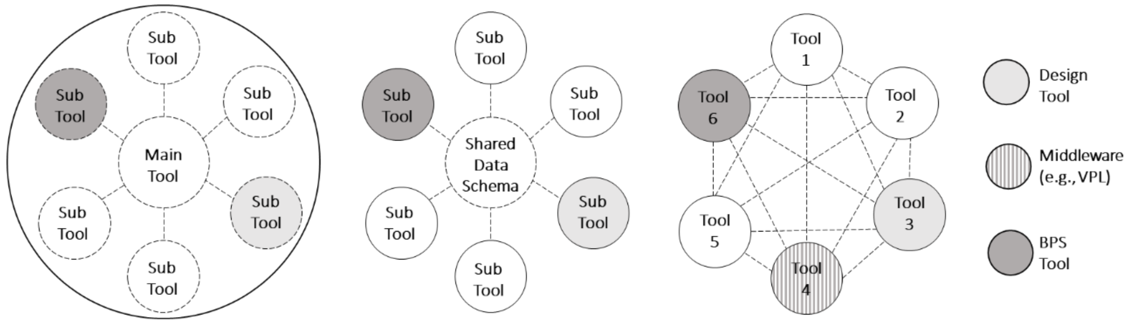



Figure 2. 4: Models of design and simulation environments: (I) Combined Model, (II) Central Model and (III) Distributed Model, (Adapted from [70]).

A work by Marsh in the late 90's, Ecotect [99,100] can be mentioned as an early example using VPL and providing a dynamic link between BPS and design models, which became quite popular in the architecture community with its features, such as, 3D modeling, architect friendly graphical user interface, gradual interaction with simulation inputs according to the design phase (less input required in early design phases), automated visual representation of results, and including a multi-domain simulation environment from climate-based analyses of radiation, sun-path and shadow to thermal, lighting, cost and acoustic analysis . Its high adoption rate is attributed to a highly visual and interactive modeling environment that presents analytical results directly in the context of a building model, and if preferred, within a site context [101,102]. On the other hand, although it was using RADIANCE for lighting analyses, the thermal model calculation was valid only in the level of teaching but not the research [103]. In 2008, the tool was acquired by Autodesk and packaged with Green Building Studio as Autodesk Ecotect Analysis. Unfortunately, Autodesk discontinued it in March 2015 [104,105] Despite the fact that Autodesk has not offered a new license for the Ecotect since 2015, in a survey study from 2020 with 418 Architects in the UK [22], Ecotect ranked second (24%) as the most recognized BPS tool by the respondents.

The very example of the application of VPL was Grasshopper (GH) [97], which came as a feature of Rhino [106] in 2007 and in some cases can be considered as a design tool itself. This was the time when Rhino was categorized differently from traditional CAD tools with its VPL feature for its ability to handle non-geometric data in addition to geometric data, and to let users create their own algorithms.

In the late 2000s, the adoption of Parametric Modeling (PM) in design practice began to increase (e.g., GH & Rhino). Concurrently, plug-ins were developed to link PM with BPS. In 2009, one of the first examples of the integration of BPS and 3D CAD design environments was Diva-for-Rhino [107], which is a solar radiation, daylight, glare and thermal simulation plug-in for Rhino with the features such as easy input and visual representation of results integrated with architectural model.

The second development regarding this integration was the increase of open-source and free tools. For instance, in 2013, Ladybug [108] plug-in for GH, which was one of the earliest examples of open source and free BPS tools in CAD parametric design environment for climate-based environmental analysis, was released. Then, in 2014, Honeybee [109] for GH was released to connect GH to validated radiation/lighting and energy simulation engines, such as Radiance [110] and EnergyPlus [111].

In the late 2010s, the integration of BPS, PM and DO methods into the 3D CAD design environment continued to increase. This development was very promising for early-stage exploration, with benefits such as providing information during design, expanding the solution space and comparing design alternatives in a design environment. However, although it is fast once the formulation is determined and the workflow is structured, the time-intensive and complex formulation within and between methods and techniques is still a disadvantage. [112].

In addition, there were recent two attempts. First, in the end of 2019, Rhinoceros introduced the Rhino.Inside.Revit, which allows Rhino and GH to run inside Revit [113]. The adoption of Rhino in Revit supports the idea claiming that BIM is not suitable for conceptual design. Second, in early 2020, Solemma [114] introduced the ClimateStudio (CS) [115] for Rhinoceros. It is a new daylighting and building energy modeling tool with prominent features, e.g. simplified and almost fully visual GUI in Rhinoceros. CS for GH is promising for flexible exploration of design alternatives, but CS lacks custom GUI due to the nature of the GH environment.

Concluding the section on the suitability of BPS for early design, the most frequently mentioned future prospects in the literature are listed as follows with a particular focus on the use of BPS tools in the early stages of projects: ease of use, ease of learning, architect friendly GUI, adequate simplification for a particular design phase, gradual increase of  input requirements, interoperability, evaluation of multiple performance aspects in relation, open source, distributed and design-integrated simulation environments, visual representation of results (and if possible on a design model), coupling with intelligent techniques, i.e. automation, parametrization and optimization.

#### 2.2.4.3. BPS as a design stimulus

Do performance related decisions can influence a design, contributing to its aesthetic quality? The very term “form”, as described by Cody [116], refers to “the appearance of a building in general and the architectural elements and means of expression used to determine it”. According to Kalay [117], performance is a measure of the merging of form, function, and context, and the issues of form” and function cannot be separated, since each one informs the other, and influences the development of each other. He claims that the relationship between form and function is much more complicated than the causality-based notion of “form follows function” implies, using the example of a chair: one function (sitting), many different designs.

Performance-based decisions clearly have an impact on the aesthetics of a design. But whether this impact can be valued is still a matter of question. Cody [7] takes this question a step further and asks whether PBD has an architectural language, adding that we will have to wait a few more decades to find out because PBD is still almost new. Following Hensen [3], it is difficult for PBD to have a single language, because PBD design is shaped by different parameters in each project: climatic, expectational, economic and social.

To demonstrate how performance-based architectural elements can have a strong impact on the appearance of buildings, some architectural examples have been analyzed and are presented in Table 2. 1.  The selection criteria of the examples are based on the representation of different types of projects (i.e. residential, commercial, educational, etc.) that have received awards for building performance and architectural design since the 2000s, when the concept of PBD emerged.

*Low Energy Apartment* (org. in German: Niedrigenergiehaus) (Table 2.1-1), toward minimizing the heating energy demand in winter, has a large, curved, south facing facade with a high proportion of glass. The depth of its balconies is designed considering the solar angle, therefore providing shading in summer and allowing solar gains in wintertime. The spatial organization of the building is based on thermal zones: the living rooms on the south side, an unheated buffer zone on the north side where the staircases and lifts are located, and the rooms requiring the highest internal temperatures, the mechanically ventilated bathrooms, in the middle [116,118].

*GSW Tower's* (Table2.1-2) with double-skin façade, with no vertical or horizontal compartmentalization within the cavity, provides natural exhaust of the offices used air by means of convection. The form of the "flying roof" construction at the top of the double skin was optimized to extract air from the flue and support the natural ventilation of the offices. The integration of the building services into the floor slabs allowed long-span spaces and maximum clear height in the office zones [7].

*Vancouver Convention Centre* (Table 2.1-3) is well known for its large green roof enlarging the city's recreational area. An important performance-based decision about the daylight autonomy had a high effect on the façade and fenestration types and dimensions.

*Guangzhou Opera House's* (Table 2.1-4) design stems from the concept of "two rocks washed by the Pearl River", but the form of the rocks (here referring to the two buildings of the opera house) was shaped by considering the shading effects on themselves and the public space, as well as the solar radiation angles for the configuration of PV panels. Another performance aspect was the daylight, which effected the proportion of PV panels and transparent part of the skin – the fenestration. Special attention was paid to the daylight autonomy of the interior public spaces, which gives a texture to the appearance of the building skin [7].

*Convective House* (Table 2.1-5), which is not built, is a design project based on the thermodynamic approach of warm air rising and cold air descending.  The design is developed as a thermal landscape with different temperatures considering the thermal expectation of each different activity zone, which shaped these zones into different depths and heights, e.g., sleeping space with lower ceiling, while the bathroom is higher. By deforming the horizontal slabs of the floors, different heights of spaces with different temperatures are created. The deformation of the slabs also gives the design its appearance [119,120].

*Bullitt Center* (Table 2.1-6) is recognized for achieving a low Energy Use Intensity (EUI) with an arrayed PV roof and a relatively large facade glazing in a heating dominated climate while preserving daylight access and views for occupants. Daylighting design goals were central to the PBD process used to develop the final design scheme and influenced decisions at all levels, including building form and massing, floor-to-ceiling height, fenestration configuration, interior zoning and programing, and the configuration of structural elements [121].

*John and Frances Angelos Law Center* (Table 2.1-7) is known demonstrating the integration of building form, varying program elements, and facade systems to minimize the demand for mechanical space conditioning and electrical lighting energy. The project provides a special example of daylighting design, which is largely reflected in the design of the atrium and facade, one of the key elements of the building. The building is organized around a daylit atrium that serves as the primary means of circulation and supports the passive ventilation of the interior spaces. The facade design of each main use (offices/classrooms, library and atrium) is tailored to the thermal and daylighting requirements of the uses [121].

*Edwin M. Lee Apartments* (Table 2.1-8) is recognized for achieving a very low EUI (18,2 Net) with the vertical south facade PV and roof PV (common loads offset by on-site PV is 90% and 60% of DHW energy loads is met by roof PVT).  Extended façade surface by triangle form works for higher daylight availability and better view-out. The building façade form and additional shading on the south façade works for visual comfort. The ceiling fans help to natural ventilation.  The central atrium includes a green roof with a skylight to distribute daylight to the interior of the building. The courtyard contains a variety of landscaping and plantings to restore the natural ecosystem and treat stormwater [122].

Table 2. 1: Example projects as a demonstration of the relation between form and performance.

| I. Architectural elements that are designed based on performance and have a strong impact on building appearance<br>II. Location<br>III. Completion date<br>IV. Project type<br>V. Architecture<br>VI. Engineering and other<br>VII. Gross area<br>VIII. Prominent awards<br>IX. Prominent features | |
|---|---|
| I. South curved building façade, building form, balconies and spatial plan<br>II. Marzahn, Berl.in, Germany<br>III. 1997<br>IV. Residential – Social Housing<br>V. Assmann Salomon & Scheidt<br>VI. Arup<br>VII. Gross area: n/d<br>VIII. “Zukunft Wohnen 1998” (Future Housing) architecture prize.<br>IX. Utilization of solar gains for winter thermal comfort, and accordingly thermal zoning: Living areas facing to south, unheated buffer zone on the north, and wet zones in the middle. | <br>**(1) Low Energy Apartment Building.** Source: [118] - Photo Credit: Christian Gahl, ASS-Archiv |
| I. Double-skin facade, solar shading devices and roof construction.<br>II. Berlin, Germany<br>III. 1999 (extension &renovation, org. built in 1950)<br>IV. High-rise office and retail<br>V. Sauerbruch Hutton<br>VI. Arup<br>VII. 54,000m2<br>VIII. Bauphysikpreis 2003, MoMA Architecture Collection, Benedictus Award 2003, Mies van der Rohe Award 2001, Deutscher Architekturpreis 2001, World Architecture Awards 2001, Deutscher Fassadenpreis 2001, RIBA Award 2000.<br>IX. - High solar thermal convection through double skin façade with, natural ventilation through the façade (flying roof” working with the face - venturi-effect), external shading by colored blinds located in the cavity of the double skin façade. | <br>**(2) GSW Tower (since 2017: Rocket Tower).** Source: [123] Photo credit: Manuel Kubitza |
| I. Green Roof, courtyard, façade, fenestration, inner space ceiling height.<br>II. Vancouver, Canada<br>III. 2009<br>IV. Commercial and Cultural – Convention and Exhibition<br>V. LMN Architects<br>VI. KD Engineering, MCM, DA<br>VII. 43,340m2<br>VIII. AIPC Innovation Award 2011, Green Building Excellence Award for Existing Building by The Canada Green Building Council 2017, Top Ten Green Projects awarded by the American Institute of COTE 2011, AIA Honor Award 2013, Urban Land Institute’s Awards.<br>IX. Conditioning with sea water heat pump system, grey water use, radiant flooring creating superior air circulation without significant energy use, Ultra-clear structural glass skin providing daylight autonomy and rich view-out. | <br>**(3) Vancouver Convention Centre.** Source: [124] Photo Credit: Nic Lehoux |

I. Building skin and form, fenestration and PV configuration.
II. Guangzhou, China
III. 2010
IV. Cultural Building
V. Zaha Hadid Architects
VI. Arup, Beijing Light & View, China Construction Third Engineering Bureau, SHTK
VII. 70,000m2
VIII. RIBA Architecture Award 2010, Top Architectural Reward 2012, AIA UK Chapter Award, Outstanding Engineering Design Excellence Award, Architectural Record Magazine China Award 'Best Public Project'.
IX. Glass skin incorporates photovoltaic cells, which help to shade the internal public areas and at the same time generate electricity.

**(4) Guangzhou Opera House.** Source: [125]
Photo Credit: Von Mr a - Eigenes Werk

I. Building form, façade, space heights and depths, leveling slabs, overhang, terraces
II. n/d (yet not built)
III. 2010 (designed for IBA Hamburg)
IV. Housing
V. Philippe Rahm Architects
VI. n/d
VII. n/d
VIII. n/d
IX. Zones are distributed in different orientations, heights and depths to fulfill the thermal comfort expectation.

**(5) Convective House.** Source: [119]
Photo Credit: Philippe Rahm

I. Roof with arrayed PV systems, the fenestration configuration on the façade, the automated façade shading.
II. Seattle Washington, United States
III. 2013
IV. Commercial & Office
V. Miller Hull Partnership
VI. PAE, Point32, Schuchart, Foushee, Solar Design, Northwest Wind and Solar, DCI, Luma, Engineering, Berger Partnership, RDH
VII. 4,645m2
VIII. AIA Seattle Energy in Design 2016, AIA Committee on the Environment (COTE) Top Ten 2015, Sustainable Building Industry Council "Beyond Green" 2013.
IX. Energy balance with rooftop solar PV system, with automated façade shading for direct solar gain in heating season, natural ventilation, night-flush cooling and daylight autonomy; Low-energy mechanical systems (ground source heat pumps, in-floor radiant heating/cooling, and Automated facade shading acts as a dynamic filter to enable both passive solar heating and solar shading when required to significantly reduce space heating and cooling loads.

**(6) Bullitt Center.** Source: [126]
Photo Credit: International Living Future Institute

I. Multi-story daylit atrium, office/classroom curtain wall façade with alternating punched window openings and automated venetian blinds. Glass rain screen of the blinds, library curtain wall façade with gradient ceramic frit creating "woven" effect, operable awning windows, all-glass multistory curtain wall atrium façade.
II. Baltimore, Maryland, United States
III. 2013
IV. Mixed-use education (classrooms, offices and administrative spaces)
V. Behnisch Architects
VI. Transsolar
VII. 17,837 m2
VIII. AIA Top Ten, WAF Awards 2013,
IX. High performance façade meeting interior daylighting objectives while controlling solar loads; Daylit atrium space a daylit atrium space that serves as the primary means of circulation and aids in the passive ventilation of interior spaces; and passive conditioning strategies (i.e., thermally activated concrete slab + radiant space conditioning and mixed-mode ventilation.

**(7) John and Frances Angelos Law Center, University of Baltimore.** Source: [127].
Photo Credit: David Matthiessen

I. Roof and partial south facade with PV systems, façade triangle form, fenestration positioning and dimensions, atrium, courtyard, linear spatial organization, material choice.
II. San Francisco, United States
III. 2020
IV. Social Housing
V. Leddy Maytum Stacy Architects, Saida+Sullivan Design Partners
VI. Luk & Associates, E Design C, Tommy Siu & Associates, KPFF Consulting Engineers
VII. 11,520 m2
VIII. AIA California Residential Design - Merit Award,
AIA National - Housing Award, ASLA - Award of Excellence - Residential Design, AIA National COTE Green Project Award AIA Top Ten 2022.
IX. Energy balance with the vertical south facade PV and Roof PV and PVT systems; Building façade form is specially design based on higher daylight availability and view-out while maintaining the visual comfort; Mainly passive ventilation strategies applied, but also cooling back-up via mechanical systems are set considering the possible future heatwaves. The roof and courtyard plantings are important design strategies managing the storm water and also make use of grey water.

**(8) Edwin M. Lee Apartments.** Source: [122].
Photo Credit: Bruce Damonte

## 2.3. BPS in Architectural Education

### 2.3.1. Relevance of BPS

Answering the question of what knowledge and skills are expected of future architects can also answer the relevance of BPS in architectural education. There is an expectation that architects should better address sustainability issues and integrate them into design processes [128]. Following a survey in 2012 [38] with participation of the 392 firms from AEC in the US, employers were looking for design excellence in their new hires, but they were also looking for candidates with insights and ideas of sustainability, interdisciplinary/integrated practice, and understanding of technology. While 59% of the firms identified design quality as one of the architecture profession's premier concerns, the issues of integrated design (52%) and sustainability/climate change (49%) rounded out the top three priorities for firms.

Focusing specifically on the gap between the knowledge and skills of graduates in the BPS and the expectations of the AEC industry, two studies [24,39] state that the gap is becoming increasingly worrying and that an urgent action is needed in the education system to equip the future workforce with the necessary knowledge and skills to contribute to a high performing built environment. One of them [16], a survey study among 171 recent graduate architects in Spain on the use of BPS tools, states that 79% of the respondents did not intend to use BPS tools due to their lack of knowledge about BPS tools. The survey of 418 architects in the UK [22] reveals that lack of knowledge is the most driving reason cited by 56% of non-users for not using a BPS tool, on the other hand, the vast majority of the respondents agreed that (1) architects should be able to use BPS tools to inform their design decisions and (2) the use of BPS by architects at the conceptual stage could help save time compared to relying on service engineers. One of the main conclusions of this research is that the problem might be a lack of knowledge that should have been acquired during higher education.

In another survey, which is conducted by the European Council of Architects in 2021 among more than 25,000 architects working in Europe [40], 75% of the architects claim that they apply the concept of low energy buildings to their work, although mostly for reasons such as legislation and client demand. However, the survey results also reveal that only 10% of them use BPS tools. This raises questions about the accuracy and then the effectiveness of the concepts applied, even if they are correct. Moreover, it is reported that 63% of BPS users have learned BPS on their own and not through formal training. This is an indication that formal training is still not sufficiently supporting future practitioners.

The practical implementation of integrated approaches, including the use of BPS in the architectural profession, depends on many parameters. A recent survey by IBPSA-USA [86] on the use of BPS tools in early design analysis cites time constraints, project budget, attitudes of firms and knowledge of BPS as the primary barriers to incorporating BPS into workflows. This supports the need for practitioners to familiarize themselves with integrated approaches and acquire the necessary knowledge and skills during their higher education. Previous studies [16,26–34] investigating the relevance of teaching BPS in higher education show that experiences gained during education play a significant role in terms of adoption of BPS tools by the architects and engineers of the future. As argued before [29,30,34–37] the first and foremost requirement for the integrated approach is to have sufficient domain knowledge and then the adequate level of experience to be able to apply this knowledge. In support of this, a study [79] reporting on the experiences of the most recent European edition of the Solar Decathlon competition, namely Solar Decathlon Europe 21/22 [129], an international university-level student competition to design, build and operate high-performance, low-carbon and solar-powered houses, in which the author of the thesis participated, shows a correlation between the level of BPS adoption by students during their design studies and the actual performance of the constructed designs.

### 2.3.2. Current use: challenges and possible solutions

Identifying the challenges and possible solutions for a better use of BPS in architectural education is of great importance, as the general understanding, skills and performance assessment approaches of architects can be enabled and shaped through this process. In this context, the most discussed points in the literature are shared as follows.

#### 2.3.2.1. Technical

<u>Simplified methods and tools:</u> As the literature review shows, there is a strong emphasis on how easy it is for students to learn and use a BPS tool. While some argue that BPS is not widely used in

undergraduate courses due to students' lack of knowledge of basic building physics [16,58,130], others argue that the available BPS tools are too advanced and complex for beginners [32,103,131]. In support of the second claim, Augenbroe [132] states that: “In many cases - here it applies to early design – a simulation only needs to be adequate for the comparative analysis of design variants.” Many authors [18,22,31,32,34,58,80,91,131,133–137] underline the difficulties related to the complexity of BPS, such as extensive data input, difficult simulation setup, high cost and long time required to perform and document simulations, vast quantities of output data, unfriendly GUI, and very importantly, the difficulties in interpreting simulation results, especially for beginners/novices, if they are not pre-designed/visually well organized by tools. In addition, Hensen and Lamberts, explaining the future challenges regarding BPS in early design [62], signify that although design parameters need to be considered in an integrated manner, different design stages need more focus on different parameters to be considered. Fernandez-Antolin [16] underlines that a smooth and gradual interaction with BPS promotes student confidence and allows students to move independently to more specific tools at a later stage. Many authors [138–142] emphasize the importance of starting with simple simulation models and gradually increasing the level of complexity. These simplifications should be considered not only in terms of BPS tools and models, but also in terms of methods. Two studies [27,143], involving the authors of the thesis, explain the importance of simplification in terms of the theory to be applied during performance simulations, i.e.: " Neutral hours method, which is more of a simplified approach to give students an insight into thermal comfort, rather than a definitive method of the cooling and heating demand of a building". Starting with a simple and later increasing level of teaching input is also valued. Schmitz [58] explains as follows: “The instructor should start the lesson as abstractly as possible. On the other hand, the task should become concrete quickly enough for the students to be able to transfer their simulation results to realistic structural problems, otherwise the initial motivation to familiarize with the complex subject will diminish.” Jian [144] emphasizes the significance of starting with simple models and adopting a one-at-a-time approach for teaching not only BPS but also the theory of building physics, so he recommends that simulation should start at the earliest possible design phase, but using a simple model, students can start by changing one or two parameters and simulating the model to understand the impact of such changes in order to become familiar with the software and building physics.

Availability in a digital design environment: The need for a stronger link between design tools and BPS tools was also one of the most frequently mentioned issues. It is claimed that not BIM environments, due to the high level of detail and complexity, as it is explained in Section 2.2.4.2, but 3D CAD modeling environments, where architecture students mostly start designing, are more promising for early integration.

Gatermann [145], in the Atlas of Architecture, while going through the history of CAD tool and design relation, refers to the American computer scientist Ivan Sutherland (b. 1938) as the developer of the first digital graphic program in 1963, namely *Sketctpad*, which enabled to draw, store, and manipulate 2D technical drawings consisting of lines and curves, and in doing so he set the foundation for GUI and CAD. However, he adds that, in the 1980s, although much progress had been made since Shutherland's first step, architects were still using CAD only for the preparation of technical drawings, bills of materials, budgets and word processing, but not actually for "designing", only for documenting what had already been designed. It is possible to say that BIM is a much more advanced version of CAD at that time, which is used for the elaboration of an existing design to turn it into an implementation project with inclusion of the necessary input and control and testing by different disciplines (such as electrical, mechanical, civil engineering), and finally the preparation of construction drawings, other related documents and coordination between engineering and architectural teams during construction.

Obviously, it is extremely useful for considering entire process of an architectural project, but not for the beginning, where the exploration of design starts. As detailed in section 2.2.4.2, while the previous role of CAD has been replaced by BIM, CAD has evolved towards being a design tool with the VPL feature allowing the designer to create forms for exploration without being tied to the predefined scripting and commands of a traditional CAD tool. Another argument in support of the "it is CAD, not BIM" approach is the nature of the BIM environment that requires very detailed knowledge of the geometric and non-geometric characteristics of a design. Moreover, this argument is supported by the fact that many tools targeting the early design phase and the integration of performance into this phase prefer the CAD environment over BIM [115,137,146–148].

Intelligent design techniques: Mitchell [149], in The Logic of Architecture (pp.179), explains the design process as the process of finding a solution to a design problem and says that it is a trial-and-error one of applying rules to generate candidate solutions. Referring to the complexity of the process, he proposes introducing a design intelligence into the design process, which can be located either in the generation mechanism or in the test mechanism. In line with this, although the generation of design alternatives and their comparison are mostly emphasized, especially for early design analyses, the use of these techniques of parametrization and optimization is still scarce in teaching. [80,103,130,133]. One reason is stated to be the high level of knowledge required to apply these methods properly, and the time-intensive learning of the theory and application of these methods. Although, how useful catalysts these methods can be once understood, and once sufficient knowledge and experience have been gained, many studies point to this issue and emphasize that they can be difficult to adopt, especially in teaching with a time-sensitive schedule.

Visual representation: As it is stated in [16,58,82,93,131,137,150], students generally tend to prefer the BPS tools with an architect friendly GUI providing more visual input options, such as importing a building model in a BPS tool, or modeling directly in a BPS tool instead of entering numbers to define the geometry. Hand [139] underlines that the clarity and consistency of a simulation interface are essential attributes especially during the training. The visual representation of results as graphical and false-color images integrated with the geometry and displayed within the context of the 3D model is known to be more attractive than dealing with numerical results. A course experience in a small class of a master's program at a school of architecture [130] quotes that: "Most of the students felt rather 'scared' when they saw so many numbers and if the simulation model does not represent -visually-what would actually happen in and around the building, the simulation results will be meaningless." This finding is supported also by Gentile et. al. [32].

Affordability and accessibility: Another most mentioned issue in regard to the adoption of performance simulation tools in teaching was the affordability and accessibility. This feature is expressed in various forms, such as "free of charge", "free educational license", "ambassador program" and "price-quality balance" [19,23,34]. Another highlight was that open source and free tools are the most promising regarding the integration of design and BPS for they bring together all the knowledge and skills from all over the world by allowing interaction based on open source and free deliveries[23,146].

#### 2.3.2.2. Pedagogical

Interdisciplinary teaching**:** The interdisciplinary teaching and learning approaches in architectural education, especially those that combine different project stages with the participation of students from different backgrounds, are mostly mentioned as a more attractive and efficient way of an integrated teaching. However, Salama [151] points out that: "Although architecture, in professional practice, is always a result of group work and collaborative effort, the teaching style in the conventional approach to design education does not encourage this view."

In the White Book on the Future of Design Education [152], which presents a perspective on the future of design education with the participation of 250 researchers and/or educators from around the world, one of the main findings on the current state of design education is as follows: “Concluding a degree course does not enable a smooth transition into the world of work. […] Design studies do not serve to integrate all perspectives on the tasks of design. […] Study is usually a sequence of isolated subjects while practice consists of projects in which all elements are equally relevant. Learning to store knowledge in case it is required should be replaced by project-based learning.” And the overall findings of the research on the future of design education points to the growing importance of **holistic and interdisciplinary approaches**, designing as an integrative process that bring many aesthetic and non-aesthetic (technological, business, cultural, political) aspects together and **project-based** study that is structured around working on real projects in cooperation with other disciplines and in contact with practitioners, so that all forms of conveying knowledge or exchanging knowledge take place in relation to a real-life example. Involving practitioners/experts/professionals from academia and/or practice can be a useful way of not being limited to the knowledge and experience of tutors for a richer learning environment [138,153].

Mahdavi et. al. [154], reporting on the experiences in the context of the Master in Building Science and Technology program, which was initiated at the Technical University Vienna, Austria, states that opening courses for attendance of the students from different disciplines (e.g., architecture, engineering, computer science, etc.) sharpened the understanding and appreciation of the interdisciplinary and collaboration requiring nature of the building design and delivery process.

In the context of interdisciplinary teaching, group work is also mentioned as a useful method, referring to learning from each other, being motivated by each other's work, and competition between groups as a driving force for better engagement and higher motivation [29,37,138,155,156].

On the other hand, many authors [130,138,157–159] mention difficulties in balancing time and course content in case of interdisciplinary teaching with the students from different backgrounds and levels of knowledge.

<u>Design-build:</u> In terms of interdisciplinary teaching, one example can be “design-build” approach for introducing students to different skill sets [77,79,160,161].

The origins of the design-build movement can be traced back to the 1960s in the United States, when a group of academics and practitioners called the Peoples Workshop, led by Badanes, took up the issue of social justice in architecture and built small-scale projects with the participation of architecture students. The pedagogical goals of involving architecture students were to develop construction skills, community engagement dialogue, and group design skills [162]. Badanes was joined by John Rigel in 1972 and Jim Adamson in 1975, and the movement has since spread to Europe (especially the UK and the Nordic countries) [163]. The worldwide recognition of this movement was supported by the establishment of the US DOE Solar Decathlon [164] in 2000, founded by Richard King, which prepares the next generation of building professionals to "design and build" high-performance, low-carbon buildings powered by renewable energy. Some of the papers sharing their experiences in the SD competitions put great emphasis on how fruitful an interdisciplinary learning environment is [165–167].

Benedict and Russell [160], who share their design studio experiences in the book "Experiential Learning in Architectural Education", acknowledge that design-build pedagogy bridges the professional knowledge gap between architectural education and practice, while the live project bridges the experiential gap, hence the term "live-build".

Kostopoulos [168] claims: “The synergies created between learning by practical application, the virtual studio, and the traditional architectural studio suggest a direction toward a new and holistic paradigm of teaching and learning architecture that can be further explored and developed.”

Experiential learning and Continuous learning cycle: Continuous Learning Cycle (CLC) is first introduced by Kolb [169] as a structure of his “Experiential Learning Theory” (ELT), which is defined as the creation of knowledge through the transformation of experience [170].

Adopting Kolb's ELT and CLC, Beausoleil-Morrison & Hopfe [29,37], based on their experience of teaching a graduate-level course on BPS to engineering and architecture undergraduate students, many of whom had never used a BPS tool before, state that CLC, which includes exposure to theories and initial application of tools in a balanced way, can be used to teach BPS effectively. They highlight that the how important is experiencing something by doing for really learning it with a quote: “Engage me, and I will become aware.” The balance between the theory (for the basics of building physics and performance) and application (of a BPS tool) is also highlighted by others [138,139,157,171], adding that sometimes diving into BPS tool directly without being familiar with the basics would result in an inefficient teaching experience.

Sharing his experiences in a master's course, Beausoleil-Morrison [135], states that the main challenge is not to teach students a BPS tool, but to enable students to produce accurate results by applying tools effectively and interpreting results, which depends on a good understanding of the limitations and issues that can arise during modeling and simulation. Based on his experience, he states that the experiential teaching approach is the most useful among many to provide an overall learning experience through theory, simulation, exercises, verification and comparison and reflection on results.

Learning by doing and playing: Learning by doing and hands-on teaching methods are commonly emphasized in the literature [29,34,150,155,172]. Reinhart et.al., [80] test a 90-minute game-based classroom exercise to introduce architecture students to the use of energy simulation in the design process of a building in order to investigate the effectiveness of a game-based teaching method and find that the hands-on session, including a "learning by playing" situation, is a useful method that really engages students and triggers their interest in building energy modeling, especially when it comes to reading/understanding simulation results and adapting the design accordingly.

Fernandez-Antolin et al. [128] claim that gamification (learning by playing) is an innovative and attractive way to increase students' motivation and engagement, allows students to apply BPS more effectively, and help them internalize the process through critical thinking.

Intensive supervision: Intensive and continuous supervision is characterized as an integral part of the learning process. Emphasis is placed on ensuring appropriate supervision and continuous feedback from professionals from different disciplines; and monitoring the learning curve of students through assignments that allow instructors to identify learning gaps and also allow students to experience the learning topic on their own, later to be supervised [37,131,134,150].

Comparison studies through simulated and measured performance data: The literature reveals how important the comparison studies including simulated and measured data to take the students’ attention to how performance assessment and evaluation relates through simulations, test, observations, and measurements, and requires an effective communication across the disciplines. In addition, this method is valued, because it allows the entire design process to be revisited, providing a critical perspective on the simulation technique and a better understanding of the key inputs of BPS [58,79,173–176].

Design-integrated teaching: Design-based teaching methods outweigh case-study-based methods because they enable the internalization of knowledge through its application in design projects [27,154,177]. A design process in a design studio should be approached as an “action-reaction” activity, where the action refers to a process and the reaction to the investigation and evaluation of the results of the action; rather than evaluating the performance of an existing design [151].

For design-integrated use of BPS in architectural education, two main types of courses are identified in the literature: BPS use (1) in an independent course, but supports design studio and (2) BPS use as part of a design studio. Grant [134], who teaches an undergraduate course for architecture students exploring the concepts of form and performance through passive design strategies, notes that when building performance topics are explained in a course that is separate from the design studio, although it supports the design studio by providing input, the main challenge for the students is that they have to find their own way to apply the knowledge gained in the course to their design work in the studio. This can hinder the application of performance knowledge. For a student to integrate this knowledge into their designs is highly error prone and can be very challenging without guidance. Working on the methodologies of teaching BPS, based on extensive literature review, course experiences and survey with students and practitioners, Neto [138] claims that, amongst all, the project- or problem-based method provides the best results for an effective learning. Brown and Russell [160] remind that the design studio, as being the core, should be an enriched as a space of synthesis where design, structure, technology, environment and society share equal value.

### 2.3.3. Integrated architectural design education: creativity and science

Exploring the ways of design thinking, Lawson [42] indicates that **reasoning** and **imagining** are probably the most important to designers as a type of thinking, while reasoning includes logic, problem solving and concept formation based on data-driven methods, the imagining is more individual process including designer’s own experience and interpretation and combined with visual thinking. He adds that these two are not independent, otherwise we would not know concepts such as **“creative problem solving”** or a **“logical artistic development”**, both of which are quite meaningful concepts for balancing creativity and reasoning. Creative thinking is most effective in the context of a good knowledge base [178].

Yildirim and Yavuz [179] describe the **architectural education** as a skill acquisition process related to how students understand, perceive and reproduce the environment by using their own elements. Salama [151], defining the **design education** as “the manifestation of the ability to conceptualize, coordinate, and execute the idea of building rooted in the tradition of humanism”, states that architectural education is subject to change as the value system changes (e.g. Beaux-Arts education in France and Bauhaus in Germany as a reflection/reaction of/to the changes of their own time) and that today, indeed since the last thirty years, as society's values have changed dramatically due to population growth, advanced technology and increasing urbanization, architectural practice must respond, yet the essence of contemporary design education is usually unsatisfactory.

An extensive literature review, by Vujovic et al. [180], surveying the relationship between science and architectural design through content analysis of selected 782 peer-reviewed papers published over the last four decades, reveals how the role of science in the architectural design process has changed and illustrates the growing importance of scientific approaches in design. Therefore, it highlights the need for further inquiries into evidence-based approaches and their integration into creative processes, which are mainly stimulated by the fast-growing influx of knowledge from different domains, such as environmental sustainability, building materials and climate change.

## 2.3.4. BPS and design studio

### 2.3.4.1. Design studio and the role of BPS

**Design studio** is the core of architectural education, not only in terms of the time and credits it covers in the curriculum, but also as a key place where architectural knowledge and skills are acquired and developed. Students devote a tremendous amount of time and academic energy to their studio learning [181]. However, although the studio is the primary means of educating architects, integrated holistic and critical approaches, including BPS, are often neglected in studio teaching [182].

**Unlike a traditional university course** consisting only of lectures, assignments and written and/or oral exams, in a design studio, students are assigned a design project, given an initial brief for the project and work on design proposals. The project is developed by the studio students through a presentation and feedback loop from tutors and classmates/peers, and the final project is presented to an audience of peers, instructors, and sometimes other invited third parties. Final grading, based on the scope and requirements of the project, is done by the instructors/tutors based largely (there are some exceptions for the design-build studios) on these visual and oral presentations.

**Critiquing**, which can be defined as commenting and giving feedback on students' design proposals and are mainly from two sources, i.e., from peers and from tutors and sometimes from an invited third party (e.g., experts/professionals in practice and academia), is generally recognized as an essential pedagogical tool in architectural design studios [181].

Examining the meaning of pedagogy in the design studio, Gunoz and Uluoglu note that in the literature, the meaning is mostly narrowed down only to methods such as *"learning-by-doing"* and/or *"problem-based"* and/or *"experiential learning";* and add that the pedagogy, as an act of teaching, strongly relates to tutors' teaching attitudes, which can widely vary from "**tutor-centric environment**" to "**discovery and cooperation based environment**". While new and emerging approaches constitute a significant amount of studio practice, the traditional studio setting continues to exist, maintaining its norms based on the "**master-apprentice**" mode of teaching with little or no change [151,153,183].

In the design studio, tutors need to focus and give feedback (critique) on many aspects, that can be grouped as measurable (i.e., physical elements) and non-measurable (e.g., cultural and aesthetic). Tutors adopt an approach according to their own design and architectural disposition (depending on their knowledge and experience) and their view of education, and this approach is reflected to some extent in the design and implementation of the studio courses [153]. Oh. et. al. [181], elaborating on the theoretical framework of the design critique in design studio in architectural education, state: "The critiques are based on the instructor's expertise and professional experiences. Nevertheless, we also find that theoretically or empirically informed discussions on design pedagogy are uncommon among the instructors of architecture studios."

On the other hand, the complexity of an architectural design project may exceed the limits of the instructors' expertise. Even the topic and the area of expertise match, the extreme design cases (e.g., designing a house on Mars) may remain outside the area of experience of tutors. In such cases, use of other methods that can provide input and feedback are required to enrich the creative and critical thinking process in a design studio. Moreover, the utilization of methods to evaluate measurables could reduce the effort of tutors, thus allowing more time and space for critique of non-measurable values [178].

Due to the broad scope of the architectural discipline, architectural education cannot be limited to a single profession and a single format [28,151,160,184], so it should not be constrained by the critiques of individuals. In order to move from tutor-centered teaching in design education to discovery and collaboration-centered teaching that presents qualitative and quantitative elements in a balanced way, BPS is an important tool as it will provide a polycentric, interdisciplinary, and factual and data-driven assessment process, especially given the extremely important but complex goals of achieving sustainability, which requires consideration of many aspects of not only social, but also environmental and economic.

#### 2.3.4.2. Design studio experiences in the literature

Using the databases **ResearchGate** [185], **ScienceDirect** [186] and **Academia** [187], which are among the most important networks of scientific literature, a search was conducted by adding the words "ecological/sustainable/bioclimatic/performance-oriented/PBD" in front of the keyword "studio" in the literature of the last 20 years. More than 50 studies were identified. However, only 10% of them described the design studio experience in detail. The examples presented in this quick review, a total of 7, are studies that address both the technical and pedagogical aspects of integrating building performance into the design studio teaching. The selection criteria for the examples are based on the claim of the studios for integrating performance into design process. For each case, basic information about the design studio, the instructors, the students, and, where applicable, the digital design and BPS tool is initially itemized to ground the shared experience.

The student profile, in the example design studios, is categorized according to the knowledge and skills about building physics and the BPS tool, at the beginning of the design studios, as described in [138]:

- **Novice** refers to a level of a student, who has no knowledge of building physics or how to use a BPS tool;
- **Intermediate** refers to a level of a student, who has some knowledge of building physics and/or the use of BPS tools, acquired in one or more courses with a total duration of between 20 and 40 hours;
- **Advanced** refers to a level of a student, who has more than 40 hours of training in building physics and/or the use of building simulation tools and has already worked on at least one project using some type of building simulation tool.

The definitions of "**consumer**, **performer** and **expert**" by Alsaadani & Bleil de Souza [24] were used to describe the role and level of activity of students in relation to BPS in the design studios investigated.

**(I) Bioclimatic Design Studio** - Department of Architecture and Building, School of Civil Engineering, Architecture and Urban Design, State University of Campinas, Brazil, 2006 [103].

<u>Design studio</u>: Undergraduate level, one-semester-long, groupwork.

<u>Instructor(s)</u>: More than 1, from architecture and engineering disciplines.

<u>Students</u>: From architecture department, novice.

<u>Digital design tools</u>: CAD (not specified).

<u>BPS Tools</u>: Ecotect [188].

<u>BPS tool selection criteria</u>: Already used for teaching in home university, architect friendly GUI, easy to learn and use, 3D modeling, available settings for passive design strategies, i.e. natural ventilation and including multi-domain BPS, i.e. lighting, energy, thermal comfort, and acoustics.

<u>Design phase when BPS is introduced</u>: During design development to evaluate already developed designs.

The project of the studio was an elementary school design. The BPS was presented to the students in the second half of the semester, during the design development phase, after making sure they understood the thermal behavior of buildings and the mechanisms guiding the design of solar shading, mainly for thermal comfort analyses related to passive solar gains.

In this experience, the student did not actually interact actively with the BPS tool. The steps of data import from the design tool to the BPS tool (3D architectural model as dxf. - Drawing Exchange Format), and simulation setup and run were performed by the tutors. The authors explain that the reasons for this were to spare the students the complexity of setting up the simulation, to ensure methodical consistency in the organization (i.e. constant inputs to the simulation), and to orient the students more towards the analysis of the results.

The use of BPS was optional and the level of student participation was low. This was explained by (1) the students' lack of awareness of the potential of the tool, (2) lack of introduction and training on the tool (the interested students learned the tool on their own), (3) low level of encouragement for the use of simulation in design studios by most of the design studio instructors in the architecture department, and (4) lack of technical equipment and infrastructure in the physical working environment of the design studio

It was reported that students were mostly surprised by the simulation results because the results were very different from what they expected, which was related to the fact that they were novice learners. The students' feedback on the BPS experience was described as positive. The main learning outcomes were said to be mainly in improving their understanding of solar geometry, daylighting, shading elements, and building form and orientation, but not so much on thermal comfort.

The main difficulties in integrating building performance with the design studio are reported as (1) students' low skills and knowledge about bioclimatic design and BPS, (2) difficulties in understanding the thermal comfort results and visualizing the thermal comfort feeling, (3) severe time constraints due to the one-semester course, and (4) difficulties with the BPS tool, i.e., as the authors state: "Although Ecotect has indeed focused on the user-friendly GUI, it still presents inaccuracy problems and does not support the export of the building models to more robust simulation tools such as EnergyPlus, ESP-r, HTB-2, and Radiance for comparison and more accurate results".

The authors conclude by pointing out the importance of the implementation of computerized ateliers to support the design studio and the value given to BPS by the whole team of trainers/teachers, adding that otherwise students will feel the disinterest of the trainers and will be less willing to implement BPS.

In this studio example, students were introduced to BPS, but at a very generic level, as consumers. They had the opportunity to evaluate their project through BPS, but they did not actively participate in the process of BPS. Nevertheless, the example is valuable considering that BPS is introduced at the undergraduate level, although the students partially experienced it.

**(II) Design Studio** (Collaboration with Arch-Engr Course) - School of Architecture, Art and Historic Preservation, Roger Williams University, United States of America, 2009 [189].

Design Studio: Undergraduate level, one semester, group work.

Instructor(s): 2 instructors, from architecture and engineering disciplines.

Students: From architecture department, novices, 11 total.

Digital design tools: (n/d)

BPS Tools: TRNsys [190] and Contam [191] (not used by the design studio students, only by the Arch-Engr course students).

BPS tool selection criteria: The ability of the tools to convey the dynamic behavior of buildings better than tools that only provide monthly or annual energy use, and the online plotter capability in TRNsys.

Design phase when BPS is introduced: In design development and advanced design phases for evaluation of already developed designs.

The design studio project was the improvement/renovation of an existing dormitory building. Students worked on the project and developed proposals in the same way as in a typical design studio course, except that the basic theory of BPS and data analyses were explained to the studio students through lectures.

For the last 5 weeks of the semester, in order to evaluate the decisions already made by the studio students, the design studio collaborated with another course, called Arch-Engr, consisting of 19 architecture and engineering students with intermediate and advanced BPS knowledge and skills. The Arch-Engr students participated in the design process as consultants responsible for the preparation of BPS models and the execution of energy, hygrothermal and acoustic simulations during the last 5 weeks. Collaboration was applied across the scales of building, building elements, material and building systems. It is reported that the lack of visual interface of the model itself in TRNsys 16 was a drawback.

This studio example is significant in that it brings architecture and engineering students together in a collaborative effort between two courses, familiarizing them with each other's professional languages and tasks. The authors express their aim to move BPS to the earlier phases of the design process. Furthermore, from a pedagogical point of view, the interdisciplinary learning environment and the promotion of peer learning are prominent features. However, the approaches originally intended to be changed, such as the late integration of BPS towards the end of the design process and the architect as a mere consumer, have been retained.

**(III) Sustainable Design Studio** - Department of Architecture and Civil Engineering, University of Bath, United Kingdom, 2020 [182].

Design studio: Graduate level (in the final year of program), two semester-long, both group and individual work.

Instructor(s): More than 6, full time teaching staff in the university and external practitioners, from architecture and engineering disciplines

Students: From architecture department, between novice and intermediate, (number is not specified)

Digital design tools: CAD and BIM

BPS Tools: n/d

BPS tool selection criteria: n/d

Design phase when BPS is introduced: n/d

The studio was structured around two design projects, a group master planning project in the first semester and an individual building design project situated within the master plan in the second semester. The projects were open-ended and students were free to explore design issues of their choice, including deciding on the nature of the masterplan intervention and the type/use of the buildings according to their own preferences. Prior to the design studio, students were introduced to sustainability and environmental design in a lecture-based course. Sustainability topics were also incorporated during the design studio by involving the external tutors as expert consultants, two or three times per student, per semester. The studio followed the typical course of "presentation and critique cycle", with an audience including peers, tutors, but also the invited external experts from practice.

The authors report that despite the strong sustainable research agenda in the department, little of this has filtered into design, and although the design studio is supplemented by lectures on sustainable design, there was little evidence of the content taught in the lectures manifesting itself in design projects. In fact, a quote from the students, collected by the tutors through student interviews, shows how little integration of the sustainability aspect occurred in the studio: "Sustainable design is something that is added at the end [of a project]" and "Sustainability is applied to the project or in some cases it is considered optional or impossible."

The authors refer to Kolb's learning cycle [169], but while the studio included "reflective observation" by encouraging students to ask questions, the steps of "abstract conceptualization", which is deeper inquiry, "active experimentation", which is testing and validating ideas, and thus "concrete experience", which is communicating findings, were missing in the studio.

It was also noted that despite the communicative environment of the studio, the "master-apprentice" approach still existed. This was thought to be related to the nature of the transfer of specialized knowledge to students. This perspective might be partly correct, but part of the problem might also lie in the fact that instructors are the only source of information and validation. The question is whether this "master-apprentice" relationship could have been broken if students had other means of evaluating the information and comments they received from their instructors.

This example is important as it shows how important it is for the basic steps and objectives of the study to be clearly defined by the trainers at the beginning in order to avoid the risk of students getting lost in the complexity of the study, especially in multidisciplinary studies (e.g. design, environment, performance). It also shows that the implementation of a sustainability approach in a project is not trivial and requires a solid methodology (i.e. quantitative performance analysis - BPS) proposed by the instructors instead of leaving the work of integration to the students, otherwise, as in this case, the intended learning objectives will not be achieved. Finally, in this case, the role of the students is even lower than that of "consumers" since they were not even allowed to interact with the results of a data-based building performance assessment, i.e., BPS.

(IV) Design Studio - School of Architecture and Engineering, University of Liège, Belgium, 2022 [192].

Design Studio: Graduate level (in the first year of master's program), one semester-long, group work

Instructor(s): 2 instructors from architecture and engineering disciplines

Students: From civil engineering and architecture departments, intermediate, in total 21 students

Digital design tools: (n/d)

BPS Tools: (not specified)

BPS tool selection criteria: (n/d)

Design phase when BPS is introduced: Not BPS, but expert feed-in provided starting in the early design phase.

The project was the design of a contemporary building, considering the relationships in urban scale, respecting complex programmatic requirements, form, function, structural systems, technical constraints, spatial qualities in building scale. The design studio was accompanied by a course called "Sustainable Architecture and Urban Design", which supported the theoretical part of the studio, for the topics of energy, environment, health and comfort. In addition, as in the previous example [182], these themes were incorporated into the design studio through collaboration with external experts from different fields in architecture, building envelope and environmental quality, structure, fire safety, accessibility standards, fluids and HVAC.

While this studio experience is similar to the third example [182] in that a theoretical lecture accompanies the studio on sustainability topics, it differs from it in that students were given a clear guidance on sustainability topics at the beginning of the studio and the learning objectives were clearly set and communicated to the students. The positive comments of the students, collected through interviews by the authors [192], about the contribution of the theoretical course, also support this finding.

The studio is a good example of an interdisciplinary learning environment in which students from both architectural and engineering backgrounds engage in an architectural design process, while at the same time expanding the scope for instructor-based feedback by involving practitioners in the process. Nevertheless, as in the second [189] and third examples [182], the role of the students in this example is less than that of the "consumer" in terms of the BPS experience.

**(V) Architectural Design Studio** – Faculty of Architecture, Gazi University, Türkiye 2015 [193].

Design Studio: Undergraduate (third year of the architecture program), one semester-long, group/individual

Instructor(s): 8 instructors (background: n/d)

Students: From architecture department, novice & intermediate, (number: n/d)

Digital design tools: CAD based

BPS Tools: Ecotect [188]

BPS tool selection criteria: Compatibility with CAD based design tool, visual GUI, ease of learning and ease of use.

Design phase when BPS is introduced: Early design

This example differs from the others in that it evaluates the integration of BPS into the design studio through a test and control group. The topic of the studio project is not mentioned, but it is stated that the project site and program were the same for the test and control groups. It was noted that prior to the design studio, all studio students had taken required environmental control courses that covered theory related basic building performance issues, so they all had basic theoretical knowledge for environmental design. The use of a BPS tool was offered to students as an option, and BPS tutoring was provided for students who chose to use it in an elective course that worked in tandem with the studio. The basics of building simulation and the use of the BPS tool were taught in the first 7 weeks of the elective course. After this period, the students were asked to apply the BPS tool to their studio projects, which were still in the early design phase. In terms of performance, the topics were passive design strategies (i.e. use of solar gains, summer night ventilation), natural ventilation, daylighting and active solar energy utilization (i.e. PV systems), climate-based design, and energy efficiency.

At the end of the studio, the authors [193] compare the projects in terms of both the architectural and the energy-ecological criteria presented to the students at the beginning of the studio.

The projects of the test group, which used BPS as a design decision support tool in their design projects met the set performance expectations in terms of energy-ecology, while the projects of the control group were less improved in this respect. The control group only included some solar control strategies (window ratio, shading elements, etc.), but in the late design phase, and they did not pay attention to the parameters such as thermal transmittance, air tightness, glazing light transmittance, etc., so their thermal comfort and energy efficiency scenarios did not work well. In the comparison of architectural criteria, which included considerations such as site building relationships, layout, program, function, massing, form, elevations, structure, and materials, the test group also performed better than the control group. The authors, who evaluated the design process and final work of the test group students, state that these students focused on orientation and use of shading elements to avoid excessive solar gain, photovoltaic systems to generate electricity, courtyards to increase daylight availability, natural night ventilation for summer thermal comfort, and thermal zoning to organize the layout, thus clearly observing the impact of performance based decisions on the building form and appearance.

The authors [193] conclude by pointing out 4 main factors for an efficient integration of BPS into a design studio: (1) student - with adequate level of knowledge in digital 3D modeling, environmental design, building physics and BPS; (2) BPS tool - with visually rich GUI, easy to use, compatible with design tools and allowing flexible modeling; (3) instructor - experienced in related fields and computer aided environmental design; and (4) studio time and infrastructure - with flexible opportunities.

From a pedagogical point of view, this studio is a strong example for paying attention to the balance between group and individual work, panels (student presentations) and one-to-one critiques, theory and practical sessions. The outcomes of the studio support that the use of a well-structured method for identifying and evaluating students' learning steps through continuous monitoring can make the learning experience more efficient. Biggs and Collis' "SOLO" (Taxonomy of the Structure of the Observed Learning Outcomes) classification [194] was adopted in the studio. It includes 5 levels: (1) Pre-structural - introduction of basic definition and information, (2) Uni-structural - making connections, understanding of the problem, (3) Multi-structural - sorting, classifying, identifying, listing and merging, (4) Relational Level - comparing, explaining reasons, integrating, analyzing, correlating, and applying, and (5) Extended Abstract - generalizing, reflecting, and producing. The strength of the studio is the inclusion of BPS at a multi-structural level during the concept design phase and the involvement of students as "performers" in the process. In addition, the design studio was not designed as a stand-alone course, but in conjunction with other courses. These other courses supported the studio in terms of both theoretical and practical knowledge (i.e., learning digital design tools and BPS), and all the knowledge was combined in a project-based design studio.

**(VI) BPS course as supplementary to Design Studio** - Department of Architecture at the Faculty of Fine Arts, Helwan University, Egypt, 2018 [195].

<u>Design Studio</u>: Undergraduate (in second year), one-semester, both group and individual work.

<u>Instructor(s)</u>: 2, (background not specified)

<u>Students</u>: From architecture department, novice and intermediate, 32 students

<u>Digital design tools</u>: CAD and BIM based

<u>BPS Tools</u>: Autodesk FormIt [196]

BPS tool selection criteria: Compatibility with early phase design, 3D modeling option, visualization, ease of learn, accessibility / affordability of the tool, compatibility / collaboration between deign and BPS tool of Autodesk, i.e., Dynamo Studio [98], Insight [197], Revit [113].

Design phase when BPS is introduced: Early design

This is an elective course for studio students, in which they were given the theoretical knowledge and taught a digital tool of design and BPS to be able to include performance evaluations in their studio projects. The course, which took place in the same semester as the design studios, was open to students from 3 different studios and the applicants were selected based on their knowledge and skills in 3D modeling and their level of interest (motivation letters written by the students for the application), taking care to include an equal number of students from each studio (10 on average). The ratio of students participating in the elective to the total number of studio students was on average one third. An introductory survey was conducted prior to the start of the training to learn about the students' level of knowledge of the course topics and to investigate whether there were significant differences between students in this regard.

The students of the course were provided with a short introduction to the tools (mainly to FormIt, which is a tool that brings together very basic environmental analysis and early design phase, allowing to sketch, collaborate, analyze and revise design concepts) and a short training for one week to make sure they understood how to start applying it to the studio projects (which was a residential villa for an artist), while the rest of the studio students worked on their projects in a typical instructor & student way. Each student used Autodesk FormIt to create their initial form prepared during the course in the design studio. The elective course focused on the schematic design phase of the projects, specifically the so-called form generation phase. The students were asked to simulate the solar analysis (sun path, solar exposure, etc.) and energy costs (working with Insight at the cloud level) on their proposed building forms using Autodesk FormIt software until they reached an optimal composition in terms of sun exposure and shadows on masses. The students were then encouraged to try to make their design decisions based on the simulation results, either in form generation or in facade treatment by manipulating building orientation, thermal transmittance, occupancy density, etc.

According to the Interviews with students at the end of the elective course, all students rated their experience as positive and found it useful to support their design decisions in terms of knowledge-based reasoning. The authors [195], while pointing out the importance of the ease of use of a tool to be applied at the conceptual design stage, emphasize that no matter how easy a BPS tool is, it requires a basic knowledge of 3D digital modeling and environmental design, and that the adoption of these tools in the design studio of intermediate students can be extended to advanced students, but when applied to novice students, difficulties are inevitable due to the lack of the knowledge.

This is another significant example of a collaboration between courses to integrate energy and comfort issues into the design studio and to give architecture students the role of "performers".

**(VII) Architectural Design Studio -** Architecture Study Program, Faculty of Engineering, University of Atma Jaya Yogyakarta, Indonesia, 2022 [198]**.**

Design Studio: Undergraduate, one-semester long, both group and individual

Instructor(s): (number and background: n/d)

Students: From department of architecture, novice and intermediate, (number not specified)

Digital design tools: CAD based (Rhino [106])

BPS Tools: Climate Consultant [199] for adaptive thermal comfort, Honeybee [109] for thermal comfort, cooling energy use and daylight analysis, Ladybug [108] for solar radiation and shadow analyses, Sefaira [200] for cooling energy use and daylight analysis.

BPS tool selection criteria: Visually rich GUI, ease of use, adoption of intelligent design technique, i.e., flexible modeling and simulation setting via VPL (i.e., Grasshopper [97])

Design phase when BPS is introduced: Early design

The project of the design studio was to design a student learning & innovation center. Besides the architectural program and function, the studio asked the students to use BPS tools to analyze the design form, layout, and building envelope through shading study, universal thermal climate index (UTCI), thermal comfort, wind, solar radiation, daylighting, and energy use analyses. Of particular interest was the balance of performance for daylight availability and cooling loads.

The studio had two phases, (1) identification phase consisting of design requirements, goal setting, and micro-macro climate analysis and (2) conceptual design phase consisting of massing study, plan layout and shading studies, and aperture study. In the identification phase, analyses of macro- and micro -climate conditions and adaptive thermal comfort in order to identify passive building design principles were conducted. In the conceptual design phase, outdoor temperature and comfort, shadow range and solar radiation daylighting, ventilation and energy analyses were applied for massing studies, spatial organization and for the design of the structural shading elements. Also, sensitivity analyses were conducted to find out the most significant parameters on cooling loads.
The authors [198], based on their experience in integrating BPS into the design studio, emphasize some points as follows: (1) Enforcing the use of BPS in a design process can waste time and lead to misunderstandings if students don't have the basic knowledge of building physics and BPS and/or if the analyses are too complex. Therefore, the best result is possible when BPS is applied in an early design phase, for relatively simple design problems and with relatively simple tools; (2) The obstacle to using VPL is that users have to develop their formulas (via visual scripting) to define the BPS workflows, which requires a deep understanding of building performance and knowledge of VPL. However, it is applicable for simple cases such as solar radiation and daylighting simulations that do not require detailed input in the case of beginners/students; (3) Time availability is critical for integrating BPS into the design studio; and (4) User-friendly BPS tools with rich visual representations should be considered, especially for a BPS tool to be used in a design studio.

The studio experience does not describe the pedagogical methods adopted for the integration of BPS into the design process, but it is a prominent example for illustrating the use of a wide range of BPS tools in a design studio at an early design stage.

## 2.4. Conclusion: Research gap and thesis focus

The investigation of the use of BPS in architecture practice through the literature review shows that most of the available BPS tools are not really designed to accompany architectural design, but rather to evaluate the design that has already been developed. It reveals that early integration of BPS into the architectural design process is a necessity, not only for a more energy efficient, environment friendly and comfortable built environment, but also for a much more efficient and fluent project process.

As it is widely recognized in the literature, for further integration of BPS into the architectural design process in practice, especially considering the early design phase, BPS tools that are easy to use and learn, provide adequate simplifications according to the design phase, with gradual increase of input requirements, interoperable with other tools of digital design and BPS, allow multiple performance analyses, open source, provide visual representation of results, coupling with intelligent techniques are promising. Based on the literature review, a summary of the challenges and developments in AEC in parallel with technological advancements with future prospects are illustrated in Figure 2. 5.

The review highlights the potential of design-integrated performance approaches for high performance built environments and points out that architects, as key actors in the design process, can make a significant impact for more sustainable design solutions, only if they adopt these approaches. However, in addition to the challenges related to tools, architects' low level of knowledge and skills in BPS also limits their role to a 'consumer' level at best, and often less than that. In the literature, the lack and/or scarcity of integrated approaches including BPS in architectural education is often cited as one of the main reasons for this. The gap between graduates' knowledge and skills in BPS and the expectations of the AEC industry is claimed to be too large. There are many calls for an urgent action in the architectural education system towards more integrated, knowledge-based and scientific methods that can act as a catalyst for more interdisciplinary and integrated design teaching.

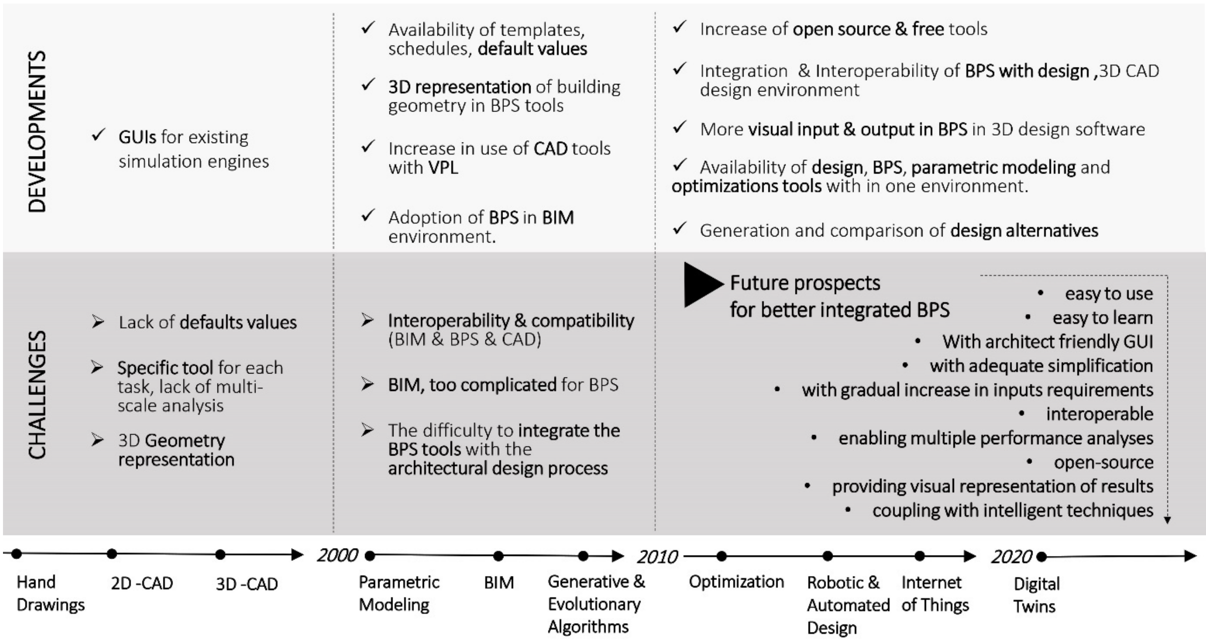



Figure 2. 5: Challenges and developments in AEC parallel to technological advancements with future prospects for the further integration of BPS into design process.

As in practice, in education also, ease of use, ease of learning, simplified methods/models, usability in a digital design environment and/or compatibility with digital design and documentation tools, coupling with intelligent design techniques, rich visual representation, affordability and accessibility were commonly mentioned as features of a BPS tool to be used more effectively in design education.

Furthermore, from a pedagogical point of view, interdisciplinary teaching, design-build, experiential learning, evidence-based, comparison of simulated data with measured data, and project-based teaching methods are broadly mentioned as effective methods for integrating BPS into architectural education to balance the theory and practice in design learning.

It is seen that it is critical to further elaborate on the design studio, which forms the core of architectural education and, in this context, stands out with its capacity and potential to bring together all the methods mentioned above.

The review of existing design studios aiming to integrate building performance aspects into the design process in architectural education shows that much remains to be done for a more comprehensive integration. The majority of design studios introduce these topics at a very generic level and the role of architecture students remains mainly as 'consumers'. Therefore, this study aims to outline a framework for design-integrated BPS teaching, focusing on the main gap identified in the literature: a performance-based design studio with a BPS experience in a digital design environment. The focus of the thesis is demonstrated in Figure 2. 6.

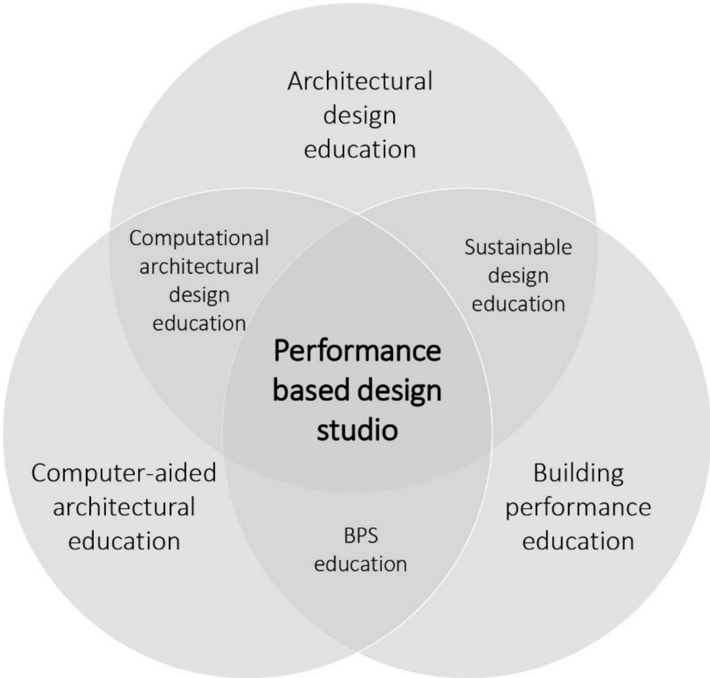



Figure 2. 6: Focus of the thesis, based on the research gap identified through the literature review: Performance based design studio with BPS experience in digital design environment.

# Chapter 3

## INVESTIGATING BPS IN HIGHER EDUCATION

This chapter shares the results of two surveys and interviews conducted as part of the thesis to further explore BPS in higher education. Firstly, the survey "BPS in Teaching" with lecturers teaching BPS in higher education institutions in Germany; secondly, the review and survey "BPS in SDE21/22" with participating teams of an international student competition; and finally, the interviews with educators are presented and evaluated.

### 3.1. Introduction

To deepen the investigation on the use of BPS tools in architectural education, a survey, namely “BPS in Teaching”, was conducted with the participation of lecturers using BPS tools in architectural and engineering education at German-speaking universities. The objectives were to understand the current situation of BPS use in German higher education and identify challenges and possible solutions, therefore the prominent teaching and learning methods for the more integrated use of BPS, particularly in architectural education.

The research was further carried out through the Solar Decathlon Europe 2021/2022 (SDE21/22) [129], which was the most recent European edition of the Solar Decathlon [164], an international university-level student competition for the design, construction, and operation of high-performance, low-carbon, and solar-powered houses. Since this competition was an example of the rich and intensive use of BPS tools, it provided an opportunity to investigate the use of BPS in higher education at international level. First, the adoption of BPS in SDE21/22 is reviewed through the official documents of the competition and the reports of the participating teams. Second, the use of BPS tools is investigated through a survey, namely “BPS Tools in SDE21/22”, which is conducted with the participation of the SDE21/22 teams.

For the investigation of the use of BPS in architectural education (**Obj1**), which is one of the main objectives of the PhD study, in addition to the literature review and surveys, interviews were conducted. To gather more answers to the research questions "How is BPS taught and used?" (**Q2**) and “What are the prominent methods?” (**Q3**), educators with a high level of experience in teaching building performance topics to architecture students using BPS tools were interviewed.

The chapter’s objective (**Obj1**), research questions (**Q2** and **Q3**) and methods (**M2** and **M3**) are presented in Figure 3. 1.

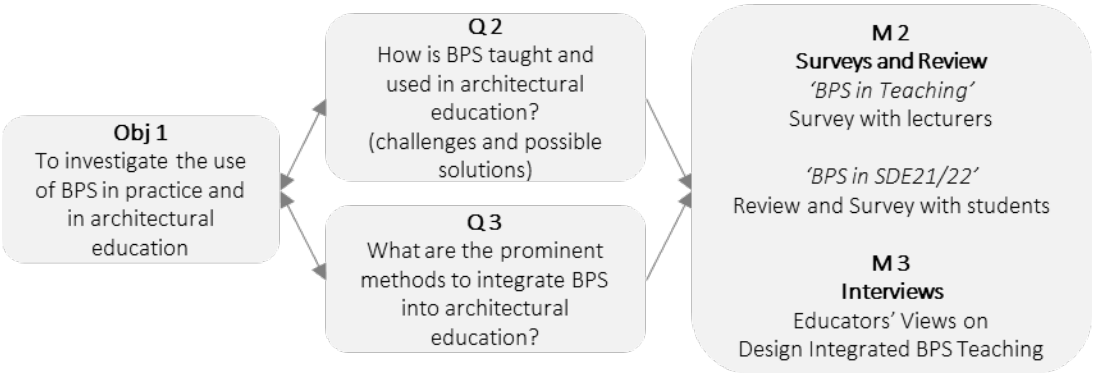



Figure 3. 1: Surveys and interviews - the objective (Obj1), research questions (Q2 and Q3) and methods (M2 and M3) of the thesis studied in this chapter.

The surveys and the review mentioned above were conducted by the author of this thesis. In previous publications [25,26,33,79,201], in which the author of this thesis was involved, the results of them were partially shared. Therefore, although some of the figures and graphs previously shared in these articles were produced by the author of this thesis, these publications are cited as references. To be more precise, some results of "BPS in Teaching Survey" are shared in [25,26,33], some results of "BPS in SDE21/22 Survey" are shared in [79,201], and some results of "BPS in SDE21/22 Review" are shared in [79].

## 3.2. Methodology

In this study, online surveys were conducted by abiding the general rules of the surveys as described in [202,203]. The surveys included the implementation of online questionnaires to collect information from a sample of individuals of an interested population through their responses, and the organization, analysis, and interpretation of data collected in order to identify general patterns on the topic of interest.

Both quantitative (e.g. structuring questions with numerically rated items) and qualitative strategies (e.g., using open-ended questions and a commentary section to allow and encourage a full answer and further comments and feedback.) are used in the surveys.

Online surveys were preferred, because they provide access to a wider range of respondents, with a good interface, at a place and time of respondents' choice. Therefore, it is possible to conduct longer questionnaires with a relatively larger number of respondents in an online survey compared to face-to-face interviews, and what was needed at this stage of the study was more questions and more user responses to identify general patterns related to the topic under study.

In-depth interviews were conducted by abiding by the general rules of the interviews as described in [202,204]. This method was chosen because it allows for individual (one-to-one) interviews and the opportunity to explore the perspectives of a small group of professionals relatively more deeply than the other methods (i.e., surveys with close-ended questions).

## 3.3. BPS in Teaching - Survey

### 3.3.1. Introduction

The "BPS in Teaching" survey was initiated within the framework of the "Standing Committee of Building Physics and Technical Services" (Ständige Konferenz Bauphysik und Technischer Ausbau) (SCBUTA) of the university lecturers in German language institutions. The use of BPS in teaching was surveyed in relation to various topics in order to identify challenges and provide future perspectives, such as:

- BPS as a research and teaching tool;
- BPS in relation to design education, BPS as an evaluation, feedback and decision support mechanism in design;
- BPS in parametric design and design optimization;
- BPS-CAD-BIM interoperability and technical topics in this regard, e.g., geometry representation, data input, processing and output, graphical user interface, file exchange and ease of use, etc.

It should be noted that a previous study by [30] titled "Understanding the differences of integrating building performance simulation in the architectural education system" was an important stimulus for this research.

## 3.3.2. Methodology

The BPS in Teaching survey was conducted in 2019-2020 with the participation of 18 lecturers, who use BPS tools for teaching mainly in architecture and civil engineering education, from 13 different universities and applied universities. The distribution of the participating institutions is given in Figure 3. 2. The abbreviations of the universities are listed in alphabetic order in Table 3. 1. The Invitations to the participants were sent by direct contact, i.e. via e-mails that included a direct link to the web page of the questionnaire. All members of the SCBUTA were invited. Additionally, personal contacts were used to address the chairs of the universities of applied sciences, as they are not members of the committee. The questionnaire was open for 4 months from November 2019 to March 2020. The results were evaluated and reported to all participants in March 2020 [25] and partly shared in a book [33] and a conference paper [26].

The questions were structured in tree main categories: the category 1 was about the personal background, the category 2 was about the courses in which BPS is applied, and the category 3 was about the BPS tools used in these courses. The structure of the survey is illustrated in Figure 3. 3. There were 9 questions for the personal information of the participants, 18 questions per each course and 11 questions per each BPS tool used in the corresponding course. Thus, for some of the questions were repeated for each course and for each BPS tool, the minimum number of the questions was 38 and the maximum number of the questions depended on the number of courses and the BPS tools used in them. The summary of the questionnaire is presented in Appendix AI and the original survey can be found in [205].

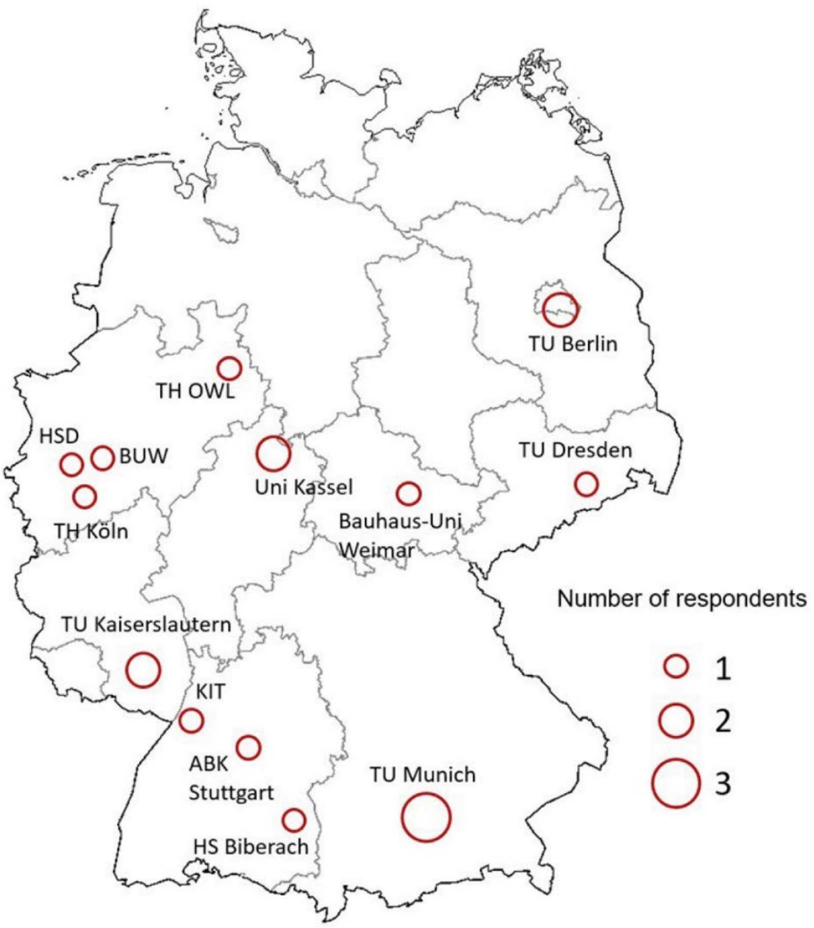



Figure 3. 2: Distribution of the universities and number of participants.

Table 3. 1: Universities and abbreviations.

| Abbreviation | University |
|---|---|
| Bauhaus-Uni Weimar: | Bauhaus University Weimar |
| HS Biberach: | Biberach University of Applied Sciences |
| TU Dresden: | Dresden University of Technology |
| KIT: | Karlsruhe Institute of Technology |
| TH OWL: | Ostwestfalen-Lippe University of Applied Sciences |
| ABK Stuttgart: | Stuttgart State Academy of Art and Design |
| TU Kaiserslautern: | Technical University Kaiserslautern |
| TU Berlin: | Technical University of Berlin |
| TU Munich: | Technical University of Munich |
| HSD: | University of Applied Sciences Düsseldorf |
| TH Köln: | University of Applied Sciences Köln |
| Uni Kassel: | University of Kassel |
| BUW: | University of Wuppertal |

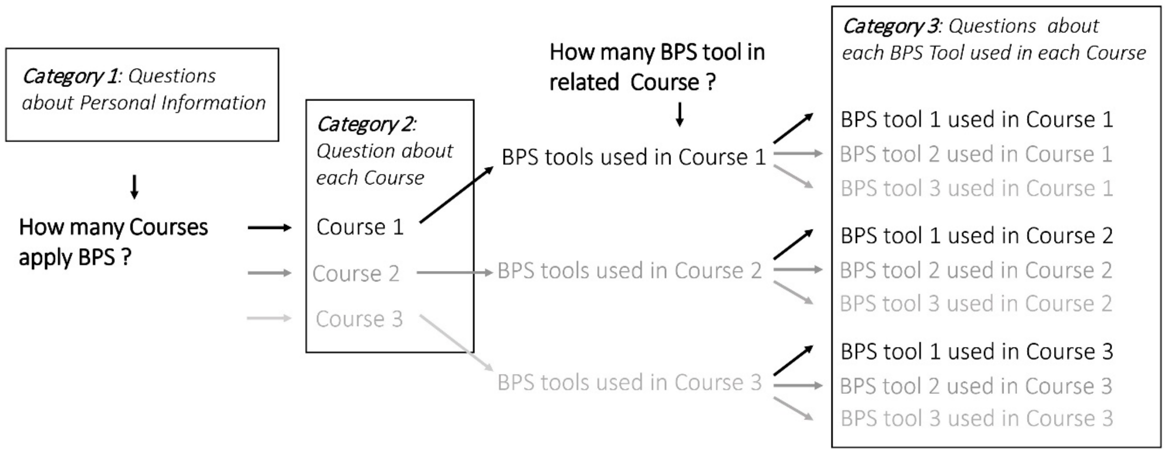



Figure 3. 3: Structure of the BPS in Teaching survey.

## 3.3.3 Results

### 3.3.3.1. Respondents' Background

Of the 18 respondents, 14 were from universities and 4 were from applied universities. 14 of the respondents were the responsible heads of their departments. The distribution of the academic level of the respondents is presented in Figure 3. 4.

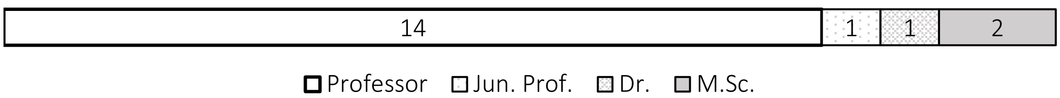



Figure 3. 4: Distribution of academic levels (in %) of the respondents.

In terms of educational background, 5 of the respondents were architects, 4 were civil engineers, 6 were mechanical engineers, 2 were physicists and 1 was a building technologist. The vast majority of the respondents were lecturers at architecture departments (13), and the rest were lecturers at civil engineering (3), and energy engineering departments (2). About the teaching experience in BPS, 3 of the respondents had less than 5 years, 8 had 5 to 10 years, 3 had 11 to 15 years, 1 had 16 to 20 years and 3 had more than 20 years of teaching experience in BPS (Figure 3. 5).

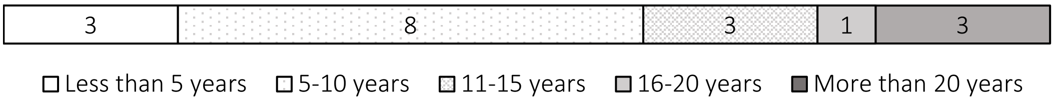


Figure 3. 5: Teaching experience in BPS (in %).

#### 3.3.3.2. Courses Utilizing BPS

At the beginning of the second category of the survey, participants were asked how many of the courses taught in their departments applied BPS. In accordance with the answer, a set of questions was repeated for each course. The total number of the courses mentioned by all respondents was 25. Therefore, the results and the evaluations of this part are based on these 25 courses.

Out of the total 25 courses, in which BPS was used, 76% were graduate and 24% were undergraduate courses. The semesters of the undergraduate courses varied between third and sixth semester. 56% of the courses were taught only to architecture students, 20% to both architecture and civil engineering students (Figure 3. 6). The credits of the courses varied between 2 and 6, but 80% of them corresponded to more than 3 credits. BPS accounted for at least 32% of the total credits of at least 75% of the courses, and the average weight was 64%. The majority of the courses were elective (68%), had no prerequisite (80%), and were taught in group studies (80%).

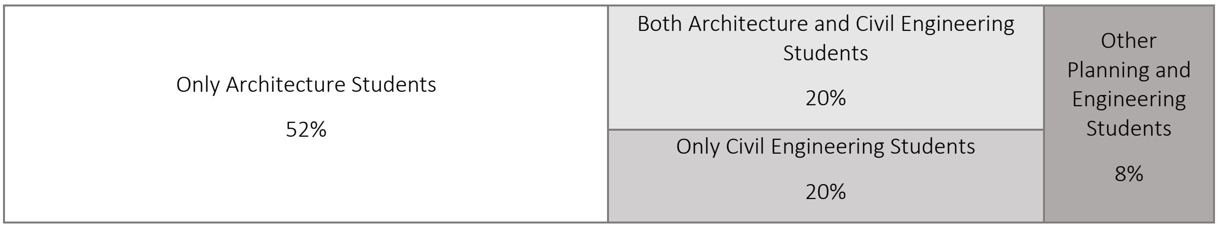


Figure 3. 6: Fields of the target students (in %).

The number of the students attending to a course per semester was around 20. A few of the courses (16%) had less than 10 students, and even less (4%) had more than 40 students. With 96%, face-to-face teaching was the most common teaching method in these courses. Alongside face-to-face lectures, online trainings and online teaching were also implemented.

The time spent on “theory”, “software training”, “application & parameter studies” and “analysis & post processing” varied widely among the courses. The average values (arithmetic mean value of the percentages for each method) were 22% for “theory”, 28% for “software training”, 29% for “application & parameter studies” and 20% for “analysis & post processing” (Figure 3. 7).

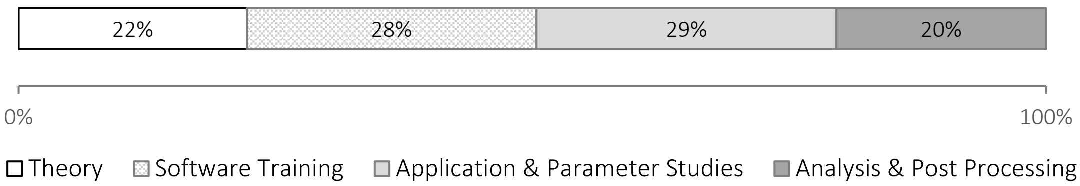


Figure 3. 7: Time spent on “Theory”, “Software Training”, “Application & Parameter Studies” and “Analysis & Post Processing” in the courses (in %).

To examine whether the time spent on different tasks correlates with the educational background of the lecturers, the time spent on different tasks (in %) in the courses was grouped according to the educational background of the lecturers for each course and the averages were calculated. Comparing the averages of the physicists (Figure 3. 8) with the total averages (Figure 3. 7), it was seen that the time spent on “theory” (43%) was higher than the general average. The values got higher for the civil engineers for “application and parameter studies and for the architects for “software training”. The pattern for the mechanical engineers was almost in line with the general pattern.

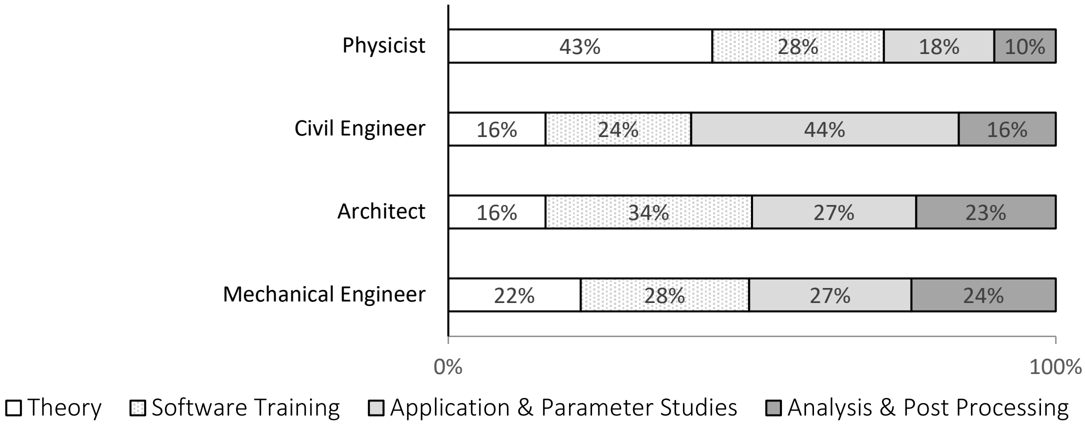



Figure 3. 8: Amount of time (in %) spent in the courses according to the educational background of the lecturers.

The time spent on different tasks (in %) was also examined with regard to the field of the target students. The courses that target civil engineering students had the highest ratio regarding the time spent on “theory” (55%). The other values regarding the field of the target students did not differ much from the general averages (Figure 3. 9).

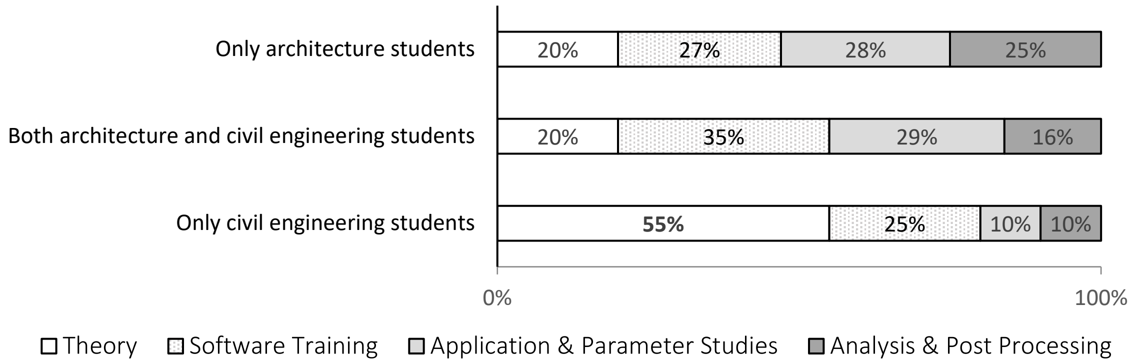



Figure 3. 9: Amount of time (in %) spent in the courses according to field of the target students. Average (arithmetic mean), median and quartile values.

The respondents were asked whether the course in question was more design-oriented or case-study oriented, i.e., whether it used BPS in the development of a design or in the evaluation of an existing design. In general, the courses were found to be more case study driven (58%) than design driven (41%) (Figure 3. 10). Detailed analyses using arithmetic means, medians, minimums, maximums, and quartiles showed that no course was 100% design-driven, but at least half of the courses were 20% to 63% design-driven.

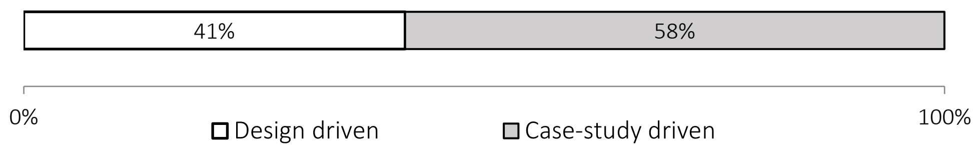



Figure 3. 10: Average percentages of the courses as design and case-study driven (in %).

The ratio of design-driven and case study-driven courses was also examined in relation to the field of the target students of the courses. When the field of target students shifted from civil engineering to architecture, the percentage of design-driven increased from 13% to 51% (Figure 3. 11).

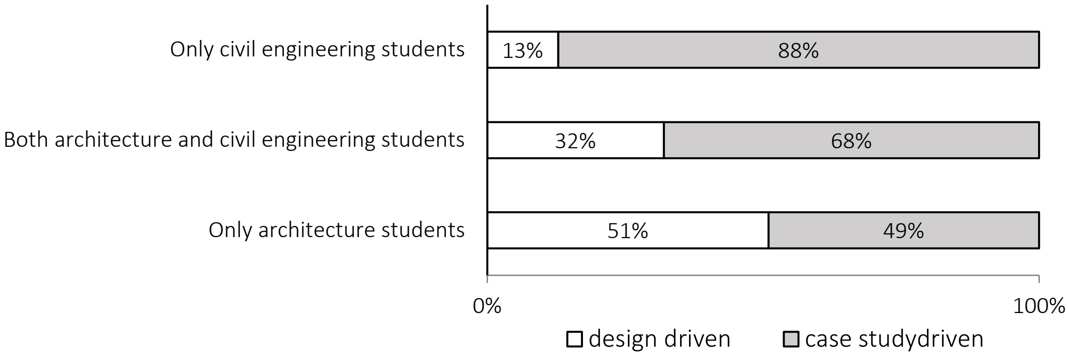



Figure 3. 11: Ratio of design and case study intensity of the courses in relation to the fields of the target students (in %).

To explore the relation between design teaching (e.g. design studio) and BPS use, it is asked whether the course is a part of a design studio or an independent course or a separate course, but supports the design studio. 76% of the respondents described their courses as independent, and the rest of the answers were evenly split between “as a part of design studio” (12%) and “as a separate course, but supports the design studio” (12%). (Figure 3. 12). When the answers were evaluated separately for the graduate and undergraduate courses, the ratio of independent courses at the undergraduate level (83%) was higher than the graduate level (74%).

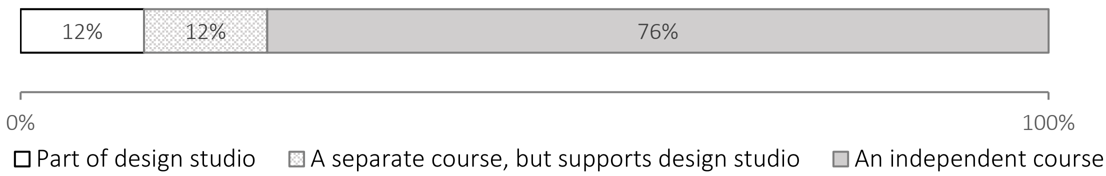



Figure 3. 12: Format of the course in relation to design teaching.

The following four questions about the courses were multiple-choice questions. Each feature of choice was evaluated separately for the courses (i.e., 25 as the number of courses and n as the number of answers for a feature: n1/25, n2/25, n3/25, …)

Written elaboration was the most preferred exam format with 76% of the courses. Oral presentation with slide-show (40%), oral poster presentation (20%), and only oral exam (4%) were also used.

Residential and office projects were the most common project types among the courses with 80%. This is followed by educational (56%), hotel (24%), healthcare (20%) and others (28%).

Most of the courses (92%) worked on building scale projects. Other scales focused on were, respectively, building envelope (60%), single zone (56%), system (52%), material (48%), building block (32%), element (24%), urban (20%) and district (16%).

The final question in the course category was about the design and documentation tools used in the courses. While CAD tools were the most preferred with 72% and physical models were the second most preferred with 56%. BIM tools was only 8%, even less than rules of thumb and hand drawing. (Figure 3. 13).

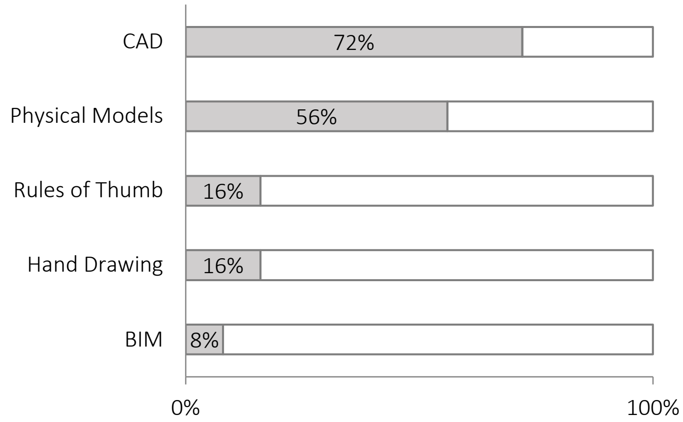



Figure 3. 13: Percentage of the courses according to the design and documentation tools.

#### 3.3.3.3. BPS Tools

The second and the third categories of the questionnaire were linked by the question: “Which BPS tools are used in this course?”.  This question was repeated for each course entered by a respondent.

The number of the tools used in a course ranged from 1 to 5. The total number of the BPS tools mentioned by respondents was 53. When the repeated tools were removed from the set, there were 30 different tools mentioned. When these tools are listed according to the density of their use, TRNSYS, Ladybug & Honeybee, EnerCalC, IDA ICE, THERAKLES and DIVA came to the fore as the most used tools with use in at least three different courses. While there were 53 entries regarding BPS tools, detailed information for only 45 of them were provided by the respondents. Therefore, the results are evaluated over 45 entries. The list of the tools, including quick links to the web pages, license status and developer information, is provided in Appendix AII.

The majority of courses (87%) did not require students to have any prior knowledge of the software to succeed in the course. The purpose of the use (domain) of each BPS tool in question was asked as a multiple-choice question and each of these answers was evaluated separately (45 as the number of BPS tools and n as the number of answers: n1/45, n2/45, n3/45, …). Energy and indoor comfort came first by a large margin (85%) (Figure 3. 14).

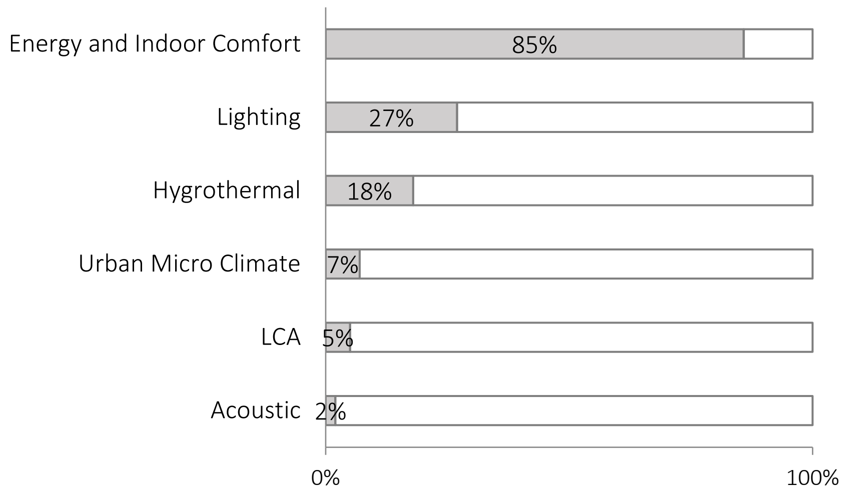



Figure 3. 14: Main purposes of the use of BPS tools within the courses (in %).

It was found that 75% of the tools in the courses were suitable for both early and advanced design phases, 18% only for advanced design and 7% only for early design phase (Figure 3. 15). The representation format of the tools was mostly both visual and numerical (73%), most of the rest (22%) was only visual, and only a few of them (5%) was only numerical.

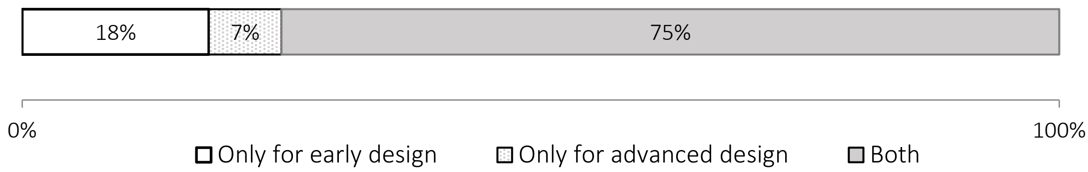



Figure 3. 15: Design stages covered by the BPS tools (in %).

Respondents were asked, with a multiple-choice question, to choose the features of the tool that they use. It is seen that most of the tools (69%) were capable of "generating design alternatives by using parameters". The other features that the BPS tools provided were "context or climate based early design advice" (56%), "real-time simulation preview" (40%), "outputs available within 3D modeling environment" (25%), "support for new building technologies" (20%) and "ready to go report templates" (18%). None of the respondents selected the feature of "comparing design alternatives" (Figure 3. 16).

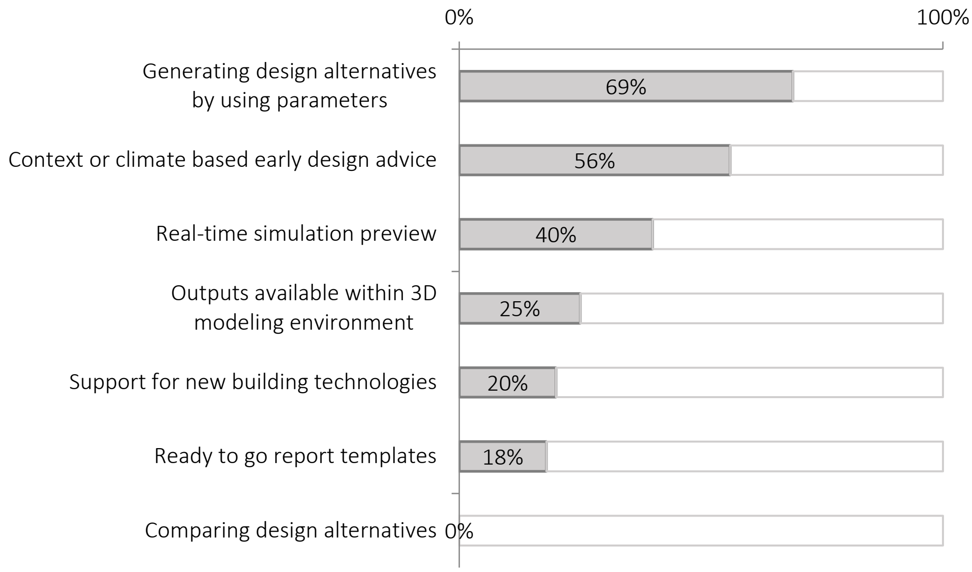



Figure 3. 16: Features of BPS tools.

In general, most of the respondents found the GUIs of the BPS tools they use to be user friendly, with an average of 61%. The average satisfaction rate with BPS tools was 72%. In more detail, the rates were 80% to 100% for half of the BPS tools, 51% to 80% for one quarter, and 19% to 51% for the other quarter.

At the end of this category, respondents were asked to indicate their reasons for using these BPS tools in teaching. 6%1 of the respondents answered this question for a total of 68% of the BPS tools. A great emphasis was placed on "how easy a tool is to learn and use". Compatibility and interoperability of the BPS tool with CAD and BIM tools was the next most frequently cited reason. In this regard, the features of 2D and/or 3D geometry import, data exchange, integration/availability with 3D design CAD environment were particularly highlighted (Figure 3. 17).

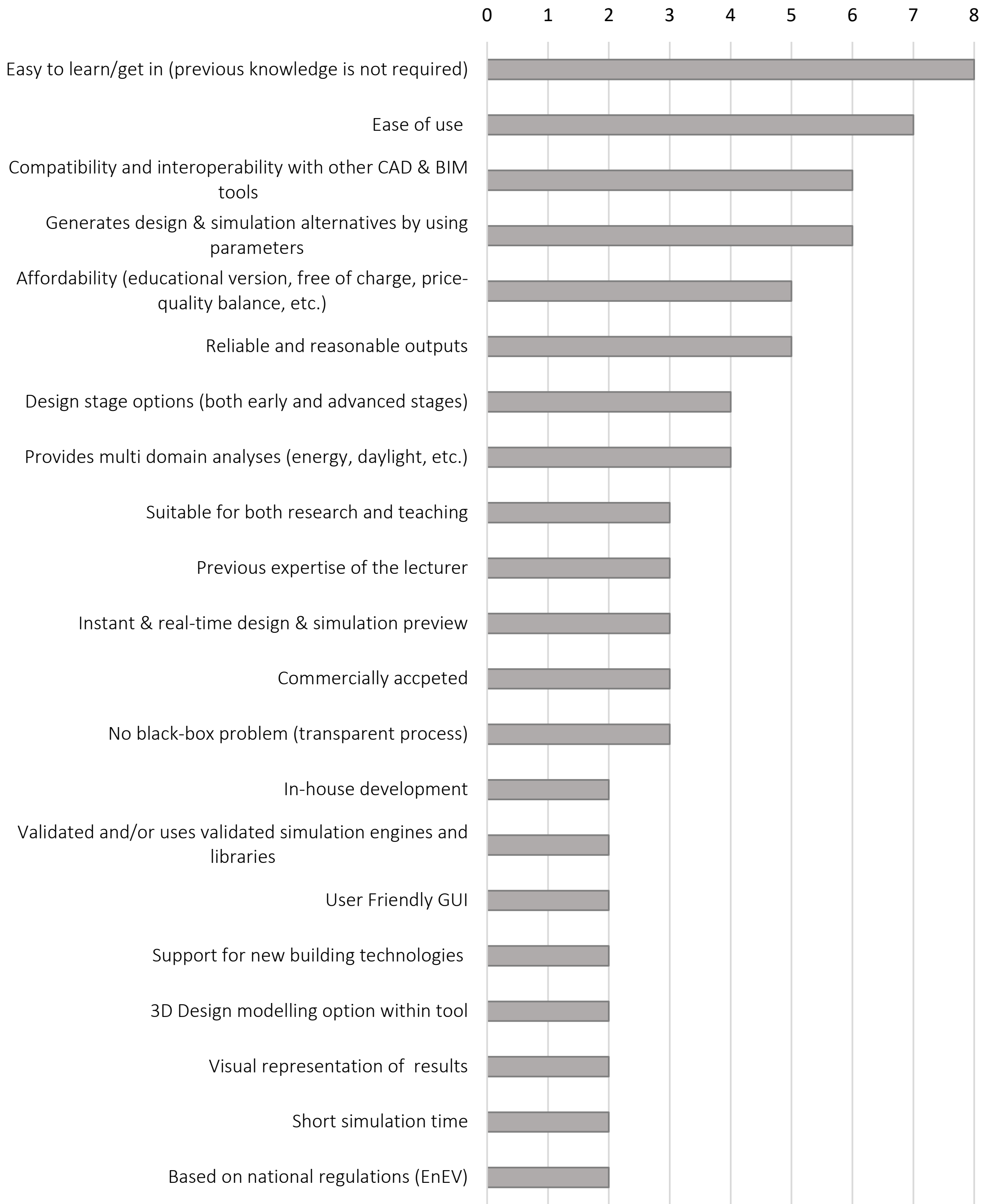



Figure 3. 17: Main reasons for using the BPS tool in question in teaching (numbers represent the number of times the same reason is cited by respondents).

#### 3.3.3.4. Suggestions and Comments from Respondents

Only 5 out of 18 participants shared their comments on BPS in teaching and their suggestions for future perspectives for better adoption of BPS in this context.

- The most commented topic was **the need for a stronger link between design and BPS tools** to achieve a better integration of BPS in design process. As it is reasoned by the respondents in more detail:

(1.) First, bidirectional, continuous and simultaneous data stream between design and performance tools, such as geometry information from design tool to BPS tool and performance information from BPS tool to design tool (i.e., representation of a simulation results on a design model by means of false color pictures);

(2.) Second, more visual input and output options in such a bidirectional link, especially considering the architecture students, who, due to their field of education, are considered to be more familiar with and comfortable using visual data.

- It is claimed that **not BIM, but CAD environment is more promising for the integration**, because:
  (1.) BIM environment is mostly used in advanced design phase, it may be late for a project to meet BPS for the first time in BIM environment;
  (2.) Also, instead of importing BIM model into a BPS tool, it mostly is preferred to create a simplified versions of a design models within BPS tools;
  (3.) And 3D CAD tools are the most preferred environments for the initial exploration and elaboration of a design work, so they have a potential to bring BPS and design together at an early stage.
- It is stated that students would be more pleased, if they could have a chance of simply handling the **main performance simulation within one tool** or within one environment that provides continuous workflows between design and different performance tasks. Because:
  (1.) It might be onerous for novices/new learners to enter BPS inputs over and over again for each performance simulation that they want to run. The possibility to use the same basic input information, e.g., site context, building geometry, material information and weather data, for a series of performance evaluations would provide a time-saving work environment that is less prone to errors, more accessible and more convenient.
  (2.) In addition, early design requires a relatively simplified BPS support to get an idea of an overall performance rather than making precise and definitive decisions through the use of advanced and detailed techniques.

### 3.3.4. Discussion

The survey "BPS in Teaching" aimed to find out how BPS is taught at German higher education institutions with the aim of identifying challenges on the way to integrated BPS teaching, especially in architectural education, and solutions that would shed light on this path.

Collecting background information on the respondents was useful in providing a basis for evaluating the answers. The vast majority of respondents were professors, and more than half of them were the heads of their departments with many years of experience teaching BPS. It can be deduced that having such a qualified and highly experienced sample group relevant to the research topic increased the value and impact of the survey results.

The main findings of the survey are evaluated below:

**Interdisciplinarity:** It turns out that almost half of the architecture students studied in groups that included students from other fields, which paints a picture of a multi-disciplinary architectural education. However, it was not possible to clarify whether the knowledge of the different disciplines remained within their boundaries or whether interdisciplinary communication was possible during the course, allowing the analysis and synthesis of different knowledge bases and the creation of links between them into a coordinated and coherent whole. While it is acknowledged that interdisciplinary education is indispensable for integrated BPS, it requires a deeper investigation, which is beyond the scope of the survey, but investigated in more detail through one-on-one interviews, which are reported in section 3.5.

Earlier introduction to BPS: BPS was mostly applied at graduate level. Only a few of the BPS tools that were the subject of this study were introduced at undergraduate level. While some of the respondents related this to the lack of knowledge of students at the undergraduate level on the basic principles of building physics and performance, some others claimed that most of the available BPS tools are too advanced and complex for the beginners/novices. Still, early introduction to BPS is one of the issues to be considered for better integration of BPS. The survey analysis has brought to the fore a gradual interaction with BPS, from simplified methods to advanced methods, preferably in a design environment, and methods that allow moving between scales of space, e.g. from zone to site, while maintaining the full picture of a design.

Early design integration – BPS as a part of design process: The results regarding the course format in relation to design teaching show that the vast majority of courses dealt with BPS and design separately. BPS tools were mainly used to evaluate existing designs/projects rather than to support or stimulate the design process. While being design driven was relatively higher in the courses targeting architecture students, it was still low in general. This can be considered as one of the barriers to the integration of BPS in design education.

Although it might have encouraged the students that the majority of the courses with BPS had no prerequisite, they were still elective courses, which opens another debate on the topic. In the survey, only one course was reported as a compulsory course among all undergraduate courses, which is less than adequate to introduce the fundamentals of building physics, therefore BPS.

Deductive approaches in the broader context: The projects of the courses were mostly on building scale, and this was followed by the scales of building envelope and single zone. It is seen that there were only a handful of courses that consider the site context at district and urban scales. However, as it is implied before, integrated approaches, with deductive methods, are vital especially for new beginners to understand the general frame of the building performance, at least in early design phase, for the qualitative demonstration of performance relationships rather than advanced appraisal of each performance requirement. Beyond this, considering the potential of energetic renovation of the existing building stock, especially in Europe, energy issues are more focused on the existing building stock within an urban environment rather than on new buildings. Therefore, the deductive evaluation of a design/project within a site context becomes more significant.

Utilization of on-line teaching methods: The teaching methods used in the courses were mostly based on face-to-face teaching; the use of online teaching methods is very low in percentage. On the other hand, online teaching can be of great value in bringing together educators and students from different disciplines to benefit from a high level of knowledge as well as enthusiasm for learning and teaching without the limitation of space, thus creating and developing educational networks. Since BPS learning sources have a wide range of options and possibilities on online platforms, the use of these methods within the courses can be more seriously considered to facilitate and enhance BPS teaching, i.e., accepting certificates from validated online learning & teaching platforms as credits in higher education curricula.

CAD tools for early design integration: Although physical models are more conventional methods compared to CAD and BIM tools, the study found that they were, by a small margin, the most commonly used design and documentation tools after CAD tools in the courses. Moreover, the use of CAD tools is quite understandable considering that most of the students subjected to the survey were architecture students and as mentioned before, CAD environment, which is usually the first choice of architecture students to start and explore design. Thus, it is a very promising and emerging platform for the integration of BPS and design education with its features such as interoperability and integrability with BPS tools, more visual representation, user-friendly GUI and the ability to integrate with other tools.

**Simplified tools with a broader scope of performance:** The BPS tools used in the courses were quite diverse. However, the purposes of the use (i.e., domains) of the BPS tools did not show the same diversity; the tools were mostly used for the energy and indoor comfort analyses. Therefore, the high variety of BPS tools used for the same purpose can be interpreted as a sign of a search for a simplified tool, especially for use in teaching, with a broader scope of performance domains instead of many specialized advanced tools. The satisfaction rate of the respondents with the BPS tools they use in teaching also supports this argument.

**Guidance for design early exploration through comparison of design alternatives:** Despite the fact that 75% of the BPS tools were asserted to have the capability to generate design alternatives through parameter studies, none of them were mentioned to have the capability to compare design alternatives. Additionally, other features that may help the incorporation of BPS into design process, such as visual representation of results in a 3D modeling environment, real-time simulation preview, ready-to-go reports and support for new building technologies were not provided by most of the tools.

### 3.3.5. Conclusion

In general, the main findings reveal that BPS exists in higher education, but the way it is taught is fragmented and attention should be paid to the following points in order to achieve the - especially design - integrated teaching: (1) early introduction of BPS to students, if possible during undergraduate education ; (2) early integration of BPS during design teaching, which might enable BPS to be a part of design process rather than just being an evaluation tool; (3) deductive approaches in a broader context; (4) utilization of online teaching methods as a means to reach a larger source of information and to extend educational networks; (5) the adoption of BPS in CAD tools; (6) simplified BPS tools with a broader scope of performance domains; and (7) the need for guidance for early exploration through comparison of design alternatives as a feature of a BPS tool.

It was accomplished to reach the most relevant sample group of the academics active in teaching BPS. The survey had a highly significant and relevant sample of respondents, that majority of whom are supremely qualified professionals with a significant teaching experience in their field of expertise. However, the size of the sub-sample groups (i.e., the number of the courses and/or BPS tools) are still not large, which limits the generalization of the survey.

## 3.4. BPS in SDE21/22 - Review and Survey

### 3.4.1. Introduction

SDE21/22 [129], held in Wuppertal, Germany in 2022, was the one of the European editions of SD [164], first organized in the USA in 2002, which aims to educate and train the next generation of AEC by equipping them with the knowledge and skills needed to create environment friendly, energy efficient and comfortable built environments.

The Faculty of Architecture and Civil Engineering of the University of Wuppertal [206] was the main developer, host and the organizing institution of SDE21/22. The project was funded by the German Federal Ministry for Economic Affairs and Climate Action [207] against the background of promoting a climate-neutral building stock by 2045 in Germany [208].

A total of 18 teams from 11 countries with the participation of more than 500 students competed on the renewal of existing urban structures through the 10 contests, Architecture (1); Engineering & Construction (2); Energy Performance (3); Affordability & Viability (4); Communication, Education &

Social Awareness (5); Sustainability (6); Comfort (7); House Functioning (8); Urban Mobility (9); and Innovation (10).

Due to difficulties caused by COVID-19, the competition final was postponed from 2021 to 2022, and two SDE21/22 teams (BKU and KMU) could not reach the final phase of the competition. Therefore, out of 18, 16 teams built their houses on a common competition site, the "Solar Campus", which is a 40,000 $m^2$ site near the city center of Wuppertal. The Solar Campus was an event area for the final phase of the competition, including evaluation by juries and measurements of the HDUs' performance and comparisons in 10 contests, as well as public visits. During 36 days on the Solar Campus, the teams built, operated, tested, measured, presented their HDUs, and explained their overall design approach to the jury, as well as to the public visitors, who were over 115,000 only in 12 days open to public. Table 3. 2 presents the SDE21/22 teams with their universities and countries.

Table 3. 2: SDE21/22 teams, universities and countries.

| Team | Name | University | Country |
|---|---|---|---|
| KIT | Team RoofKIT | Karlsruhe Institute of Technology | Germany |
| TUE | Team VIRTUe | Eindhoven University of Technology | Netherlands |
| TUD | Team SUM | Delft University of Technology | Netherlands |
| GRE | Team AuRA | École Nationale Supérieure d'Architecture de Grenoble | France |
| HSD | Team MIMO | Düsseldorf University of Applied Sciences | Germany |
| FHA | Team Local+ | Aachen University of Applied Sciences | Germany |
| ROS | Team Level Up | Rosenheim Technical University of Applied Sciences | Germany |
| UPV | Team Azalea | Polytechnic University of Valencia | Spain |
| HFT | Team CoLLab | Stuttgart University of Applied Sciences | Germany |
| ION | Team EFdeN | Ion Mincu, University of Architecture and Urbanism Bucharest | Romania |
| NCT | Team TDIS | National Yang Ming Chiao Tung University | Taiwan |
| HBC | Team X4S | Biberach University of Applied Sciences | Germany |
| CTU | Team First Life | Czech Technical University | Czech Republic |
| ITU | Team Deeply High | Lübeck Technical University of Applied Sciences & Istanbul Technical University | Germany & Turkey |
| UPH | Team Lungs of the City | University of Pécs | Hungary |
| CHA | Team Sweden | Chalmers Technical University | Sweden |
| BKU | Team SAB | Bangkok University | Thailand |
| KMU | Team UR-BAAN | King Mongkut's University of Technology Thonburi | Thailand |

Since the inception of SD, which also applies to SDE21/22, the competition has been unique in that it provides a backdrop for students, the future actors of the architecture, engineering and construction industry, to experience real-life challenges through the "design, build and operate" project process, where design is not only a creative problem-solving exercise, but also an integrated process that requires analytical, organizational and practical skills. The number of publications at the intersection of building performance and design [78,209–213], less than a year after SDE21/22, is a clear indication of the importance of the competition and the interest in the topic. The extensive adoption of BPS tools as one of the main assessment methods, in addition to the interdisciplinary setting of the SDE21/22 competition, which brings together research and practical experience, especially in the area of teaching and learning, provides a unique example of the use of BPS in education. Moreover, SDE21/22 was the first edition to be inspired by the work and outcome of the IEA EBC Annex 74 [214]. The edition included updates that were applied for the first time and greatly influenced the way of adoption of building performance simulation in the competition [78].

Therefore, the research was continued through SDE21/22. The main objective of the SDE21/22 investigation was to understand the integrative effectiveness of methods used in the application of BPS tools in the scope of competition.

### 3.4.1.1. SDE21/22: Urban Situations, Challenges, Contests and Scoring

SDE 21/22 was the first edition organized with a European urban profile. As a response to climate change, targets were set to achieve climate-neutrality in an existing urban building stock, by focusing on renewables, especially the active use of solar energy, increasing energy efficiency and reducing energy demand, especially based on fossil fuels.

Three different urban situations were given as options, and the teams were asked to choose one of these situations: (1) **renovation &extension**, (2) **closing gaps**, and (3) **renovation & addition** (Figure 3. 18). As an example, real situations were provided to the teams from a neighborhood in Mirke, which is a district of Wuppertal, but the teams were also free to find and work on a similar situation from their own countries.


Figure 3. 18: Urban situations: Renovation & Extension (1), Closing Gap (2), and Renovation & Addition (3), ©SDE21/22, [209].

Two challenges were presented to the student teams (Figure 3. 19):

- In the "**Design Challenge**" (DC), the teams created a design and energy concept by planning a whole building transformation addressing one of the urban situations.
- In the "**Building Challenge**" (BC), the teams designed a **House Demonstration Unit** (HDU), which is to be a representative of the DC, and built it on the Solar Campus at the competition final. HDUs were one- to two-story houses with up to 110 m2 of living space.

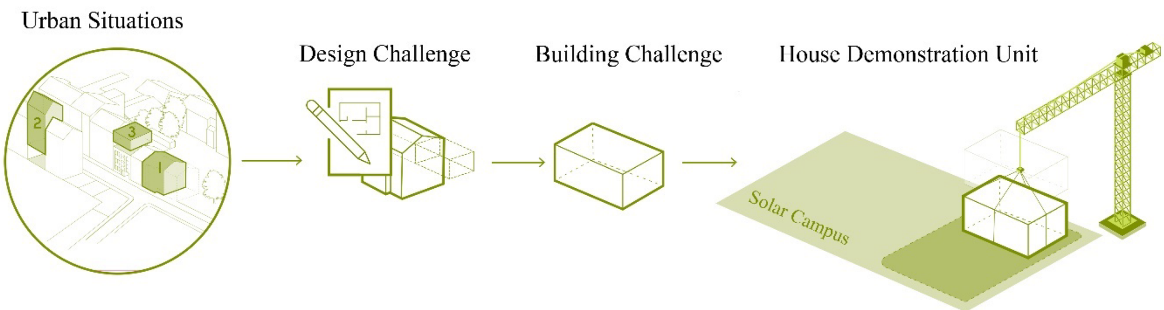



Figure 3. 19: Urban situations (1,2,3), Design Challenge, Building Challenge and House Demonstration Unit, ©SDE21/22, [209].

In total, there were 5 different ways for the teams to earn points (scoring type): jury evaluation, guest evaluation, task completion, tests and monitoring in-situ. Still, the main evaluations were based on jury and monitoring, 30% of the points in 10 disciplines were distributed based on monitoring and 70% on jury evaluations.

The teams worked on the planning and design of their projects for 3 years. In order to ensure the gradual continuation of the work and provide feedback on the work of the teams, they were asked to make a series of submissions until the final stage of the competition. These submissions, namely "deliverables", included all the documents, drawings and other materials that the teams had to submit to the SDE21/22 organizers.

## 3.4.2. Methodology

The adoption of BPS in SDE21/22 is reviewed through the official documents of the SDE21/22 (i.e., the SDE21/22 Rules, Content and Criteria documents) and the reports of the participating teams (i.e., the teams' project manuals), which were submitted just before the competition final. The evaluation includes 16 of the 18 teams that competed in the final event. All data and documentation used for the review are available on the Building Energy Competition & Living Lab Knowledge Platform [215]. The author of the thesis also gathered information from on-site inspections, which she had the opportunity to personally participate as a member of the SDE21/22 developing and organizing team. The findings of the review are cross-analyzed with the competition results about the teams' ranking [216], in order to analyze the effectiveness of the methods applied in the competition for the integrated use of BPS. Additionally, the deployment of building performance topics in the curricula of the participating universities is investigated. The level of adoption and the competition results are also cross-analyzed to see whether higher adoption led to higher rankings. Also, the teams' SWOT (Strengths, Weaknesses, Opportunities and Threats) analyses are reviewed to identify the most prominent aspect for the strategic integration of SDE21/22, in particular the topic of building performance across the curricula.

The use of BPS tools by the SDE21/22 teams are investigated by a survey, namely *"BPS Tools in SDE21/22"*, which is conducted in an anonymous format after the completion of the competition via the online communication platform of the SDE21/22. Out of 18 teams, 12 teams participated. The questions were close-ended with single- and multiple-choice options. In total, there were 10 questions. Some of the questions were provided with definitions of the terms used in the questions to avoid misunderstandings and/or confusion, for example, the definitions of the design phases were given in the questions about the design and documentation tools used in different design phases.

## 3.4.3. Results

### 3.4.3.1. BPS in SDE21/22 - Review Results

In SDE21/22, in order to assess the performance of the designs, the teams were asked to provide annual simulations to estimate the sustainability and efficiency of the energy concepts over the course of a year, continuously through deliverables. Besides that, BPS accompanied to in-situ tests and measurements.

BPS studies were deliberately encouraged in SDE21/22 by targeting 3 main didactive points:

- Studying the variations during design development to find the optimum solution for a targeted performance.
- Testing the robustness of a design; e.g. to test the resilience against extreme weather conditions (e.g. heat wave effect) and/or extreme/unexpected user behavior (e.g. operation of blinds, windows).
- Initiating the generation of simulation data to be compared with measurements as a part of Performance Gap Task (PGT).

BPS tools were mainly utilized in the scope of the Contest 2 - Engineering & Construction, Contest 3 - Energy Performance; and Contest 7 – Comfort, as well as Contest 1- Architecture. The contests are presented in Table 3. 3, with dots indicating the sub-contests where BPS was used.

Table 3. 3: BPS in the contests and sub-contests at SDE21/22. Dots refer to the sub-contests where BPS tools were used [79].

| Contest | | Sub- contest | Scoring type |
|---|---|---|---|
| 1 | Architecture | ● site integration | jury by team reports |
| | | ● building design | jury by team reports |
| | | ● interior & lighting design | jury by team reports |
| | | ● solar system integration | jury by team reports |
| 2 | Engineering & Construction | ● energy concept | jury by team reports |
| | | ● performance analysis | jury by team reports |
| | | ● life cycle carbon footprint | jury by team reports |
| 3 | Energy Performance | ● energy consumption | monitoring by in situ measurments |
| | | ● energy balance | monitoring by in situ measurments |
| | | ● self consumption | monitoring by in situ measurments |
| | | ● pv system performance | monitoring by in situ measurments |
| | | ● grid interaction | team task |
| 4 | Affordability & Viability | affordability | jury by team reports |
| | | viability | jury by team reports |
| 5 | Communication, Education & Social Awareness | communication | jury by team reports |
| | | education | jury by team reports |
| | | social awareness | jury by team reports |
| 6 | Sustainability | ● circularity | jury by team reports |
| | | sufficiency, flexibility & | jury by team reports |
| | | environmental performance | jury by team reports |
| 7 | Comfort | ● temperature | monitoring by in situ measurments |
| | | ● humidity | monitoring by in situ measurments |
| | | ● air quality (CO2) | monitoring by in situ measurments |
| | | ● lighting | monitoring by in situ measurments |
| | | ● sound insulation | test in situ |
| | | ● air tightness | test in situ |
| | | ● performance gap | team task |
| 8 | House Functioning | appliances | monitoring & team task |
| | | hot water & water balance | team task |
| | | dinner | guest evaluation |
| | | user friendliness | guest evaluation |
| 9 | Urban Mobility | mobility concepts | jury by team reports |
| | | urban mobility tasks | team task |
| 10 | Innovation | | iury by team reports |

- **BPS in the design stage in SDE21/22**

Almost all the teams used BPS starting from early design phase. These investigations at the intersection of design and performance were used to compare, evaluate, and identify prominent design alternatives and then move on to further design details. Some early design and design development investigations, at the intersection of the design and performance topics, for HDU, as well as DC are illustrated in Figure 3. 20.

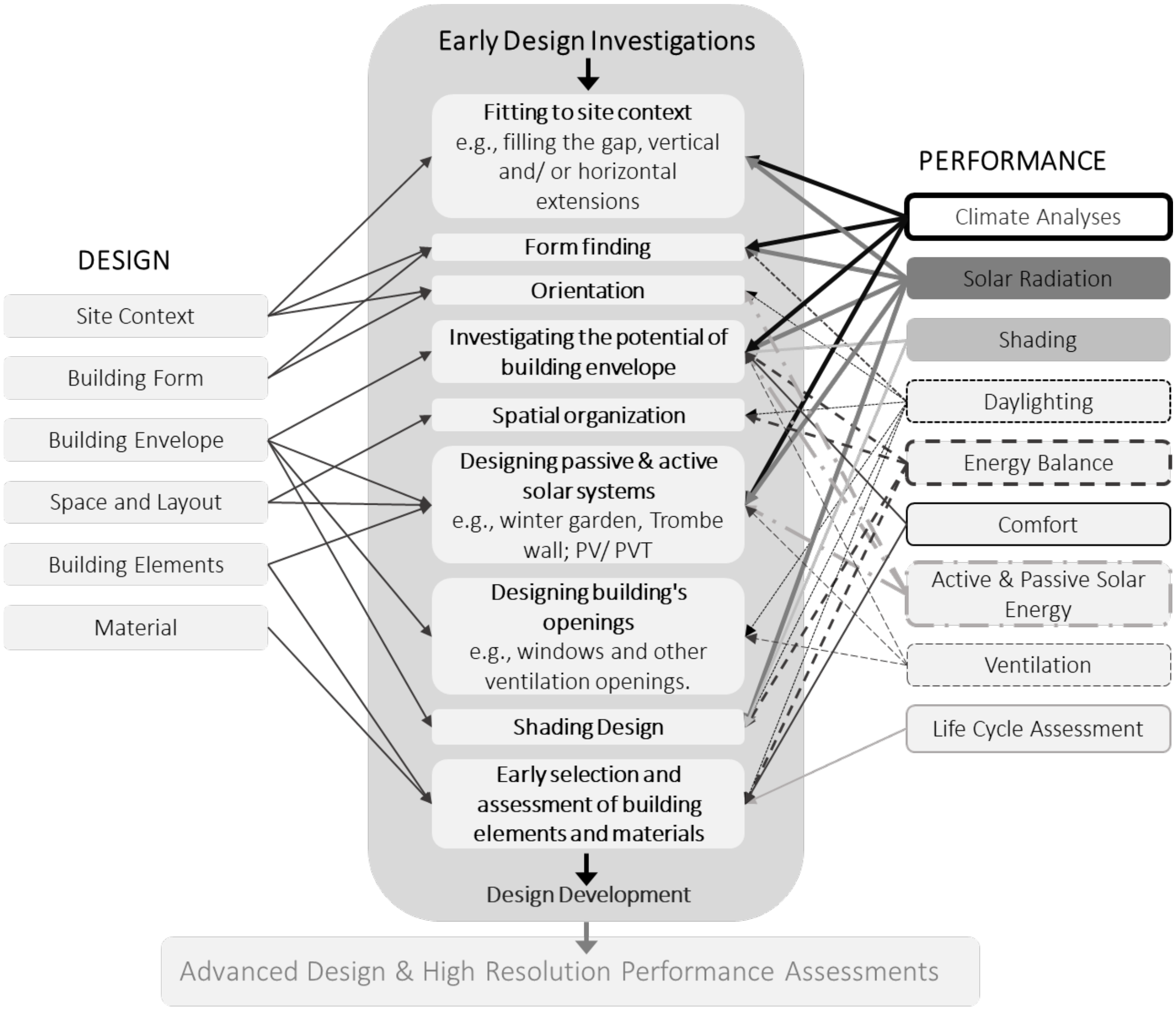



Figure 3. 20: Early design investigations and design development for DC and HDU by the teams at the intersection of design and performance [79].

Accordingly, a wide variety was observed amongst the BPS tools used by the teams, in terms of calculation methods (un-dynamic, dynamic, semi-dynamic), field of application (i.e., domains of energy, comfort, PV/PVT, LCA etc.), level of integration with the design tools (i.e., integrated, semi-integrated, independent), as well as intelligent design options provided by the tools (i.e., parametrization and optimization). Figure 3. 21 presents the use of BPS tools in the context of the SDE21/22. The tools used by the teams are presented according to the field of application in Table 3. 4.

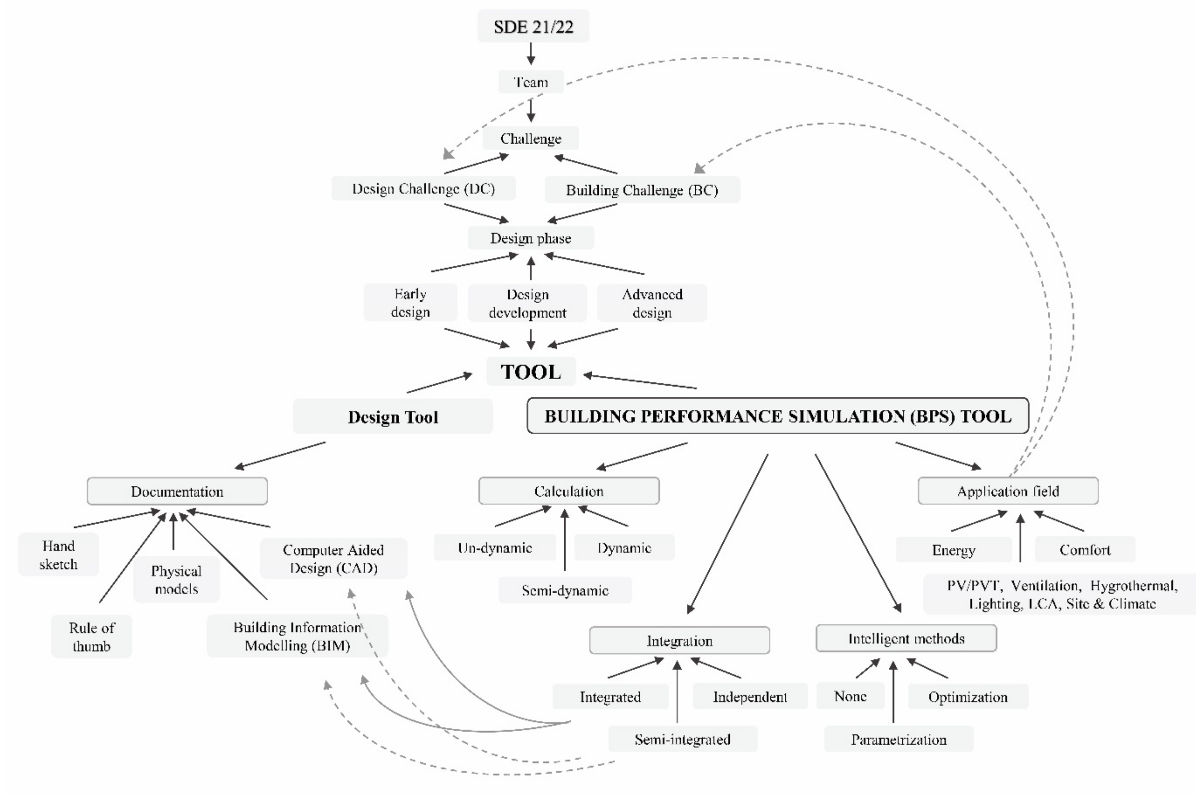


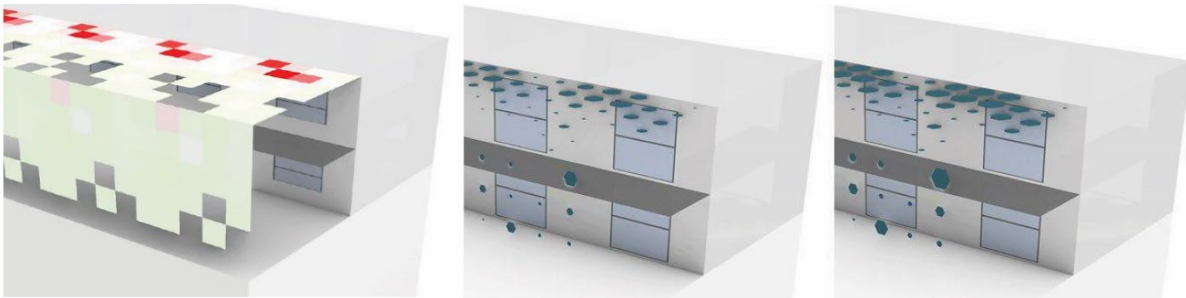

Figure 3. 21: Use of BPS tools in the context of the SDE21/22, © SDE 21/22, [201].

Table 3. 4: BPS tools and their fields of application [201].

| | Site & Climate | Energy | Comfort | PV/PVT System | Ventilation | Hygrothermal | Lighting | LCA |
|---|---|---|---|---|---|---|---|---|
| FIELD | Site integration | Use | Thermal Comfort | Design | Passive | Heat | Daylight design | Cost |
| | Radiation | Cost | Air quality | Production | Mechanical | Moisture | Artificial light design | Carbon footprint |
| | Shadow | Balance | Humidity | Grid integration | | | Visual Comfort | Circularity |
| TOOL | RESBy | Design Builder | Design Builder | PVlib Python | Ladybug Tools | WUFI | Autodesk Revit | UMI Tool |
| | Vi-suite | MATLAB / Simulink | SimRoom | PVGIS | Plancal Nova | Lesosai and Flixo | IDAICE | eLCA/Bauteileditor |
| | Ladybug Tools | Ladybug Tools | TRNLizard | AutoCalSol | DDS-CAD | Therm | Dialux Evo | SimaPro 9.0 |
| | Climate Consultant | IDAICE | TRNSYS 18 | Polysun | TRNFLOW | PsiTherm | Radiance | Caala |
| | Climate Studio | SimRoom | ENERCALC | TRNLizard | | | VELUX | OneClickLCA |
| | | EN-13790 Tool | ETU Sim. Gold | Sunny Design | | | IES-VE | |
| | | Plancal Nova | IES-VE | PV*SOL | | | RELUX | |
| | | EnergyPlus | | T*SOL Valentin | | | | |
| | | DDS-CAD | | OpenModelica | | | | |
| | | TRNLizard | | PV syst 7 | | | | |
| | | TRNSYS 18 | | POLYSUN | | | | |
| | | ENERCALC | | SolarEdge | | | | |
| | | ETU Sim.Gold | | | | | | |
| | | IES-VE | | | | | | |
| | | PHPP | | | | | | |
| | | ClimateStudio | | | | | | |
| | | Open Studio | | | | | | |

One example study from the team HFT, which is recently published [210], presents the work of the team about the optimal placement of PV cells, by the use of parametric design and BPS tools. In the study, solar gains are reduced for summer thermal comfort, while being utilized for winter and at the same time high efficiency is achieved for the PV system. An example image from the work is shared in Figure 3. 22.

(1)



(2)

Figure 3. 22: An example image from the work of the team HFT - Design of the building envelope with integrated use of BPS: (1) Final Design, (2) Design development –Evaluation of direct irradiation for the detection of shading need. ©SDE21/22, ©Team CoLLab [79].

Another example is provided by the team KIT about their experience in using BPS during design process to support decision-making and achieve the realization of their proposed design, which is also recently published [212]. It is explained how the solar-based heating system of their HDU was optimized, decisions regarding the area and angle of the PVT collector and the storage control strategies were structured by adoption of BPS. In addition to the work presented in the study, the team also used BPS to determine window area and positioning to study the influence of night ventilation on local thermal comfort, and to optimize insulation thickness and thermal mass.

Another highlight at the intersection of design and performance was the implementation of active solar energy systems and their integration into the design as an architectural element. A paper [78], in which the author of this thesis is also involved, focuses on solar engineering and discusses the topic in more detail. It is worth mentioning that although the maximum power output of a PV/PVT system was limited for competition-related reasons and only the systems on the roof of the HDUs were more than sufficient to fulfill the competition requirements, many teams chose to demonstrate their integrated design ideas by using PV/PVT systems on the facades, even though they were not actively connected to electrical or thermal energy during the competition.

To promote the use of BPS, one of the important steps taken by the SDE21/22 organizers was the introduction of a simplified single-zone energy and indoor climate simulation tool, namely "SimRoom" [217]. Also, it is aimed to ensure a homogeneous modeling and simulation experience among the teams. SimRoom was preferred because it is a free Excel-based tool that is easy to use and learn in a short time. Additionally, it was already proven by positive didactive experiences in many schools of architecture and engineering in Germany [218] and by validation studies [219].

SimRoom was mainly utilized for two purposes: (1) indoor climate and energy calculations of the HDUs, (2) PGT as a part of the comfort contest. The use of other BPS tools in addition to SimRoom was also encouraged for all related performance evaluations.

The teams' process and experiences with SimRoom, and their simulation works on indoor comfort and energy balance, were constantly tracked and supported by workshops, question & answer sessions, guiding documents (e.g., user manual, content and criteria etc.) and reviews by the SDE21/22 organizers and the experts, who were appointed for the tasks. The teams made 6 deliveries until the competition final. Starting from the deliverable 4, teams were required to submit their SimRoom simulations on the HDU for review. These submissions were not intended to be graded, but only to give the teams feedback on the quality and plausibility of their work.

The teams' ranking in the "performance analysis", which is the sub contest of the "engineering & construction" contest, focusing on indoor comfort and energy concepts, and decided by jury, is compared to the teams' performance in the SimRoom reviews (see the Table 3. 3 for the contest and sub-contest at SDE21/22). To do so, both the review and the ranking are proportioned between 1-100 (%) and compared (Figure 3. 23). The teams BKU and CHA, for they did not submit any documents for the SimRoom review, and the team KMU, for could not attend the competition final, are excluded from the comparison. The patterns of the review and the jury ranking are quite similar, except for the teams ITU and UPH.

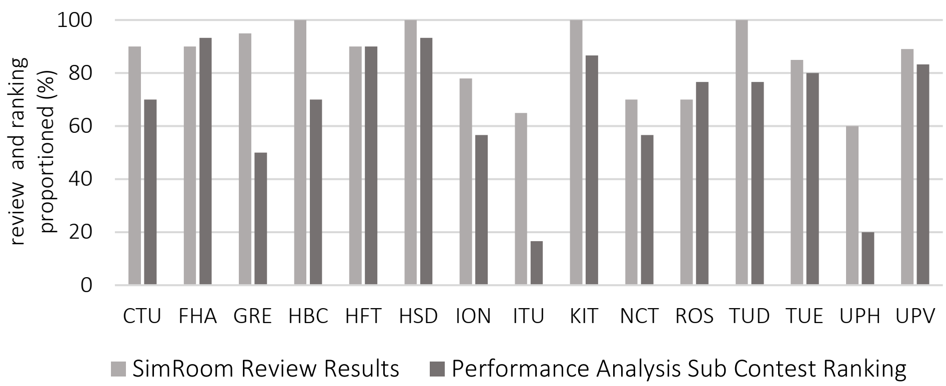



Figure 3. 23: Comparison of the SimRoom review results with the performance analysis sub contest ranking [79].

Another cross-analysis is made between the teams' BPS use intensity and the teams' ranking in the contest of "engineering & construction", which includes the sub-contest of "energy concept", "performance analysis" and "life cycle carbon footprint" (see Table 3. 3 for the contests and sub-contests at SDE21/22). The number of the domains, which are investigated by the teams for performance assessment of their DC and HDUs, are listed by the review of the teams' reports. A range is defined as low, medium, high and very high, based on the number of domains to define the intensity of BPS use. When the ranking in the contest is compared to the intensity of BPS use, a consistent pattern between the ranking and intensity is observed, except for the teams HBC and NCT (Figure 3. 24). The minor deviations in the pattern might be related to that the performance sub-contest addressed addressing both DC and HDU, while the review was on the performance assessment of the HDUs by SimRoom.

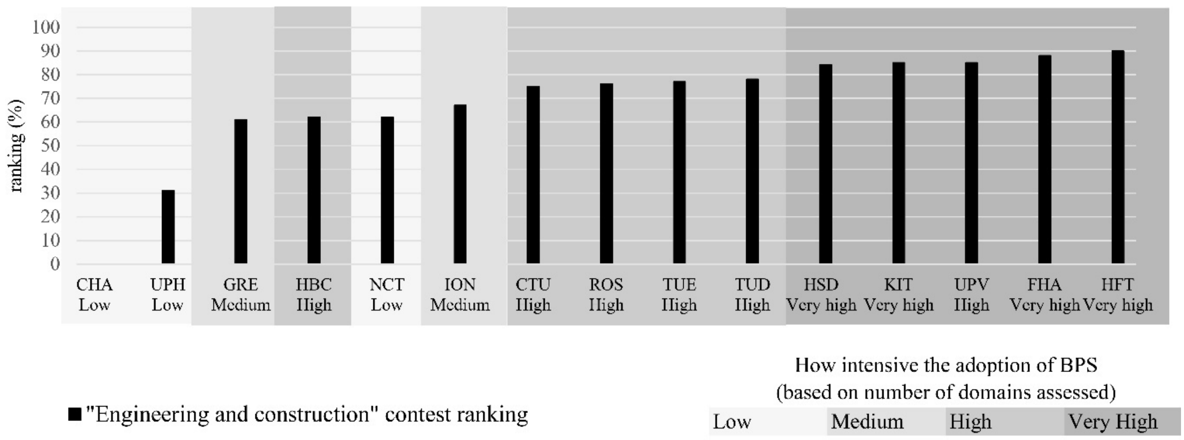



Figure 3. 24: Comparison of the BPS use intensity with the engineering and construction contest ranking [79].

- BPS in the operation stage in SDE21/22

Two recent studies [78,211], including the author of this thesis, report specifically on the building physics aspects of SDE21/22 houses, explaining the monitoring and measurement results. In the scope of this chapter, the use of BPS in the operational phase is presented, focusing on the integrative effectiveness of methods for teaching BPS.

The PGT, which refers to the investigation of the difference between anticipated and actual performance, is selected as a showcase for demonstrating the use of BPS in operation at SDE21/22. In the scope of PGT, the teams were requested to deliver their HDUs' performance simulations for specified period of time, during which the co-heating tests were performed - for the first time at SDE21/22 - and the operative temperatures were monitored to be compared to the simulation results.

The co-heating test is defined as an assessment of the as-built performance of a building by comparing the heat input into a building against the disparity between temperatures inside and outside the building [220]: "During a co-heating test, the investigated dwelling is homogeneously heated to an elevated steady-state interior temperature, e.g. 25 °C, using electric heaters and ventilator fans scattered throughout the building.". Earlier studies on dynamic test methods for buildings were used by the SDE21/22 organizers as a guide, particularly those from "Annex 71 - Building Energy Performance Assessment Based on In-situ Measurements" in the IEA EBC program [221].

The three main objectives were (1) to enable students to have an overview over the topic of building performance at the intersection of indoor thermal comfort and thermal characterization of the HDUs, (2) to stimulate the teams to do better work, keeping in mind that their work will be evaluated and (3) to provide a data set for post-competition research and teaching.

- BPS in the curriculum of the participating universities

To investigate the level of adoption of building performance topics in the curricula of the participating universities, in the context of SDE21/22, a review is made based on the information shared in the teams' reports. In the scope of the review, the topics of building performance include energy, indoor thermal comfort, indoor air quality, ventilation, hygrothermal assessment, lighting, and related building technical equipment, as well as building integrated renewable energy. It is observed that the number of the building performance related courses was higher when the majority of students were from more technical and/or engineering-oriented departments rather than design and art. While the topics of sustainable design and lighting design were more commonly seen at bachelor's level in architecture, technical topics such as thermal comfort and the other topics related to the building thermal and optical properties were more common at the bachelor's level in engineering. Almost half of the participating universities centered the design studios in bachelor's or/and master's programs on the SDE21/22 challenges including performance topics.

The number and weight (in %) of building performance courses in the total number of courses offered at the universities of the participating teams within the scope of SDE21/22 are presented in Table 3. 5. Some reports mentioned the existence of some courses in the study programs related to SDE21/22, but did not give details about the topics of the courses, so in these cases the information was not applicable (n/a).

Table 3. 5: Number of the courses and the number and the weight (in %) of building performance courses in the total number of courses offered at universities within the scope of SDE21/22. Abbreviations refer to the 18 teams [79].

| | Bachelor Courses | Master Courses | In total (%) | PhD Studies |
|---|---|---|---|---|
| BKU | n/a | n/a | n/a | n/a |
| KMU | 7 out of 28 | n/a | **25%** | n/a |
| NCT | 2 out of 18 | | **11%** | n/a |
| ITU | n/a | n/a | n/a | n/a |
| ROS | 5 out of 24 | 3 out of 7 | **26%** | n/a |
| UPH | 2 out of 4 | n/a | **50%** | n/a out of 11 |
| HBC | 3 out of 13 | 1 out of 2 | **26,6%** | n/a |
| HSD | 4 out of 16 | 7 out of 16 | **34,40%** | n/a out of 3 |
| ION | n/a | n/a | n/a | n/a |
| KIT | 11 out of 17 | n/a | **64,7%** | n/a |
| TUE | n/a | n/a | n/a | n/a |
| CHA | n/a | n/a | n/a | n/a |
| CTU | n/a | n/a | n/a | n/a |
| FHA | 4 out of 16 | n/a | **25%** | n/a |
| GRE | 3 out of 5 | | **60%** | n/a out of 3 |
| HFT | 6 out of 30 | | **20%** | n/a |
| TUD | 1 out of 4 | | **25%** | n/a |
| UPV | 7 out of 11 | 2 out of 5 | **56,25%** | n/a |

**n/a**: not applicable

The results are cross-analyzed with the teams' ranking to see if a higher weight of the building performance topics led to a higher success in the contest of architecture, engineering and construction, energy performance and comfort where building performance assessments were extensively applied. The first 4 teams, in whose universities the topic of building performance has a weight of at least 50% among the other topics of SDE21/22, are investigated (Figure 3. 25). It becomes clear that the teams with higher rankings were those from the universities with the higher weight of adoption of performance topics. For example, the KIT team from the university with the highest weight of building performance topics (64%) was the winner of the competition with the highest overall ranking. The pattern remains same for the second (60%), third (56%), and the fourth (50%) teams.

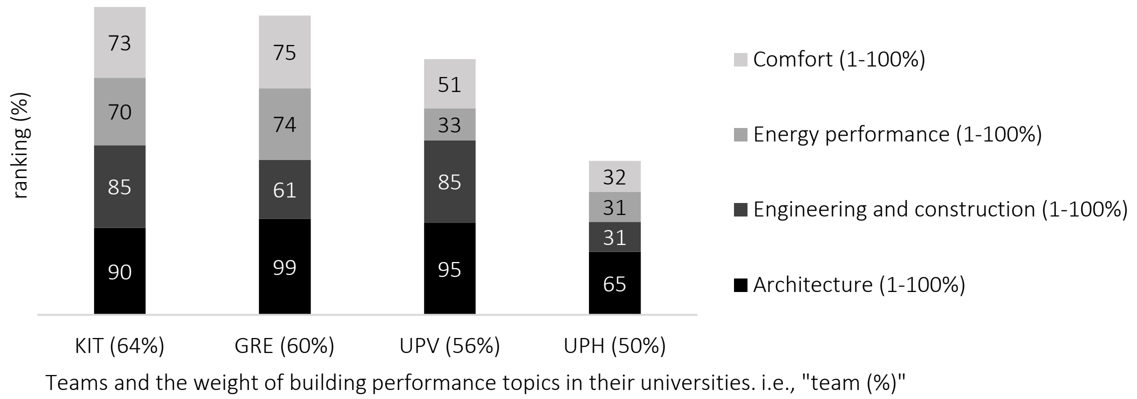



Figure 3. 25: Comparison of the teams' ranking for the contest that BPS are applied to the weight of the building performance topics in the curriculum of their universities [79].

To see the common opportunities and obstacles for the strategic integration of SDE21/22, particularly the topic of building performance across the curricula, the most prominent aspects mentioned in the teams' SWOT analyses as a part of their education reports are compiled and presented in Table 3. 6.

Table 3. 6: Most prominent aspects which are mentioned in the teams' SWOT analyses for the strategic integration of the topics of building performance across the curricula [79].

**Strengths**

- Available infrastructure and resources of university
- Multi-disciplinary teams of students
- University curriculum in engineering and architecture
- Collaborations within and between universities
- Interest boost from the previous Solar Decathlon participation
- Impact and appeal of previous Solar Decathlons / Decathletes

**Weaknesses**

- Tedious and complex bureaucracy of educational institutions
- Scarce of project-based pedagogical approaches
- Rarity of interdisciplinary education and research
- Low level of knowledge if a team consists mostly bachelors
- Lecturers/supervisors with high teaching load
- Restrictions due to the Covid-19 pandemic

**Opportunities**

- Digital transformation for online teaching and learning
- Adaption of new pedagogical approaches/methods
- Raising awareness for sustainable built environment
- Promoting inter-disciplinary skills of students
- Contributing to solving the global challenges
- Enlarging collaborations within and between universities

**Threats**

- Strict curricula that conflict with SD timetable and works
- Solar Decathlon being a time limited event
- Risk of scientific criticism being reduced by sponsorships
- High cost for organization of educational activities
- Unstable politics and economy worldwide

### 3.4.3.2. BPS Tools in SDE21/22 - Survey Results

The teams were asked which design tools were used in which design phase, i.e., early design, design development and advanced design, during the challenges (DC and HDU) (Figure 3. 26). While the use of hand sketches and physical models was common in the early phases, the use of digital tools, i.e. CAD and BIM tools became more dominant in further steps of the design process. When the challenges are compared, the adoption of CAD tools was intensive in both DC and HDU. In all design phases, the utilization of BIM tools is significantly higher for HDU, compared to DC. On the other hand, while the use of BIM increases from early phase to advanced phase, CAD is always the most dominant tool of the whole design process. Considering the intensive use of BPS tools in the whole design process, these findings are likely to indicate that the effectiveness of CAD was higher than the other design and documentation tools for integrated design and performance workflows and also that the use of BIM was an integral part of the integration especially in the design development and advanced design phases.

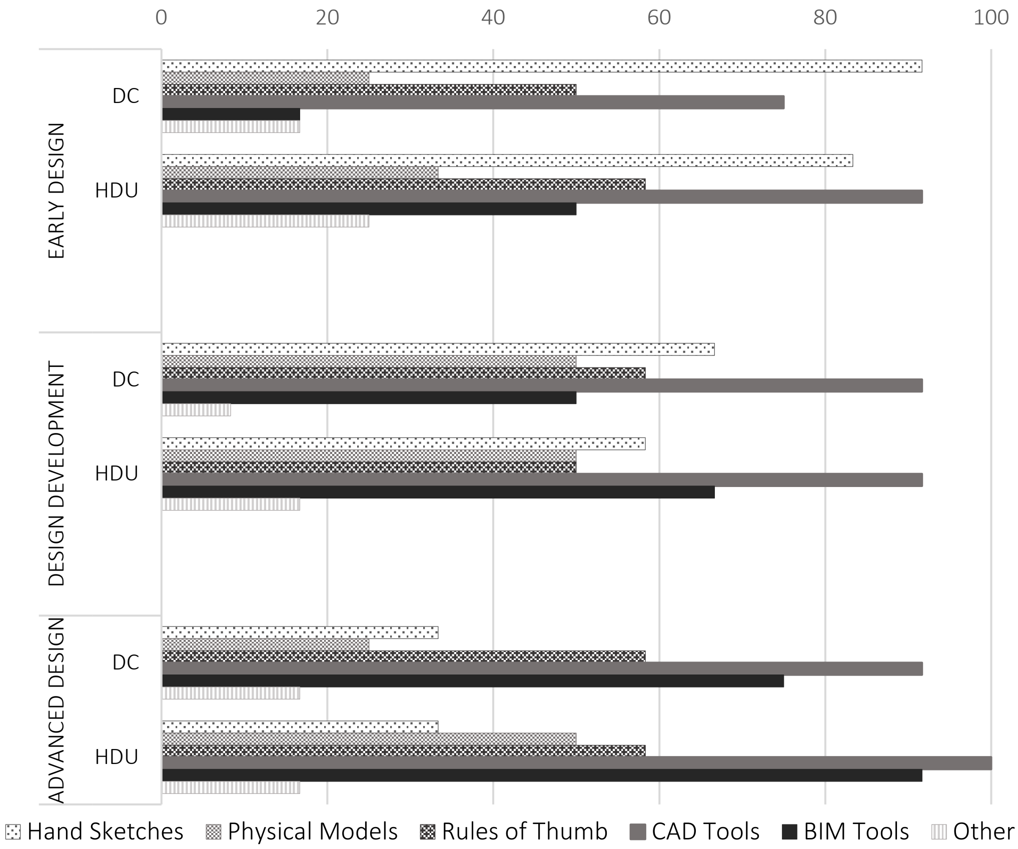



Figure 3. 26: Use of design tools based on design phases (early design, design development and advanced design) in relation to design challenges. The teams' selection represented in percentage (%) [79,201].

The level of integration of a BPS tool, which refers to the physical availability of the BPS tool directly in a design environment, was asked (Figure 3. 27). The four levels of integration were defined, (I) non-integrated, (II) partially integrated, (III) mostly integrated and (IV) fully integrated. Non-integrated refers to a BPS use where all design process and performance simulations are conducted completely in different and separate environments, and there is no file exchange between these two processes. Fully integrated means that all BPS tools are available in the design tools. The results show that BPS tools were mostly partially integrated, yet the integrative effectiveness of HDU was higher than that of DC.

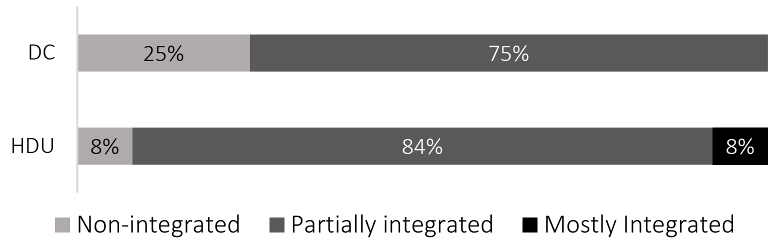



Figure 3. 27: Level of integration of BPS tools into the digital design environment in relation to challenges (DC and HDU). The teams' selection represented in percentage (%) [79,201].

Regarding the phase in which the teams started using BPS tools, the teams showed a varying pattern for the DC. On the other hand, for HDU, the majority of the teams (75%) started to include BPS in their design workflows in the early design phase (Figure 3. 28).

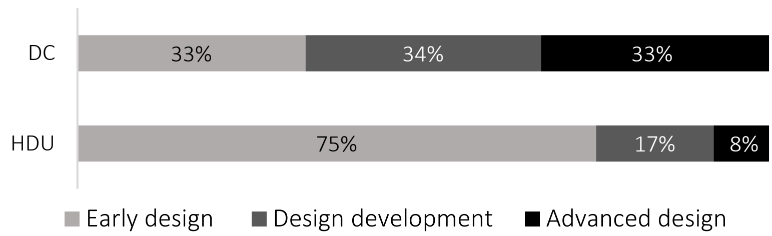



Figure 3. 28: Use of BPS tools in different design phases (early design, design development and advanced design) of the challenges (DC and HDU) [79,201].

The overall influence of the conducted simulations on the architectural designs - especially the impact of the BPS results on a design form - was considered differently (Figure 3. 29). This result may be related to the fact that the teams used BPS at different intensities in the early design phase. Nevertheless, more than 50% of the teams indicated that the influence of BPS on design decisions was high.

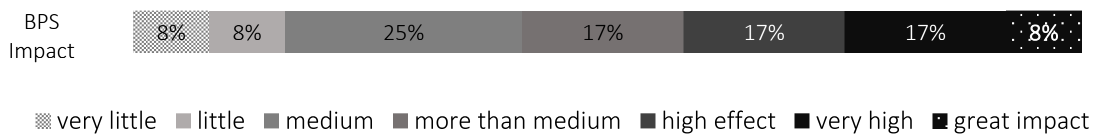



Figure 3. 29: BPS impact on architectural form-related design decisions [79,201].

The teams mainly agreed on that BPS, especially in early design, was useful for creating design alternatives, raised confidence for decision making and supported creativity (Figure 3. 30).

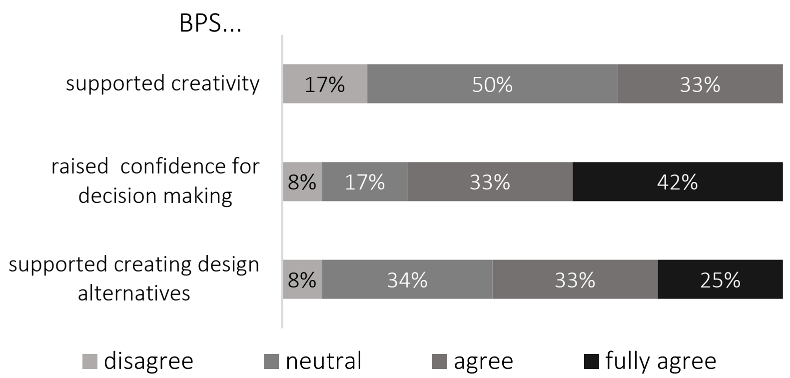



Figure 3. 30: Descriptions about the effect of BPS tools in early design process [79,201].

It is stated that only a small amount of the simulation work (8%) was performed by external experts. For the internal works (which is 92% of the total work), team members from the field of engineering were more active. In terms of student level, the involvement of graduate and undergraduate students was almost evenly distributed.

When asked about the top three features of a BPS tool to be used in the early design phase, the teams ranked "ease of use" as the most important feature. This was followed by "guidance (e.g., by providing explanations for limit values)" and "comparison of design alternatives". "Integration with a design tool", "availability of intelligent design/simulation methods, i.e. parametrization, automation, optimization, etc.", and "being suitable for both early and advanced design stages" were voted equally.

### 3.4.4. Discussion

The review and the survey on the adoption of BPS in the SDE21/22 competition aimed to understand the integrative effectiveness of the teaching and learning methods applied in relation to design and performance, and to identify challenges and possible solutions for a more integrated use of BPS.

<u>The review on the adoption of BPS in SDE21/22 showed that;</u>

- <u>with a particular focus on the design stage,</u>

1. **early design investigations at the intersection of design and performance** by adoption of BPS has a high potential in order to compare, better evaluate and identify the prominent design alternatives. The use of BPS during the design process can support design exploration and decision making, i.e., fitting to site context, form finding, orientation, designing building envelope, openings, shading elements, and early selection and assessment of other building elements and materials.

2. The introduction of a **simplified BPS tool**, SimRoom, by the organizers and the quick adoption and successful use of this tool by the teams was noteworthy, not only because it provided a convenient basis for reviewing and comparing the results of the teams, but also because it supported the argument that simplified approaches can be useful for enabling *"easy get-in"* and "*easy use",* especially considering the beginners in BPS.

3. The results of the cross-analysis of the teams' ranking and review performance support that the **continuous support and tracking of the teams' BPS studies**, especially with the reviews provided by the SDE21/22 experts, was a highlight for escalating the learning curve.

4. The results of the cross-analysis of the teams' rankings and BPS use intensity support that performance investigations that include multiple domains are likely to support the integrated learning experience. The consistent pattern serves as evidence that **multiple view/domain assessments** provide a better understanding of the relationships between different performance requirements and thus the overall performance of a design can be improved in an integrated manner.

- <u>with a particular focus on the operation stage,</u>

5. The **PGT stood out as a significant component of the integrated BPS approach for creating a link between design and operation**. Students had the opportunity to compare the measurements, and performance expectations, which were assessed mainly by the use of BPS tools during the whole project process, to learn what was wrong or missing in their assessments and/or in the overall building process. It was also an important stimulus for deeper investigation of the performance of the design, for the teams knew that the real performance was to be tested in the final step. On the top of these, it was noteworthy for providing a source for post-competition education and research activities. Recent studies [78,212], using the data and experiences gained during the PGT, stand out as evidence of this.

- with particular focus on the curriculum,

**6**. The **adoption of multi-domain performance investigations** exhibited a positive correlation with the overall success of teams in the competition, not only in engineering contests, but also in architecture. While it is not possible to speak of definitive causality without more detailed research, as the information on the level of adoption is based only on the review of the teams' reports, the findings point to the potential for multi-domain investigations to be an important component of the integrated BPS approach.

**7.** The **SWOT analysis on the strategic integration of building performance topics in the curricula** of the teams' universities highlights the challenges stemming from the strict curricula, the varying levels of students' building physics knowledge due to their varying backgrounds, the time limitations, also on a more general level, the high costs of organizing educational events, and the unstable political and economic situation worldwide. In response, (1) the provision of flexible curricula that allow for collaboration between departments of different disciplines and further between universities to pool existing knowledge and resources and provide a more interdisciplinary education environment, (2) the use of all possible teaching platforms, from face-to-face teaching to online teaching, to increase access to educational materials regardless of time and place, (3) the application of pedagogical methods such as "learning by doing", "challenge-based learning", and "experiential learning" [169], which link different project stages such as design, construction, and operation, and thus can help to move traditional classroom-based learning toward more interdisciplinary and hands-on models, seem to be potential solutions for realizing integrated BPS teaching.

The survey on the use of BPS tools by the SDE21/22 teams showed that;

**1.** the **CAD tools were used more intensively** than any other design and documentation tool. This is an important outcome that should be considered in the further development of digital platforms that combine CAD and BPS tools to allow for greater integration of performance analyses, especially in early design.

**2.** The level of **physical integration of a BPS tool into** a design tool was higher in case of the HDUs compared to the DC challenge. it is also seen that, while working on HDU design, the teams mostly started to involve BPS earlier in their design workflows compared to DC. Students were found to be more likely to adopt BPS when they knew that their designs would be built, and as-built performance tested. It is observed that especially for architecture students, performance research on their own designs was more attractive than performance research on an existing design, which supports the idea of using BPS as an element of the design process rather than just as an evaluation tool to better integrate BPS into architectural design education. In general, these findings can be interpreted as more the learning & teaching methods (in the case of SDE21/22, this refers to the "challenges") integrate the project stages (e.g., design, construction, operation), the more the BPS is incorporated into the design environment. It can be said that the integrated teaching methods support and, moreover, require the integrated use of BPS tools with design tools.

**3. BPS has a significant impact, not only on performance but also on form related architectural decisions.** If integrated in an early phase, it can be useful for creating design alternatives and raising confidence for decision making.

**4.** The **"ease of use"** is voted as the most prominent feature of a BPS tool to be used in early design, by the teams, which in line findings of the review. The following preferences of the teams on expected features for early design use were the "comparison of design alternatives", "integration with a design tool", "availability of intelligent design/simulation methods, i.e. parametrization, automation, optimization etc.", and "being suitable for both early and advanced design stages". These results also support the previous findings.

### 3.4.5. Conclusion

The results of the "BPS in SDE21/22" review and survey largely correspond to the findings of the "BPS in Teaching" survey conducted at the national level, which is remarkable showing that the pattern identified also exists at the international level.

From the results it is clear that for better realization of design integrated use of BPS , the deployment of teaching and learning methods, which are (1) adopting BPS in early design investigations, using adequately simplified BPS tools, if possible one integrated into a digital design environment, easy to use, enabling comparison of design alternatives and supported by intelligent methods of parametrization and optimization for early design (2) including multi-domain assessment of design and performance together, (3) using BPS as an element of the design process rather than using it as an evaluation tool, (4) providing continuous support by tracking learning experience of students; (5) enabling combined experience and acquisition of interdisciplinary knowledge and practical skills, is a must rather than an option.

The findings of the study are mainly based on the experience gained in SDE21/22. The results cannot be generalized to a larger scale. Yet, the findings are remarkable as they allow a glance at the current methods of teaching BPS at the international level, highlight potential solutions and offer future perspectives.

## 3.5. Design-Integrated BPS Teaching - Interviews to capture educators' views

### 3.5.1 Introduction

The paramount issue with the interviews was to reach professionals with a high level of experience in teaching building performance to architecture students using BPS tools. Five candidates were selected and invited via e-mails introducing the interviewer, informing about the PhD study and explaining the aim and content of the planned interviews. With the motivation of investigating both national and international applications, 3 candidates were selected from Germany, 1 from the United States and 1 from Switzerland, all of whom are internationally well known for their research and teaching activities in the field. All of the five invited candidates were interested in the study and accepted the invitation. The interviews were conducted via videoconferencing in 2023.

### 3.5.2 Methodology

Each interview took place one-to-one between the interviewee and the interviewer. Although the consent and capability for recordings in audio and/or video existed, a paper-and-pencil approach was preferred as the only recording method to provide a more comfortable interview environment. Answers were simultaneously filled in the questionnaire document, which had been prepared before the interview and was visible to the interviewee during the interview. The interview format was semi-structured. A set of questions was prepared to be answered during the interviews, and some questions were added during the interviews in order to clarify and/or expand on some issues. The total duration ranged from 45 to 60 minutes, depending on the length of the respondents' answers to the open-ended questions. The interview had 4 main parts. Figure 3. 31 illustrates the structure, content and timeline of the interview. The Interview questionnaire is provided in Appendix AIII.

The part 1 included 5 questions. The first 4 questions of this part were close-ended with single- and multiple-choice options, and the last question was open-ended. This part took between 5-10 minutes depending on how detailed the interviewee's answer on the fifth question was.

Another main objective of the interviews was to capture educators' feedback on the developed course prototypes of performance based early design in the scope of the thesis. In part 2, the prototypes were presented to the interviewees in a 20-minute-long PowerPoint presentation. This was followed in part 3, by a total of 2 open-ended questions, the first asking about the pros and cons of the studio prototypes, the second asking about general comments of the interviewees on how to upgrade them. This part took between 10-15 minutes. The interviewee's feedback is presented in the section 5.4 of chapter 5, where the prototypes are explained. Part 4 had two sets of questions aiming to learn about the interviewees' own experiences in teaching BPS to architecture students. This part took between 10-15 minutes. Due to privacy compliance, the names of the interviewees are not included in this thesis. Assuming the interviewees as variables, A, B, C, D and E alphabetic attributes are assigned.

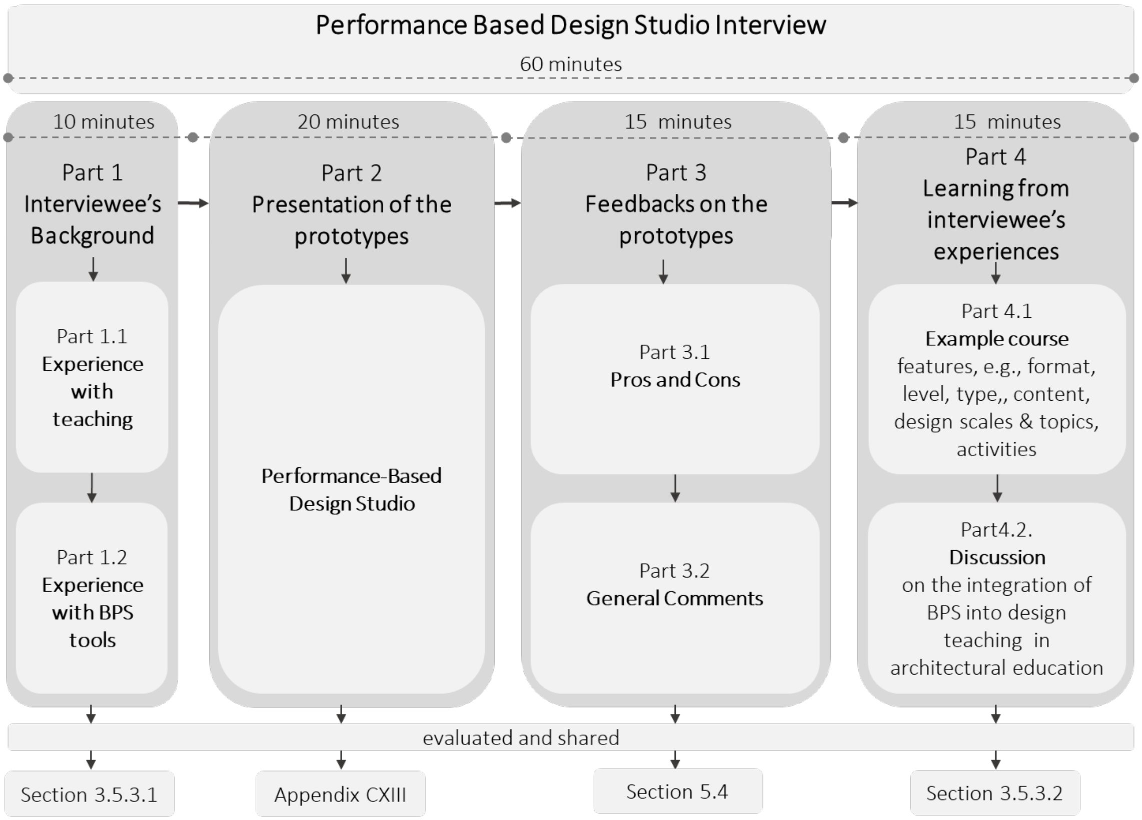


Figure 3. 31: Structure, content and timeline of the Interview.

## 3.5.3. Results

The interviewees' experiences on teaching BPS to architecture students, which are the results of Part 1, and the interviewees' backgrounds as a starting point are presented in this chapter.

### 3.5.3.1. Interviewees' background

All interviewees have the title of professor and are teaching building performance topics to architecture (and engineering) students in higher education institutions. Table 3. 7 shows the interviewees' title, major, location, years of experience in teaching to architecture students and teaching the topics of building performance.

All the participants stated that they teach the subjects of building performance to both architecture and engineering students at both undergraduate and graduate levels. All of them have a high level of experience in teaching:

Table 3. 7: Interviewees' title, major, universities and locations.

| | Title | Major | Years of experience in | | Location |
|---|---|---|---|---|---|
| | | | teaching to architecture students | teaching building performance | |
| A | Prof. | Physicist | 20 | 8 | Switzerland |
| B | Prof. | Environmental Engineer | 16 | 16 | Germany |
| C | Prof. | Physicist | 18 | 18 | United States |
| D | Prof. | Architect | 25 | 14 | Germany |
| E | Prof. | Mechanical Engineer | 27 | 25 | Germany |

The participants were requested to describe their experiences with BPS tools in general. All stated that they use BPS tools for both research and teaching. Three of them are also developers. Two of them indicated that although in the early years they had taught students how to use the BPS tools, now it was taken care of by their assistant lecturers, and today they only explain the principles and concepts of the BPS and the BPS tools.

#### 3.5.3.2. Learning from interviewees' experiences

Among the courses taught by the interviewees, the courses closest to the performance integrated design study were discussed. The performance content, level, type, format, ratio of design content, number of the students, design scales, activities, tools and the assessment methods of the course are presented in Table 3. 8.

Table 3. 8: Representative courses which are taught by the interviewees.

| | A | B | C | D | E |
|---|---|---|---|---|---|
| Content | Indoor comfort, passive and low energy strategies | Indoor thermal comfort and energy efficiency in buildings | Sustainable building design, building performance evaluations, occupant comfort and low carbon emission | Climate resilient design, passive design and indoor comfort | Energy balance and thermal comfort |
| Level | Master | Master | Master & Bachelor | Master | Master |
| Type | Elective (3credits) | Compulsory (6 credits) | Elective (NA**) | Elective (NA**) | Elective (NA**) |
| Format | In-person | In-person + online supervision | Online | In-person + online supervision | In-person + online supervision |
| Design content | 20% | 40% | 20% | 40% | 40% |
| Number of students* | 40 | 20 | more than 1000 | more than 20 | 10-16 |

| | | | | | |
|---|---|---|---|---|---|
| **Design scales** | • Building<br>• Elements<br>• Materials | • Settlement<br>• Site<br>• Building<br>• Element<br>• Material | • Site<br>• Building<br>• Element<br>• Material | • Building<br>• Element<br>• Material | • Site<br>• Building<br>• Element<br>• Material |
| **Activities** | • Theoretical lectures<br>• Case-studies<br>• Workshops<br>• Supervision | • Theoretical lectures<br>• Case-studies<br>• Workshops<br>• Supervision | • Literature research<br>• Case-studies<br>• Lectures<br>• Supervision | • Theoretical Lectures<br>• Laboratory<br>• Supervision | • Literature research<br>• Case-studies<br>• Lectures<br>• Workshops<br>• Supervision |
| **Tools** | • Rhinoceros 3D<br>• ClimateStudio | • IDA-ICE<br>• Polysun | • Rhinoceros 3D<br>• ClimateStudio | • CAD tools<br>• IDA-ICE | • BIM & CAD tools<br>• EnerCalC<br>• SimRoom<br>• DesignBuilder<br>• TRNSYS<br>• LadybugTools |
| **Assessment method** | • Oral exams<br>• Written report | • Assignments,<br>• Oral exams | • Comprehension questions<br>• Weekly assignments<br>• Presentation | • Oral exams | • Assignments<br>• Final oral exams and reports |

*Per semester **Not available

The interviewees were requested to give examples that demonstrate the relation between design and performance actions. The relations mentioned are demonstrated in Figure 3. 32.

They were also asked to identify main difficulties in integrating building performance, particularly BPS into design process in architectural education in general. Difficulties in achieving **interdisciplinary teaching and learning** were related to scarce of collaborations between teaching chairs/departments and the low competence of educators in building science. The unwillingness of both students and educators to include BPS in design workflows and/or to act on the results was thought to be due to lack of awareness of environmental issues and/or difficulties in understanding BPS results and/or high levels of uncertainty in early design and/or difficulties in interoperability between design and BPS tools, i.e. data exchange between them. Again, not having **a high consciousness of environmental issues** and/or **limited teaching time** for a course were mentioned as reasons for not achieving the desired level of collaborations between faculties of architecture and engineering schools. It is stated that the varying level of building physics knowledge of master's students due to varying backgrounds from bachelor's education is another difficulty that hinders to start directly with design integrated BPS work. Students with different backgrounds in a master's program do not have the same level of skills for setting up simulations and knowledge for interpreting simulation results. Hence, the course content is organized as BPS-centered, explaining the basics of BPS, and design cannot be the main part of the course. Overall, all these interactions limit the integrated discussion of design and performance, and therefore the realization of design-integrated building performance education. Figure 3. 33 illustrates the highlighted difficulties and the solution suggestions with the cause-and-effect relation as mentioned by the interviewees. The arrow direction shows the direction of influence between the components.

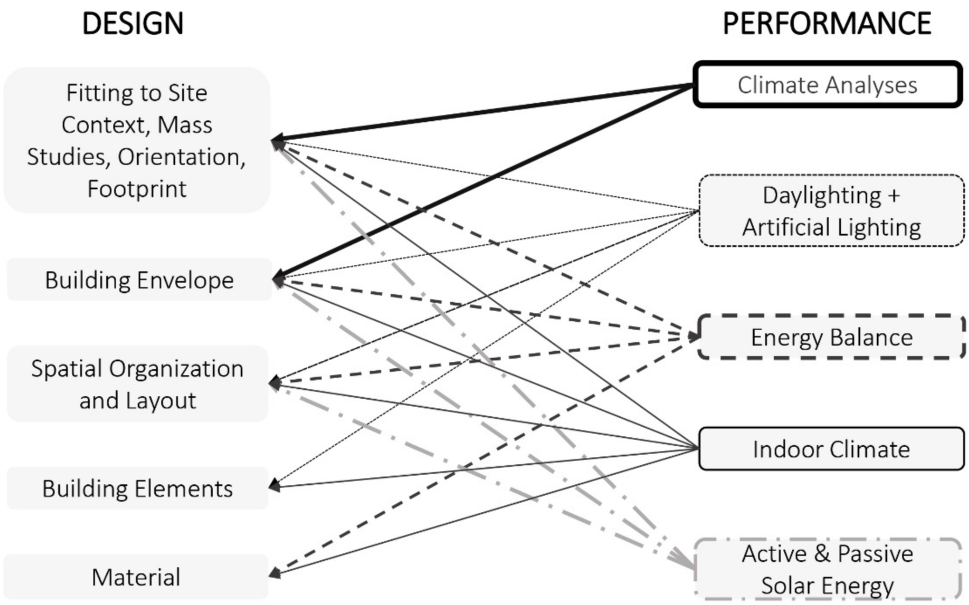



Figure 3. 32: Relations between design and performance in the courses taught by the interviewees.

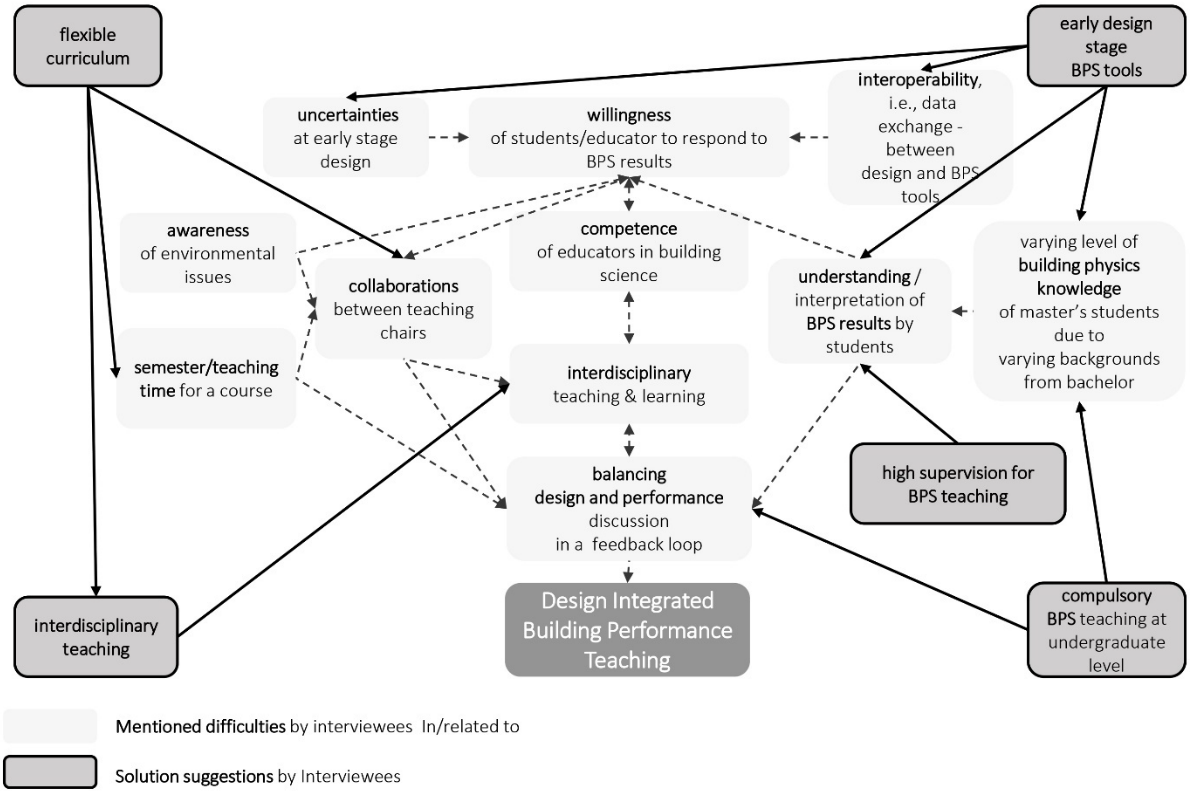



Figure 3. 33: Main difficulties in integrating building performance – in particular BPS into the design process in architectural education in general and possible solutions suggested by the interviewees.

It is stated that if the curriculum was flexible enough, it would allow the collaborations between teaching chairs. Additionally, it would be possible to break up the curriculum that allowing block-structures to achieve more interdisciplinary teaching and learning environment through collaborations, therefore design and performance would be taught in an integrated manner. It is mentioned that compulsory BPS education at bachelors' level would help to bring students to master's study with higher level of knowledge and skills for BPS, therefore it would be possible to start directly from the discussion for design integrated performance investigation. The need for BPS tools that can be adopted in early design was also another highlight. The features of (1) easy to get in and use, (2) providing easy simulation set-up, integrated or interoperable with a design tool, (3) automated graphics presenting simulation results with 3D representation, (4) enabling comparison of design alternatives were mentioned as the features of a BPS tool that is suitable for early design. And the final comment was about the necessity of high supervision for students.

### 3.5.4. Discussion

Through discussions over the example courses taught by the interviewees, it is aimed to take a closer look at their ways of teaching and integrating BPS into design process and the difficulties they experienced in this way, as well as to hear solution suggestions for improving this integration.

The main performance considerations of the example courses cumulate around the topics of indoor thermal comfort and energy balance with consideration of climate patterns. All of the courses were at master's level, which can be interpreted that a certain level of knowledge of building science and simulation is a prerequisite for students to be able to combine the performance topics in their design projects. Amongst, only one course was compulsory. The number of the credits of the courses varied between 3 and 6. The ratio of the qualitative design consideration in the scope of the courses (i.e., architectural design content) ranges from 20% to 40%, which shows that these courses are representative for performance-oriented courses, and rather than the design, the performance evaluation is the core. The discussions on the relationship between design and performance showed that almost all performance tasks of climate analysis, daylighting, energy balance, indoor climate, active and passive solar energy are related to almost all form and material related aspects of design. Nearly all the courses had theory lectures, case studies, workshops and supervision as main teaching activities. The weight of the CAD tool was higher than the BIM, but not with a big difference. While 3 of the courses use only CAD tools and 1 of them both CAD and BIM, one course did not include any 3D design tools. Two of the BPS tools used in the courses – ClimateStudio [115] and Ladybug Tools [146] are integrated to a 3D design tool – Rhinoceros [106]. In other words, they are plugins, which are software modules that extend the functionality of the main software by adding commands, features, or capabilities. The other three BPS tools – IDA-ICE [222], TRNSYS [190] and DesignBuilder [223] are standalone tools, that provide 3D modeling in the scope of the performance analyses provided as a simplified simulation model. And the remaining two tools – EnerCalC [224] and SimRoom [225] are Excel-based energy simulation tools without 3D modeling option. The design, documentation and simulation tools adopted in the courses were another indicator for understanding the design workflows of the courses and the level of integration. The discussion during the interviews highlighted that the availability of a BPS tool in a design tool is advantageous to maintain the feedback loop between design and performance analysis, considering the possible difficulties due to interoperability and file exchange between the standalone design and BPS tools. Regarding the types of learning assessment methods, oral exams combined with visual presentations were the most common, which is very much in line with the nature of architectural education.

The overview on the relation between design and performance actions was noticeable showing how form related decisions can be affected by the results of performance analyses. The performance tasks of climate analysis, daylighting, energy balance, indoor comfort, active and passive solar energy, in the scope of the discussed courses, demonstrated strong relation on design decisions of fitting to site context, volume massing, orientation, design of footprint, building envelope, spatial organization, layout, building elements and materials.

The interviewees strongly emphasized that, in a broader perspective, the level of awareness and sense of responsibility for climate action should be raised by increasing the visibility of possible risks, both in the scientific community and in the general public. They stated that this is essential not only for the targeted integration, but in a broader sense for the targeted sustainable future.

More collaboration among departments and chairs of schools of architecture and engineering is needed for multidisciplinary teaching and learning environment. As the main obstacles, the rigid curriculum can be improved to be more flexible, and the workload can be reduced by fair sharing of workload, such as involving graduate students as teaching assistants. Especially considering that learning a BPS tool requires intensive supervision and that graduate students are familiar with simulation tools, they are good candidates as student assistants because they can help novices. Another suggestion was to have compulsory building physics and BPS courses at the undergraduate level to better ground the basic knowledge, so that more advanced performance integrated design courses could be structured at the graduate level.

The final comments focused on tool-related technical aspects. Most of the respondents agreed on the need for early-stage BPS tools that are integrated into a digital design environment, are interoperable with other design and BPS tools, have an architect-friendly graphical user interface, and, if possible, allow design exploration and comparison with gradually increasing levels of detail for simulation inputs and outputs.

### 3.5.5. Conclusion

The interviews aimed to learn about the experiences of professionals on performance integrated design teaching, through the courses taught by the interviewees.

Flexible curricula, intra- and extra-university collaborations, use of BPS tools supporting early design, intensive and interdisciplinary supervision, and well-balanced course content in terms of design and performance were mentioned as key points for design integrated BPS teaching.

In the courses, design discussions are included as a part of performance discussions and the core tasks were primarily performance related. Although they are not particularly representative of performance-integrated design teaching, they were significant for establishing some of the key components of integrated design and performance teaching, such as knowledge of building science, continuous feedback loop, collaboration, and environmental awareness.

The courses demonstrated a significant relation between design and performance actions. The inference can be drawn that performance investigations have the potential to stimulate the design investigations if they are included in the design process at an early stage.

The results cannot be generalized to a larger scale as the interviewees were a small group and the number of courses was small. On the other hand, the experiences of the professionals were noteworthy for providing a closer look at the current and possible future models of BPS teaching by reconsidering the challenges and opportunities on the path to integration.

# Chapter 4

## EARLY DESIGN BPS PLATFORM FOR TEACHING

This chapter presents platforms prototyped in the thesis for performance-based early design to be used in teaching activities in architecture master's programs, and shares experiences of implementing and testing them in an architecture master's seminar.

### 4.1 Introduction

One of the most important common conclusions drawn from the literature review, surveys and interviews was that the availability of a BPS tool in a design tool has the potential for the aimed design and performance integration.

Rapid prototyping and testing prototypes in a seminar are used as methods to answer the research question "How beneficial is employing BPS in a design tool for the aimed integration?". The objective is to explore if the adoption of simplified BPS in a design tool supports the integration of BPS into early design process. The objective (**Obj2**), research question (**Q4**) and methods (**M4** and **M5**) of the thesis studied in this chapter are demonstrated in Figure 4. 1.

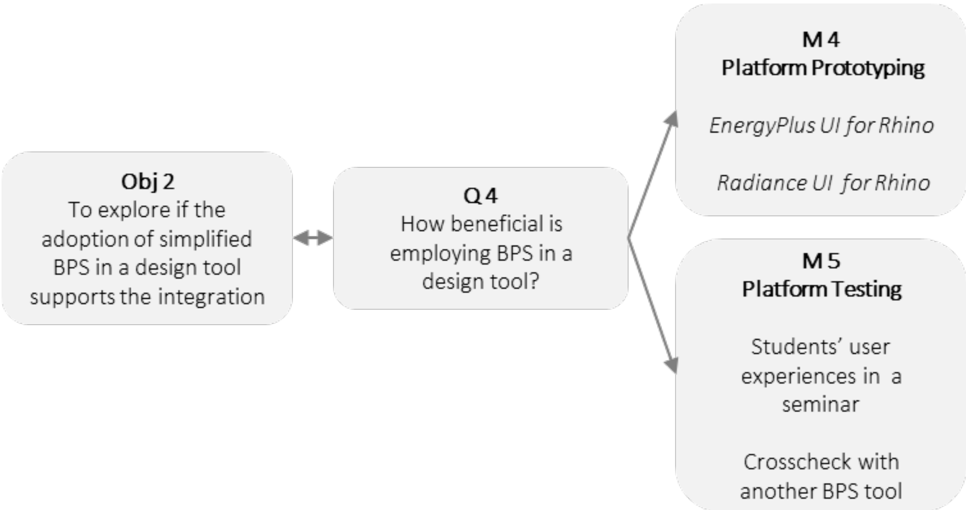



Figure 4. 1: Platform prototyping – the objective (Obj2), research question (Q4) and methods (M4 and M5) of the thesis studied in this chapter.

Providing design integrated performance simulation experience for educational purposes was the main motivation for the prototyping. The previous works have shown that BPS tools play a significant role in the learning experience of students. Unlike experienced architects, students do not have much knowledge or experience that might help them intuit and/or approximate the possible performance of a design. BPS tools can provide a learning playground for beginners by testing and experiencing different design alternatives and understanding key parameters for a design case. On the other hand, most of the BPS tools are too complex for quick testing and comparison of design alternatives, especially for beginner level users. In this case, for students, formulating the simulation problem, managing the simulation settings, deciding on the outputs, interpreting the results and managing the data flows between separate design and performance tools are not easy, time consuming, may be overwhelming and require expert support. However, it is also not reasonable to ignore these tools completely, as otherwise students would have to rely only on their teachers' comments, which can limit the learning experience to a 'master-apprentice' one, which in some cases can lead to incomplete learning.

Therefore, the platforms also aimed to provide a leaning ground for students at the intersection of design and performance.

The work in this chapter is based on the hypothesis that if the core tasks and workflows of performance simulations are simplified and made available in a design tool - a 3D CAD environment - with an architect-friendly user interface that provides real time interaction between design and BPS tools with simple input and output options, students can incorporate performance simulation into their design workflows easier.

## 4.2. Methodology

A method of prototyping is applied to provide a concrete representation of an integrated digital platform for design and performance. As described by [226], *"a prototype is a working model built to develop and test design ideas."* Types of prototypes can vary between a rough pencil sketch, a mock-up of a device made of foam core or cardboard that focuses on a final appearance, a video tape that shows the simulated behavior of a proposed product, a digital model/interface of a software and/or a partially implemented version of the product with most of the properties and behaviors of a real thing [227]. The method of prototyping is an iterative experimental process that involves gathering requirements, defining goals, rapidly structuring and testing solution models, and improving them. Simply, the aim is to introduce and evaluate an early concept of a solution (design/product) by presenting it to users. It is intended to increase the efficiency of the overall solution finding process, since it enables early detection of potentials and failures on the way to final design and fixing and/or refining the solution before investing a vast amount of resource. It can be applied during the design/product development phase, thus acting as an engine of a development process of a final product. The fidelity of prototyping describes how easily prototypes can be distinguished from the final product and can be manipulated to emphasize aspects of the design [226].

Based on this description, the two main types of prototypes are:

- **Low-fidelity prototypes** that do not allow user interaction, i.e. user experience (UX) ranging from a series of hand-drawn sketches to printouts.
- **High-fidelity prototypes**, which enable user experience by bringing the user as close as possible to a real interaction with a built mock-up.

This study adopts the high-fidelity approach in order to be more precise and descriptive during the platform prototyping and to be able to provide answers rather than general suggestions and questions.

The platform, in the context of the thesis, refers to a digital ground created by using present tools of 3D design, building performance simulation, and algorithmic modeling via visual scripting for performance-based early design investigations.

Rhinoceros [106], which is a 3D CAD software, is chosen as the base design environment, because, in the literature review, it is found out to be one of the most commonly used 3D design tools starting from conceptual design, and it is possible to use other tools within Rhinoceros as plug-ins. The scripting work is done in Grasshopper [97], which is a visual scripting plug-in (i.e., VLP) for Rhinoceros. Ladybug and Honeybee, which are open-source Grasshopper plug-ins that allow climate analysis, energy and daylight simulations to be performed using simulation engines such as Open Studio [228], EnergyPlus [111], Radiance [110], Daysim [229], are used to structure the prototypes' simulation templates, schedule libraries and workflows. Human UI [230], another open-source plug-in for Grasshopper, is used to create a Graphical User Interface (GUI) for the prototypes. The tools used to structure the platforms are demonstrated in Figure 4. 2.

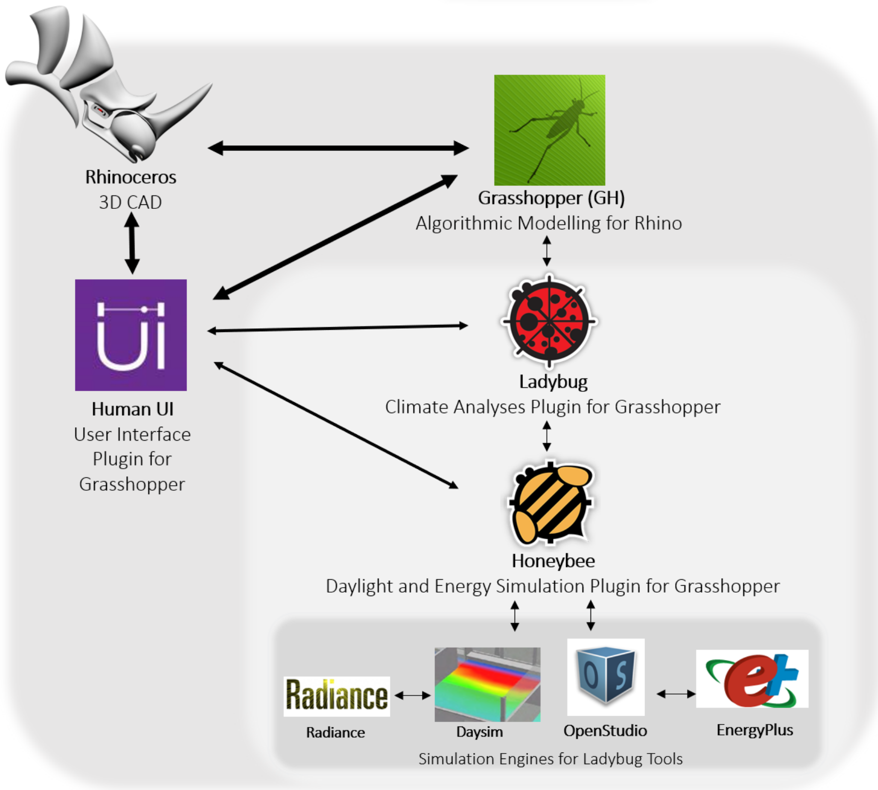



Figure 4. 2: Tools used to structure the platforms.

**The prototypes have 6 basic features:**

**(1) Integration into a 3D CAD design tool**, which eliminates the error-prone and time-consuming process of exchanging data between design and BPS tools, allowing BPS to be used directly in a design tool

**(2) Graphical User Interface (GUI)**, which is a separate window that opens on the Rhino screen and provides a smooth and fluid UX with simplified input and output options compared to direct interactions between the user and BPS tools without the without interference with Grasshopper.

**(3) Inclusion of basic building performance domains,** which is via validated simulation engines, especially important for early design:

- Prototype I - namely ***"EnergyPlus UI for Rhino"*** *enables* climate analyses, energy balance, indoor comfort simulations.
- Prototype II – namely ***"Radiance UI for Rhino"*** enables radiation, shadow analyses, daylight simulations.

**(4) Multi-scale analysis from zone to site,** which allow users to keep the whole picture of design environment, while being able to focus on a specific scale when a particular analysis requires it; for example, within the same 3D model, radiation analyses can be performed at the site scale and thermal comfort at the zone scale, so that simulations take place in their context within the environment.

**(5) Geometry related simulation inputs,** which are specifically tailored to investigate the performance of an architectural element in relation to its form as a pure design object, via a GUI, allow users to conduct conceptual investigations to explore design options in early design phase performance investigations, without getting too involved in the details of technical and mechanical elements, at least in the early stages of design process.

(6) **Visual post-processing,** automatically executed by the platform to visualize BPS results through graphs, charts and false-color images integrated into a 3D model, assists users in understanding and interpreting an assessed performance.

## 4.3. Prototype 1: "EnergyPlus UI for Rhino "

"EnergyPlus UI for Rhino" is a single-zone energy simulation platform, which is developed by using Rhinoceros version 5 (2013) and its Grasshopper version, Ladybug Tools version 0.0.63 (2018), and Human UI version 0.8.1.2 (2019). Users only interact with Rhino and can manage all simulation inputs through the prototype GUI. No user interaction with Grasshopper is required. Figure 4. 3 shows how the prototype provides the data flow between Grasshopper and Rhino, and the interfaces with which users interact and do not interact within this flow.

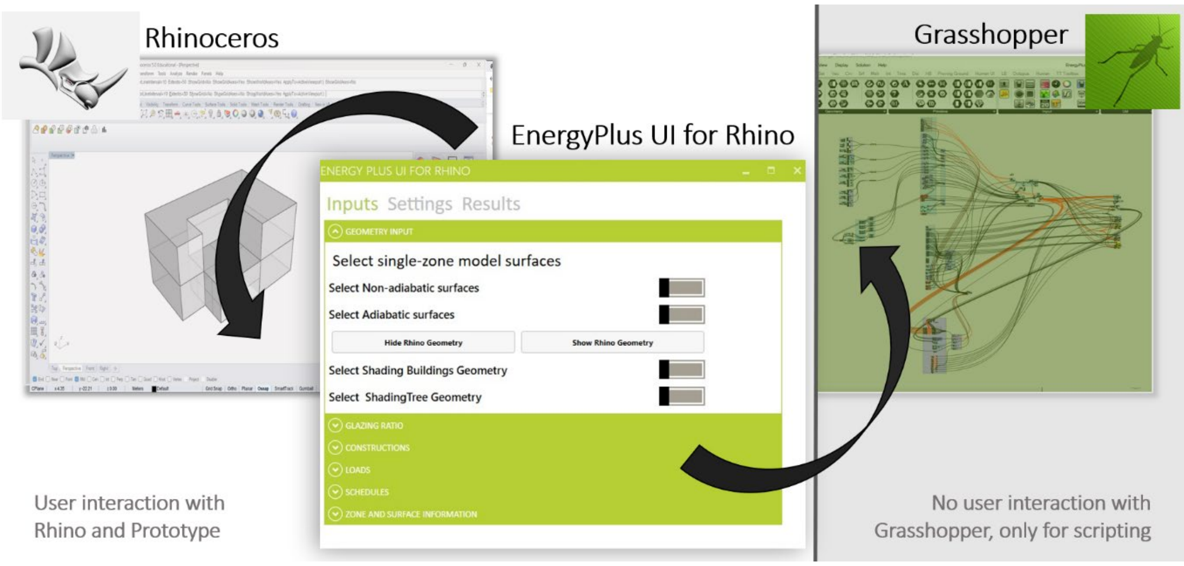



Figure 4. 3: Data flow via the "*EnergyPlus UI for Rhino*" prototype and user interactions.

Configuring the prototype as "single-zone" energy modeling was a deliberate approach, given that multi-zone modeling might be too complex to be integrated into early design performance considerations due to the large and detailed simulation inputs and the computing power required. For a fast and iterative workflow to explore alternatives in early design stage, the single-zone approach has a potential to respond relatively quicker to the process as it is less demanding in this respect.

The single-zone experience is provided as a part of the 3D architectural model to maintain the links to the overall picture of design and performance. The platform's flexibility across scales and its unified context distinguishes it from tools that do not allow for a 3D representation of the performance model or that represent it in isolation without visualizing its relationships as part of a whole. This is an important didactic step in teaching BPS to architecture students, as it differs from EnerCalc [224], which does not provide a visual representation (i.e., 3D Model). Analyses within a site context are valuable not only for new designs, but also for the performance evaluation of existing buildings and to find solutions within the existing built environment to achieve sustainable future goals by making cities more compact rather than expanding them.

The interface of the prototype had three main sections: (1) **Inputs**, (2) **Settings**, and (3) **Results**. The Inputs section enables defining geometric and non-geometric features, including geometry input of zone, surrounding buildings and vegetation; glazing ratio; building elements by construction types; loads of equipment, lighting, occupant infiltration, and ventilation, schedules of occupancy, lighting, equipment and ventilation; and attribute selection for zone and surfaces. A special attention was given to the design of "Input" interface to allow users to quickly define and change the form of a design. For example, enclosing surfaces can be assigned directly by selecting them in Rhino screen using adiabatic and non-adiabatic options, and then easily adding transparent surfaces by entering glazing ratios for facades via the interface.

The Settings section enables selecting simulation time step, the analysis periods for a design week and day, the comfort class, the conditioning option, as well as naming simulation and running it. The Results section demonstrates the annual values per square meter, enables capturing Rhino views and saving them, and creating layers in Rhino from simulation results. Main sections and sub-section can be seen in Figure 4. 4.

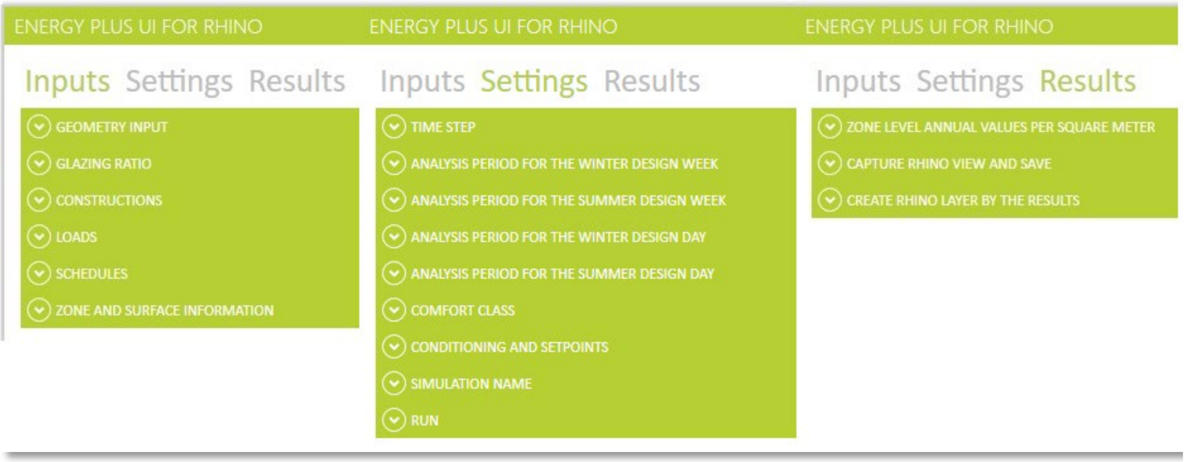



Figure 4. 4: Interface sections and sub-section of the "EnergyPlus UI for Rhino" prototype.

The scripting work for the "EnergyPlus UI for Rhino" includes four parts: (1) creation of templates for materials, elements and schedules, (2) creation of GUI (3) creation of simulation workflows, (4) representation of results. Figure 4. 5 shows the "EnergyPlus UI for Rhino" scripting conducted in Grasshopper.

One of the simplifications provided is that the prototype distinguishes and labels building elements, such as a wall or a roof, by their angles according to the horizontal plane. Each building element has an associated color, so that after assigning an element, user can check if they are assigned correctly. Another simplification is the easy definition of windows as the glazing ratio of a façade. Via construction sub-section, opaque closures, i.e. building elements as vertical, upper and lower, can be assigned. Example scripting for a building element with materials is included in Appendix BI. The opaque elements - walls, floors and roofs - are adjusted with the same thermal transmittance (U-value), but with varying thermal mass capacities, namely as "light, medium and heavy". It is intended to enable students to understand the effect of thermal mass on indoor thermal comfort. Example scripting for a building element with different thermal mass properties is included in Appendix BII.

Transparent elements - windows - are scripted as triple glazing in two types, i.e. "Triple Glazing Window" and "Triple Glazing Window with Solar Control Glass". The main idea was to enable students to understand the impact of solar gains on energy balance and thermal comfort. The Loads sub-section allows entering the internal loads of equipment, lighting, occupants, infiltration, and also define the rates of infiltration and ventilation (natural ventilation for fresh air with fans with options of occupied and non-occupied times). In the Schedules section, pre-defined schedules of occupancy, lighting and equipment and ventilation are provided with residential and non-residential use options.

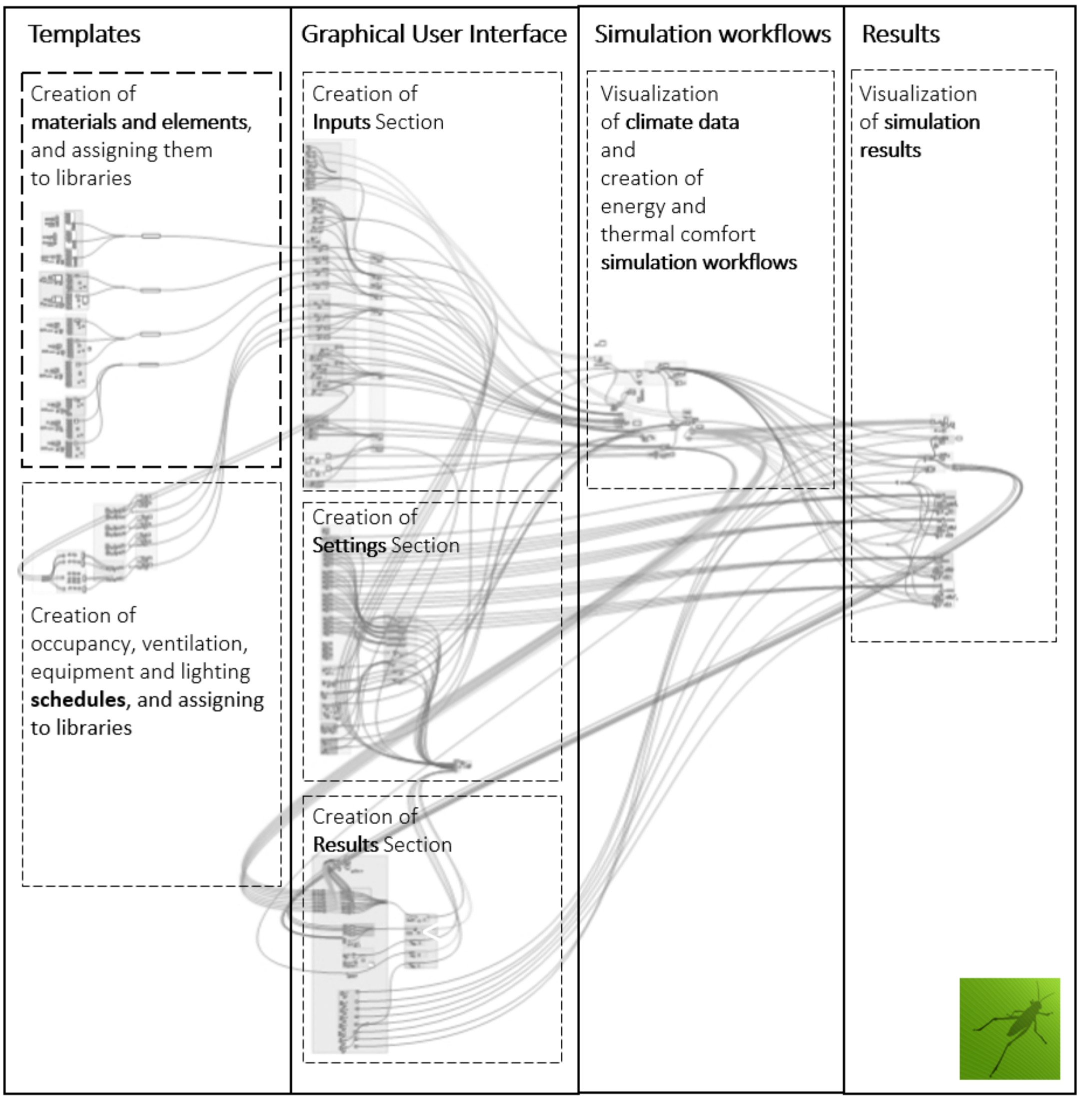



Figure 4. 5: "EnergyPlus UI for Rhino" scripting in Grasshopper.

And the final sub-section allows users to see the attributes of a zone and building elements by simply selecting them via the interface; for example, the attributes of a zone, such as name, floor area, volume, conditioning state, equipment load, infiltration rate, lighting density and number of people per square meter; and the attributes of building elements, such as type, boundary condition, if it is exposed to sun or wind or if it is planner can be seen on 3D model. The Input section and sub-sections are shown in Figure 4. 6 with its connection to Rhinoceros with arrows highlighting the settings for geometry related inputs.

In the Settings section, time-step of the analysis can be defined as hourly or monthly values. Typical weeks and days for winter and summer are provided directly from a selected weather data and projected to the interface, which allows user to easily focus on a certain time of a design season. An option to select the comfort class – according to DIN EN 16798 (new version of DIN EN 15251) [231] – makes the evaluation of simulation results easier, as it is represented as hours of cold, hot and neutral in an automated result graph of the protype. The user can select whether a zone is conditioned or not. There is no input option for Heating, Ventilation, Air Conditioning (HVAC) systems. The *Ideal Loads Air System* [232] is set as the default for conditioning. And the final subsections are provided for naming the simulation work and running the simulation. The GUI of the prototype for "Settings" is presented in Appendix BIII.

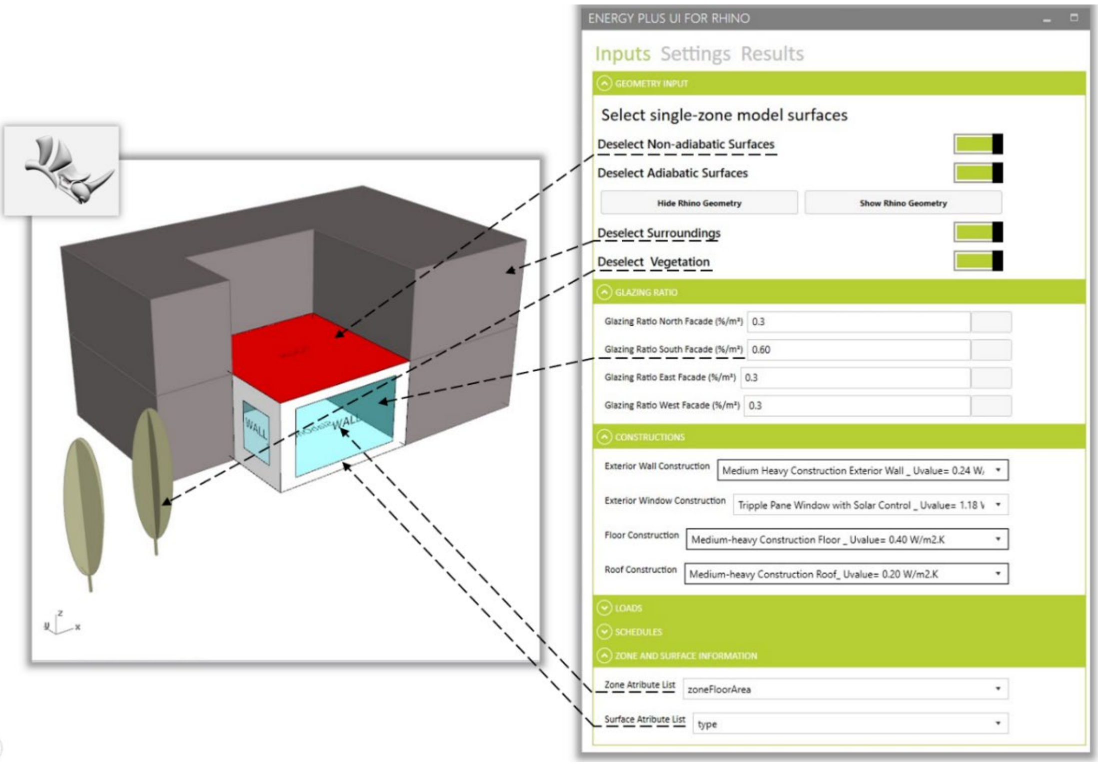



Figure 4. 6: Input section and subsections with connection to Rhino.

After simulation is run, results are available both in the Rhino window and in the results section of the interface. Annual values of energy losses and gains of heating, cooling, lighting, equipment, solar, occupants, infiltration, ventilation and surface conduction per square meter, as well as pie chart graph representing percentage of hours of cold, hot and comfortable hours according to the selected comfort class are simultaneously shown on the results section of the interface, and graphs of energy balance and thermal comfort on the Rhino screen. The Results section and sub-sections are shown in Figure 4. 7 with its connection to Rhino.


Figure 4. 7: Results section and subsections of the prototype with connection to Rhino screen, on which rest of the results are displayed.

## 4.4. Prototype 2: "Radiance UI for Rhino"

"*Radiance UI for Rhino*" is developed by using Rhinoceros version 5 & Grasshopper (Rhinoceros, 2013), Ladybug Tools version 0.0.63 (2018), and Human UI version 0.8.1.2 (2019). The prototype provides simulations for daylight factor, point-in-time illuminance, shadow range and radiation analyses. The GUI of the prototype can be seen between the windows of Rhinoceros and Grasshopper in Figure 4. 8.

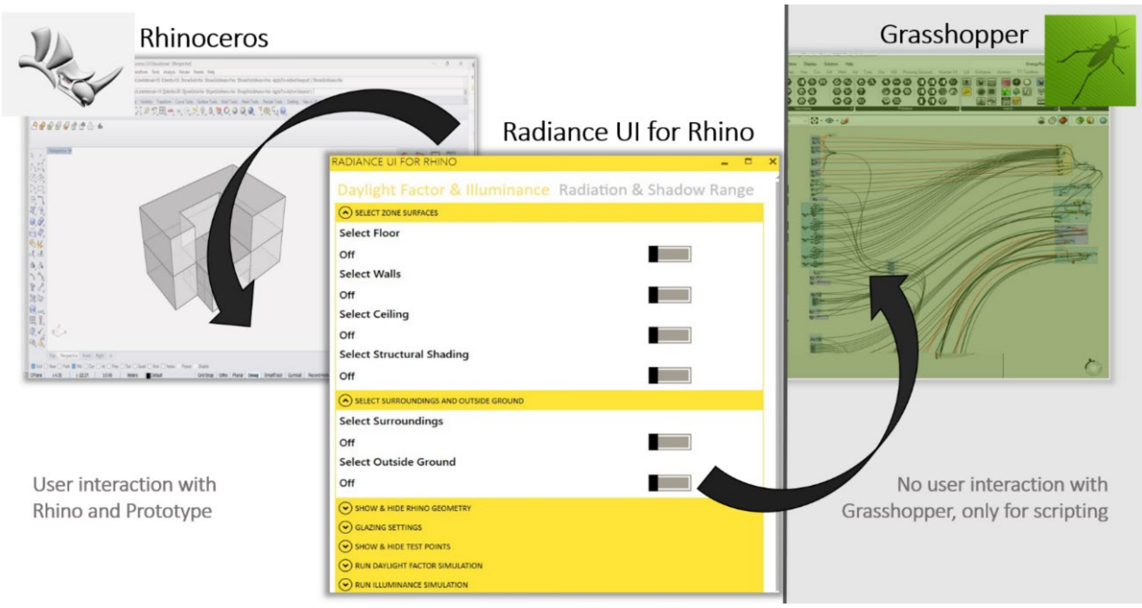



Figure 4. 8: Data flow via the "*Radiance UI for Rhino*" prototype and user interactions.

Unlike Prototype 1 – "EnergyPlus UI for Rhino", "Radiance UI for Rhino" has a larger scale ranging from zone to site due to the application space of analyses as internal and external. While radiation and shadow range analyses are mainly conducted in site and building scales, the daylight simulation can be run in building and zone scales.

The interface of the prototype has two main sections: (1) **Daylight Factor & Illuminance** and (2) **Radiation & Shadow Range.** In the first main section, daylight factor analysis can be run by defining geometric and non-geometric features, including zone surfaces, structural shading, surroundings and outside ground. In the same section, by assigning a weather data and a point in a year, also illuminance analyses can be run. The second main section enables radiation and shadow range analyses. It is possible to visualize a climate-based cumulative sky dome and rose chart for radiation analysis. The interface also enables users to create Rhino layers via the results of analyses. Main sections and sub-section can be seen in Figure 4. 9.

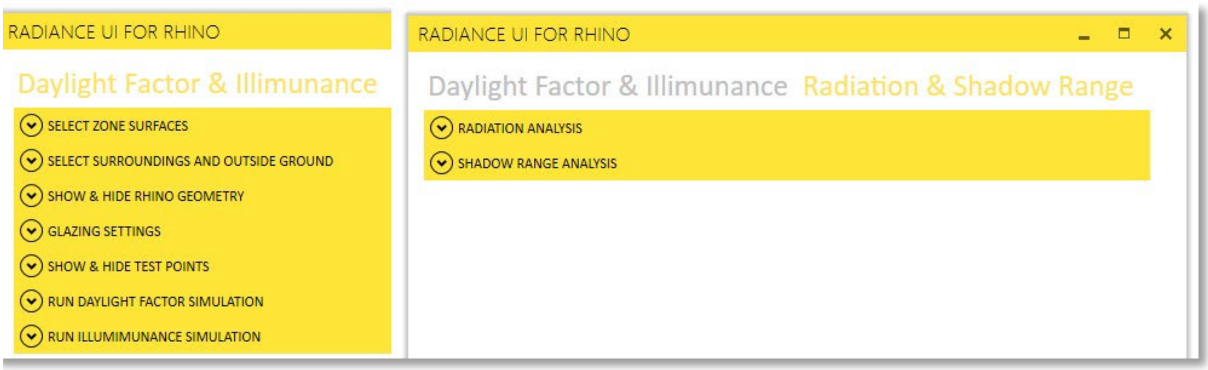



Figure 4. 9: Interface sections and sub-section of "Radiance UI for Rhino" prototype.

The interface allows users to assign analysis surfaces, i.e. walls, ceiling, floor and glazing, as well as structural shading and surroundings, by directly selecting model elements from Rhino. Different than Prototype 1 - "EnergyPlus UI for Rhino", "Radiance UI for Rhino" has more input options for glazing. Daylight design requires more detail than just the dimensions of windows and other transparent surfaces. In addition to the glazing ratio, the distance between transparent openings in a façade, their proportions, height and sill height are important for analyzing the presence of daylight in a space, not only in terms of light availability, but also to visualize its distribution as an aspect of the architectural ambiance. Therefore, in order to allow easy input for these aspects and their easy modification, the interface of the "Input" section for the glazing settings was designed with special attention, i.e. easy modification of the glazing through the GUI using sliders and text box that instantly change on the Rhino geometry as inputs are provided. Part of the interface for glazing settings is shown in Figure 4. 10.

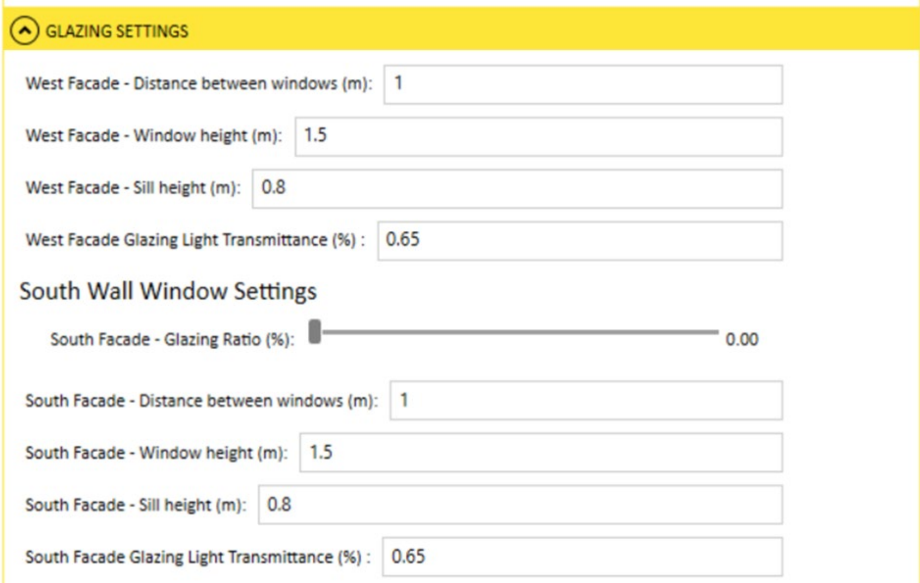



Figure 4. 10: Interface of inputs for glazing settings of “Radiance UI for Rhino” prototype.

The scripting work for the “Radiance UI for Rhino” includes two parts: (1) creation of the GUI, (2) creation of simulation workflows and visualization of the results. Figure 4. 11 shows the “Radiance UI for Rhino” scripting conducted in Grasshopper.

The light reflectance of opaque surfaces and the light transmittance of transparent surfaces can be defined via the interface. For didactic reasons, only the key optic parameters, i.e. light reflectance and transmittance, are allowed, and the rest is assigned as default values in scripting. Each selected element is framed by red lines, so that the users can understand that they correctly assigned all surfaces.

Illuminance simulation can be run by selecting a location (via weather file) and an hour of a day of a month in a year. All simulation results are directly presented via false-color images on the analyzed model, and they can be saved as Rhino layers, which enables comparison of the design alternatives. Example illuminance analysis on Rhino via “Radiance UI for Rhino” is shown in Figure 4. 12. Example daylight factor analysis can be seen in Appendix BIV. The second main section allows the selection of analysis period, analysis surfaces and weather data for radiation (Appendix BV) and shadow range analyses (Appendix BVI). As with daylight analyses, users can record results as Rhinoceros layers.

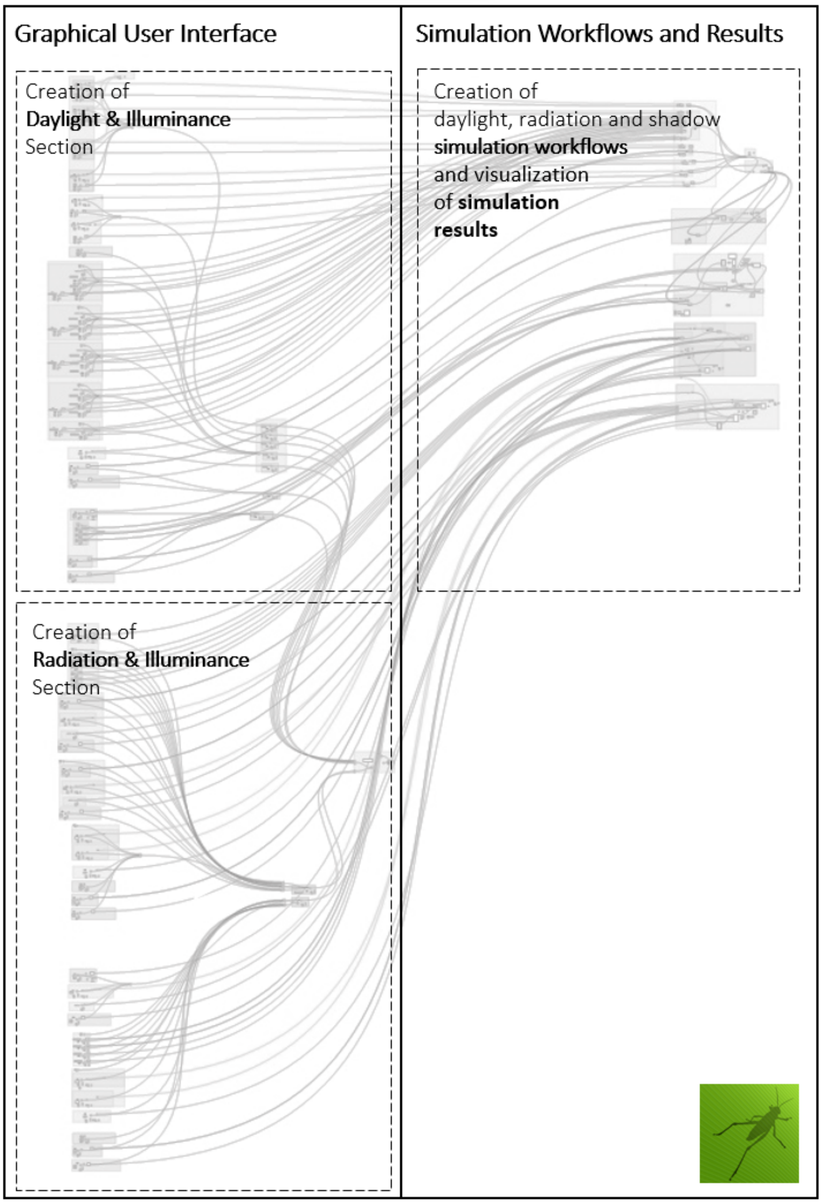



Figure 4. 11: “Radiance UI for Rhino” scripting work in Grasshopper.

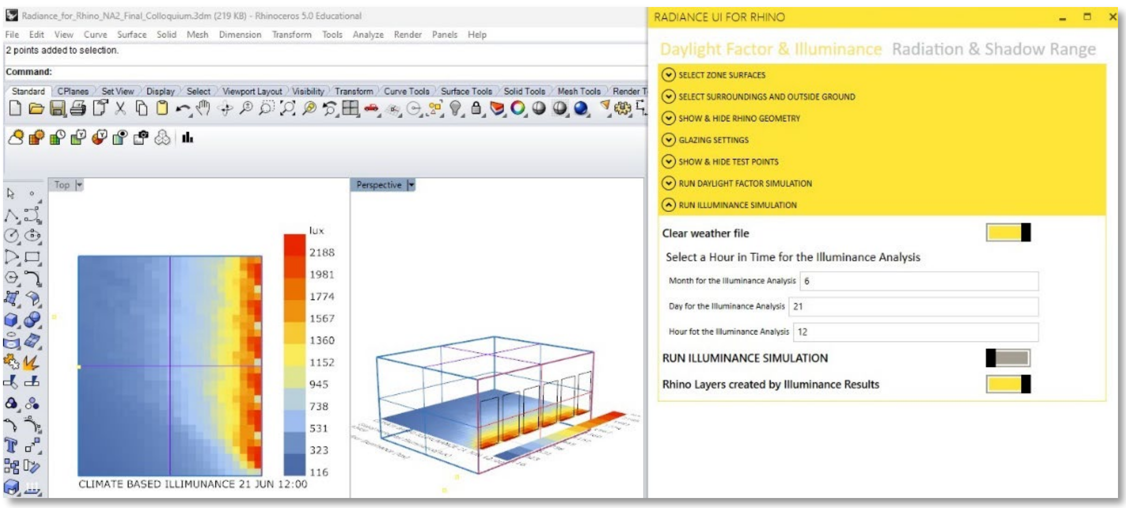



Figure 4. 12: Point-in-time illuminance analysis on Rhino via “Radiance UI for Rhino”.

## 4.5. Testing Prototypes

The prototypes were applied in an architecture master's level elective course (NB.2) in Summer Semester 2019. Although not compulsory, it is recommended that students take another course (NB.1), where they learn how to improve/upgrade the energy performance of a building to a net energy positive building, before taking this course.  The course (NB.2), where the prototypes are tested, is about simplified indoor climate simulations and real site measurements by comparison of confidence intervals. Therefore, students taking the preliminary course have a chance to refresh their building physics and BPS knowledge before being exposed to real/measured data and comparison of it with simulation data.  In both courses, students usually use the Excel-based BPS tools "SimRoom" [225] and "EnerCalc" [224], which are not integrated to a digital design tool, no file exchange is possible, and all geometric inputs should be entered manually via numeric values of a model geometry.

To answer the research question (Q4) "How beneficial is employing BPS in a design tool for the aimed integration?", the developed prototypes were tested in the second course by observing the students' experiences in comparison to the Excel-based tools mentioned above. The course had 4 students. The main performance tasks of the course were energy balance, thermal comfort and daylighting. The students brought their designs, which were developed or being developed in a design course. Energy and thermal comfort simulations were first conducted in SimRoom, which is a single-zone energy modeling tool. Afterwards students conducted same simulations plus daylight simulations using the prototypes.

The simulation model and inputs of Prototype 1 (EnergyPlus UI for Rhino) was specifically tailored to comply with SimRoom to allow achieving similar results. The aim was to eliminate the confusion that might be caused by different calculation methods and/or different inputs as much as possible. In order to teach how to use the prototypes, students were intensively assisted from the installation to running simulations via workshops and individual consultation hours.For the mid-term exam, a comparison of the results from SimRoom and from Prototype 1 (EnergyPlus UI for Rhino) were requested from the students. Figure 4. 13 shows the comparison studies of students for the operative temperature of their investigated designs over the course of a year.

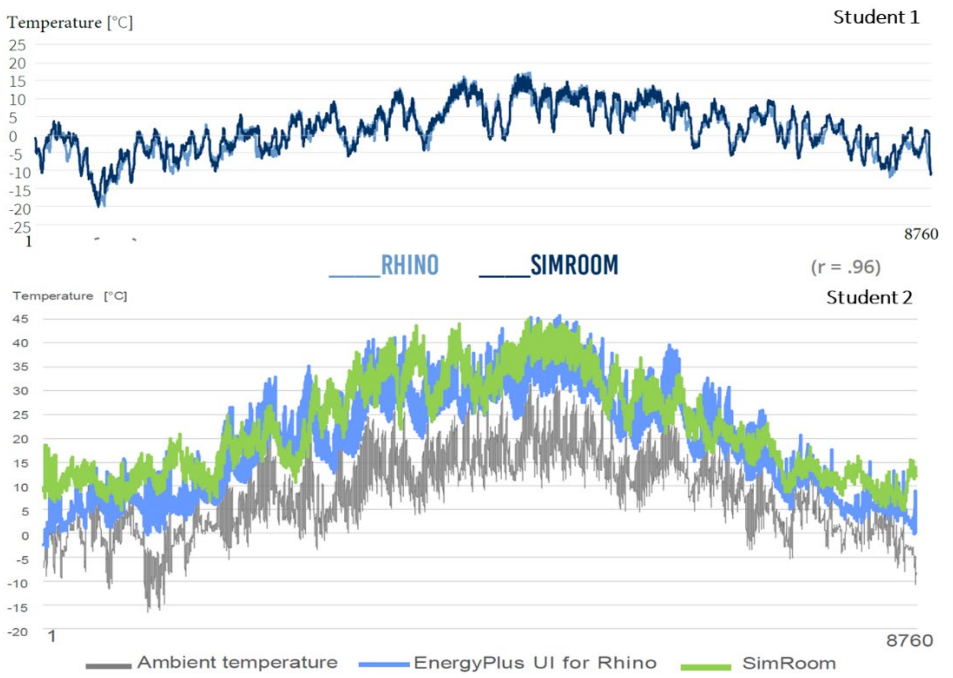



Figure 4. 13: Comparison studies of the students for the operative temperature over the course of a year.

Daylight simulations, which were not provided by SimRoom, were run using the Prototype 2 (Radiance UI for Rhino). Example studies of the students can be seen in Figure 4. 14.

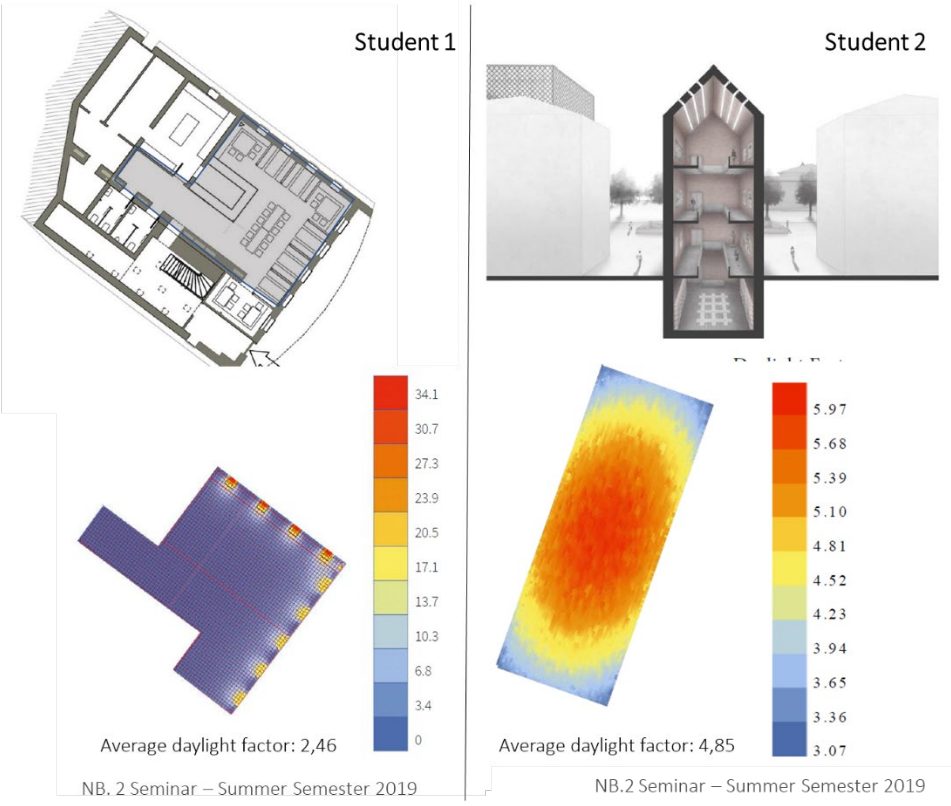



Figure 4. 14: Daylight simulations – Students' work.

In the final submission, students shared their experiences with the prototypes. Quotes from the students are presented in Table 4. 1.

Table 4. 1: Some final comments quoted from the students of the course regarding the challenges and opportunities of the prototypes.

| | |
|---|---|
| Challenges | (-) *"In any case, modeling with "EnergyPlus UI for Rhino", it takes longer than generating several variants by typing in different values* (in the to Excel-based tool). *By the prototype; the geometries must always be drawn in a certain way; i.e. the restrictions to convex geometries. A good program should not restrict the designer and should therefore offer many design options."*<br>(-) *"Due to the complexity of the façade design, an abstraction is needed for thermal comfort simulations. Due to an unknown reason precise evaluation was not possible; the reason might be an unsuccessful abstraction or low resolution of the prototype calculation."* |
| Opportunities | (+) *"Anyway, the future workflows of design and performance is likely to be brought together in a CAD environment, so that the direct verification of building performance can be assessed through the 3D models during the design. Personally, I see CAD integrated BPS as a great opportunity to make important ecological and economic decisions in the basic phase of a design. I would like to use the prototypes in my future works."*<br>(+) *"Radiation and shadow range analysis with Radiance UI for Rhino perfectly showed how important the deviation from the perfect southern orientation is. The presentation of the analysis in false colors confirms the expectation that the area intended for the PV system is irradiated the most, which was helpful to validate my design decision."*<br>(+) *"Working with dynamic simulation tools in a 3D design environment is undoubtedly useful in order to be able to better assess the real complexity. However, the results should be viewed critically."*<br>(+) *"High knowledge is required for the use of BPS programs, so "example workflows" and "templates" should be available, which was favorable with prototypes, but needs to be developed more."* |

It is referred as a challenge that EnergyPlus do not recognize non-convex surfaces. They should be split into convex surfaces for a valid energy modeling. An example problem from a student work is shown in Figure 4. 15.

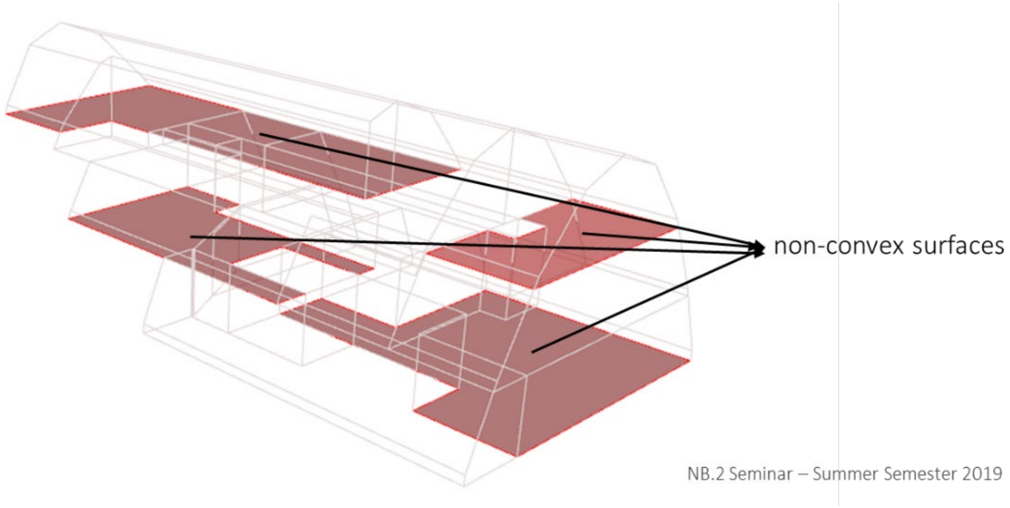



Figure 4. 15: Perspective view from a student's energy model and non-convex surfaces in color that caused problem for energy simulation.

The level of abstraction was another challenge for the energy models. One design had a very detailed perforated façade, which also needed to be simplified for it to be converted in an energy model. Figure 4. 16 shows the facade abstraction of a student work.

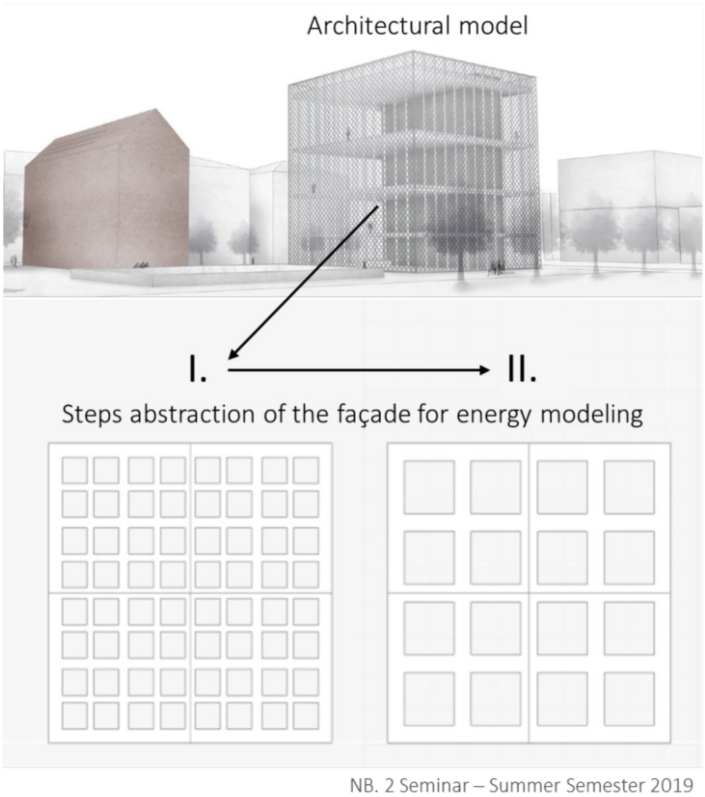



Figure 4. 16: Students' abstraction for the energy modeling.

## 4.6. Discussion

In general, the students' interaction with the prototypes was positive regarding pre-defined workflows guidance of user interface and being integrated to a design tool that they were already using. On the other hand, simulation run time (3 to 8 mins) was unfavorable due to the use of a high number of tools in tandem.

Students found Prototype 2- Radiance UI for Rhino easier to use compared to Prototype 1 - EnergyPlus UI for Rhino. This was mainly due to the abstractions required to transform the architectural design models into an energy model. More easily, they were able to use their architectural models directly for daylight, radiation and shadow range analyses without the need for any abstraction. Students were assisted in solving these geometry related problems faced during the abstraction. However, for the future development of the prototype, it is possible to script a solution in Grasshopper to automatically detect non-convex surfaces and split them into convex sub-surfaces. It is also possible to provide notification for possible modeling errors, e.g. marking unclosed surfaces on their geometry with false-color images. The ease of use of the "Radiance UI for Rhino" can be attributed to the fact that students can more easily interpret the results of radiation and daylighting analyses because the results are presented on architectural digital models as false color images rather than graphs of data curves as in energy and thermal comfort analyses.

The test of the prototype in comparison to the SimRoom tool was moderately successful. Besides the differences stemming from the ventilation and load calculation models, the results were almost in line.

## 4.7. Conclusion

The tool prototyping and testing aimed to explore how performance analysis integrated into the design affects students' learning experience and design process. The results cannot be generalized due to the small group of students, but they are remarkable for showing the exponential improvement in the learning curve. In addition, the limitations that students may have experienced due to the online nature of the teaching caused by the COVID-19 pandemic and native German speaking students taking the course in English were not investigated in detail in this study, but their possible impact on the overall results should be considered.

To overcome the unfavorable runtime, the prototypes can be programmed as original Rhino plug-ins instead of using a group of plug-ins via visual scripting in Grasshopper. The course experiences supported the argument that the simplified performance simulations, which are integrated into a design tool with an architect-friendly UI that provides real-time interaction between design and BPS tools, make it easier and more attractive for architecture students to involve performance simulation in their design workflows.

# Chapter 5

## PERFORMANCE BASED EARLY DESIGN TEACHING

This chapter presents the studio prototypes structured and tested in the scope of the thesis for performance based early design teaching in architecture master's program. Not only the course observations, but also the surveys with the studio students and interviews with professional educators are conducted and shared as an evaluation of the work.

### 5.1. Introduction

The platform prototyping and testing in a course showed that the integration of BPS tools into a digital 3D design environment is a promising way to bring performance assessments into design process, but also that the integration should be supported by pedagogical methods.

Studio - Sustainable Building and Building Performance, which is the subject of the prototyping, is a 2-semester design course in the master's program in architecture as module 1 and module 2 with a total of 12 credits.  Modules refers to courses that are developed and designed through the collaborations of teaching chairs of the master's program. The content of the studio modules is linked to the relevant research work of the participating chairs and is specially developed each year according to the common interests of research and teaching, and in this regard the module types vary as seminar or studio. Similar to the architectural project design studios in the bachelor's program, the design-focused courses in the master's program are called studios. Each student in the master's program is required to attend at least one of these studio courses, consisting of at least two modules, in order to complete the program, but they may choose which studio to attend.

The structure of the master's program supports students with two preliminary courses as a base for the studio. Although these are not prerequisites for the studio, students are advised and guided in this order. One of them (NB.1) is about improving the energy performance to an annually net energy positive building, while maintaining architectural quality, through well-known residential case studies from the classical modern style. The other one (NB.2) is about simplified indoor climate simulations and real site measurements by comparison of confidence intervals. Therefore, it can be said that students come to the studio with a certain level of BPS knowledge. Further, BPS can accompany the integrated design course (E5) and the master thesis, depending on the content and the students' preference.

In the scope of this work, the experiences gained at Studio Module 2 through two separate winter semesters are shared. In winter semester 2020/2021 (WS20/21) the first studio prototype, namely "Semi-integrated Studio" and in winter semester 2022/2022 (WS21/22) the second studio prototype, namely "Integrated Studio" is structured and tested. The courses in the master's program that BPS is addressed and Studio Module 2, where the protypes are tested in different semesters, is illustrated in Figure 5. 1.

To clarify the weight of the "Studio Module 2" course, when converting credits to hours, 1 credit equals 30 hours of student work including class participation. A semester is 14 weeks and 6 credits equal 180 hours. Considering 180 hours for 12 weeks, excluding the 2 weeks for exams, this means 15 hours of study per week for a 6-credit course.

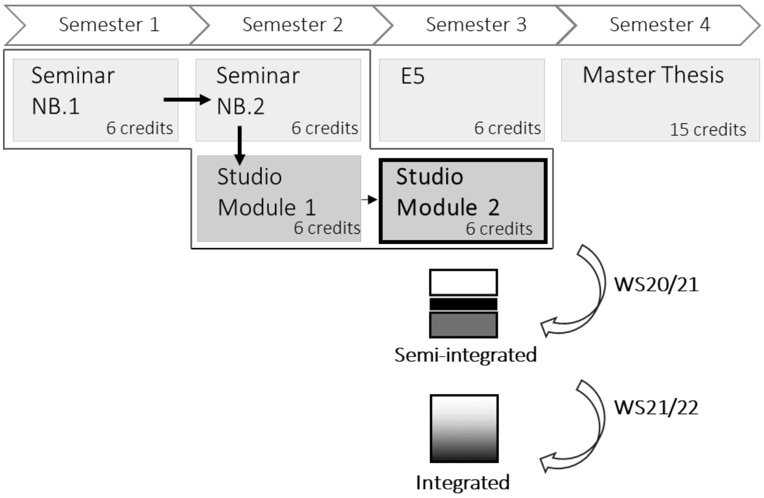



Figure 5. 1: Courses in the master's program that address BPS, and Studio Module 2, where prototypes are tested.

In the context of this study, "**integrated**" refers to a "studio" that adopts BPS in the design process as early as possible and utilizes BPS tools integrated into a design tool. Performance investigations are coupled at the very beginning, aiming at an uninterrupted and fluent design workflow, using BPS not as a performance evaluation tool, but as an informer and a stimulator. "**Semi-integrated**" refers to a "studio" that uses BPS tools that are integrated into a design tool, but only for the evaluation of existing designs, so that an interruption between the early and advanced phases of a design is to be expected. If BPS is integrated in the middle of the design process and the design is revised according to the BPS results, a dual structure such as before and after BPS is likely to emerge. The icons of the studios designed based on the above definitions are presented in Figure 5. 2.


Figure 5. 2: Icons of the Semi-integrated and Integrated studios.

The objective of this work is to find out how to improve the integration of BPS in the early design phase by means of a design studio. The questions “What should be the main components of an integrated design studio?” and “Is the design studio a useful method to integrate BPS into the design process in architectural education?” are answered through the methods of course prototyping, evaluation surveys and interviews. The objective (**Q3**), research questions (**Q5** and **Q6**) and methods (M6, M7 and M3) of this section are presented in Figure 5. 3.

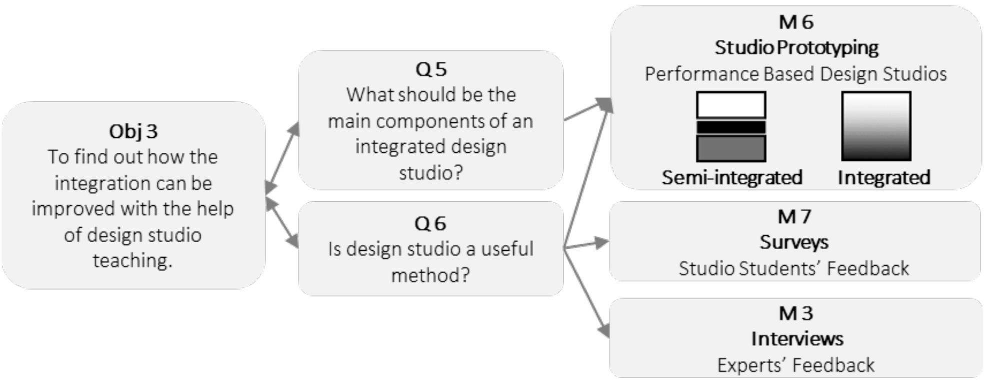



Figure 5. 3: Studio Prototyping – The objective (O3), research questions (Q5 and Q6) and the methods (M6, M7 and M3) of the thesis studied in this chapter.

## 5.2. Studio Prototype 1: “Semi-Integrated Studio”

In the summer semester 2020, the module 1 was carried out by the Chair of Building Construction, Design and Materials Science with a focus on renewable raw materials. Following, in winter semester 2020-2021, the module 2 was held by the Chair of Building Physics and Technical Building Services with a focus on "Performance Based Design". Although each semester one chair has the main responsibility for moderating the studio, these two semesters are usually formed as a collaborative work of the participating chairs. During the colloquiums and supervisions, all discussions are conducted together.

In the module 2 in winter semester 2020-2021, “performance-based design” refers the further investigation of the existing designs for a set of performance tasks, which are energy efficiency, utilization of active solar systems, daylighting availability, visual and summer thermal comfort. In the first module, Café Ada, an existing building in Mirker Quartier in Wuppertal, with culinary and cultural use, was the case study. The studio students designed a vertical extension for the existing café, with the use of "cultivated" materials. The existing designs, that were created in pair work in the first module, were individually examined and re-evaluated based design and performance criteria. The students analyzed the light, thermal, and energy performance of their existing designs on a large scale, considering the surrounding environment and climate. Later, they combined task-oriented upgrades into a final upgrade. By the end of the second module, seven designs developed in pairs in the first module were further developed into 13 different upgrades based on building performance.

Although the language of the studio was English, the studio lectures were also supported in German and student presentations in German were welcomed.

Due to the worldwide COVID-19 pandemic, the studio was primarily conducted using the videoconferencing tool provided by the university. Some of the consultations and mid-term exams were held face-to-face, when required.

The descriptions in section 5.2. refer only to the second module in the winter semester 2020-2021, where the first prototyping and test of it took place, the so-called “semi-integrated studio”.

### 5.2.1. Content, structure and tools

The existing designs were examined and evaluated for the performance tasks of climate and site integration, visual comfort and daylighting, thermal comfort, active solar energy utilization, and energy balance. A design upgrade for overall performance was requested as a final studio assignment. Students worked individually.

Learning goals were to:

- conduct a series of BPS simulations to analyze the climate pattern, daylighting, thermal comfort, and energy performance in an integrated manner, without compromising the aesthetic quality;
- acquire the knowledge required to critically discuss and present the environmental concept of a building;
- gain integrated approach for sustainable building design.

The studio was structured in 3 phases based on the performance tasks (1) climate and energy, (2) daylight availability and thermal comfort (2), and (3) sustainable building design. The structure and timetable of the studio is presented in Figure 5. 4.

| Semester Weeks | Course Phase | Phase Content |
|---|---|---|
| 1<br>2<br>3<br>4 | I | Climate and Energy Demand |
| 5 | First Colloquium | |
| 6<br>7<br>8<br>9 | II | Daylighting Availability and Thermal Comfort |
| 10 | Second Colloquium | |
| 11<br>12<br>13 | III | Sustainable Building Design |
| 14 | Final Colloquium | |

Figure 5. 4: Semi-integrated studio – Structure and timetable.

Rhinoceros, a 3D CAD tool, was used as the base digital design environment. ClimateStudio (CS), an environmental modeling and simulation plug-in for Rhino, was used as a BPS tool. The fact that CS is integrated into Rhino, that offers an interface, and that the BPS model can be created directly in the architectural modeling environment were the factors that were effective in choosing CS. EnerCalC [224], an Excel-based multi-zone energy modeling tool, was used for the final energy demand calculation and sizing of photovoltaic (PV) systems. Because the calculation of the total energy demand is relatively easier with EnerCalC, as it provides more appropriate supply-side options for Europe compared to the full modeling with ClimateStudio (using EnergyPlus). The interactions between the tools are presented in Figure 5. 5.

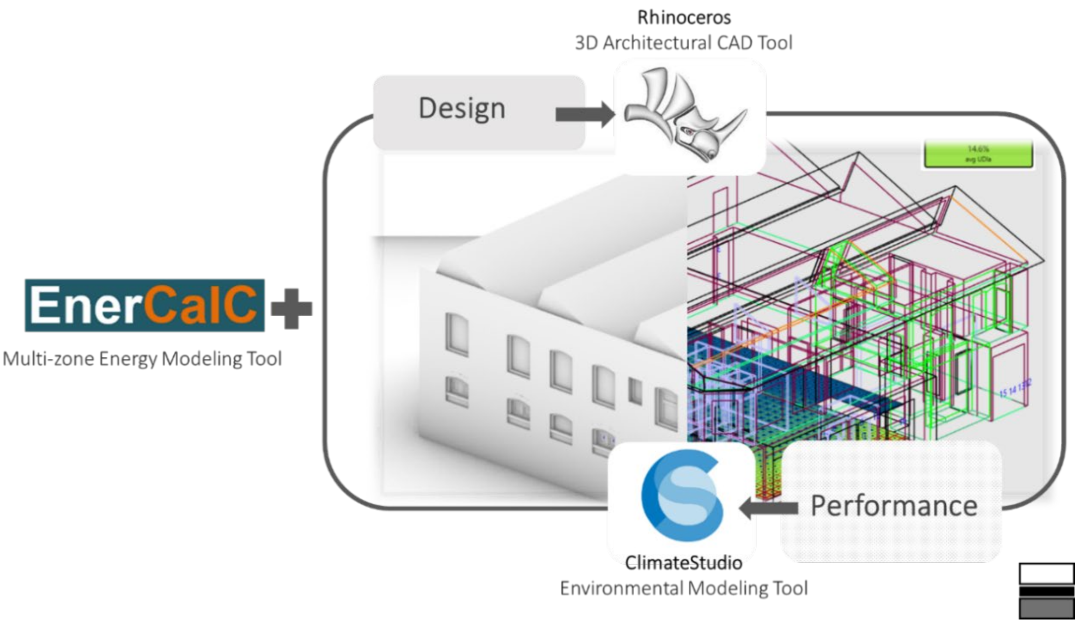



Figure 5. 5: Semi-integrated studio – Digital tools of design and BPS.

While single-zone energy modeling was preferred during platform prototyping, choosing multi-zone modeling for the studio may raise a question. In this studio, the students evaluated the performance of the designs they had already developed. The developed designs included non-residential uses such as restaurants, workshops, and exhibition halls, which had a high impact on energy use. Therefore, multi-zone modeling was a necessity for energy use and balance simulations.

The semi-integrated studio syllabus, which describes the course content, structure, activities, and schedule of the studio, is included in Appendix CI.

### 5.2.2. Studio entrance survey

The methods to be used in the studio were planned and the materials were prepared before the start of the semester. However, to understand if the planned work was coherent with the students' background and expectations, an evaluation survey was conducted after the first lecture introducing the studio's content, tasks, and schedule. The questions were provided in the form of a non-anonymous survey through the university's online learning platform. Ten of the 13 students in the studio participated. The survey questions are presented in Appendix CII.

After the introductory lecture on the studio, students were given some predefined phrases explaining possible first impressions and were asked to select the one that most closely matched their first impression. Ten students' selections are presented in Table 5. 1, with the number of students that selected the phrase.

Table 5. 1: Semi-integrated studio – Students' first impressions of the studio.

| | |
|---|---|
| 1 | I felt excited and looking forward for the next classes. |
| 4 | I felt satisfied with the content of the course, which was what I expected |
| 2 | I felt neutral after first lecture, I will consider it in coming lectures. |
| 1 | I was surprised with the content of the course, which is not what I expected |
| 2 | I felt overwhelmed because of the intensive and heavy content of the course |

They were requested to share their comments on the course structure, content, and materials. Seven students provided comments. First impressions after the first lecture are presented in Figure 5. 6, with the students' own quotes.

First impressions were that the course content was intense but interesting at the same time. The structure was found to be well-planned, the learning tasks were clear to the students. Two of the students expressed their positive impressions about the weekly assignments, only if the completion of the assignments would help them to complete the final main assignment. The weekly assignments were already structured to enable students to gain required skills and knowledge for the final assignment. Furthermore, some of the assignments were a kind of rehearsal for the mid-terms, and final term papers.

The English language of the course was not very attractive for most of the students. As it is pointed out by many, they were not familiar with the English terminology of the course topics. Only a few students were fluent in English.

A selection range between 0 (not at all familiar & low knowledge) - 4 (extremely familiar & excellent knowledge) was given to the students to learn how familiar they were with the topics and how much knowledge they had about BPS: While 3 students selected "very familiar", 7 students selected "somewhat familiar". The average of the selections was (2.3) showing that the students were familiar with the topics. One student indicated his BPS knowledge as "low", 4 students as "little", 4 students as "good" and 1 student as "very good". The average value of the knowledge was 1,5, which refers to between little and medium. Their experiences with the BPS tools were mainly limited to the tools, i.e.

EnerCalc [224], SimRoom [225], Relux [233], which they had been taught in previous master seminars. Only 2 students had an experience with the design integrated BPS tools of Ladybug [146] and Diva-for-Rhino [107].

When asked which design environment they preferred, all students rated CAD tools (e.g. Rhinoceros, Sketchup) over BIM tools.

In a range between 0 (not at all important) and 5 (extremely important), the students on average found the topics of the course very important: 2 students selected "moderately important", 6 "very important", and 2 "extremely important". The workshops were rated as the most attractive activity, and “Part 3: Sustainable building design” as the most important.

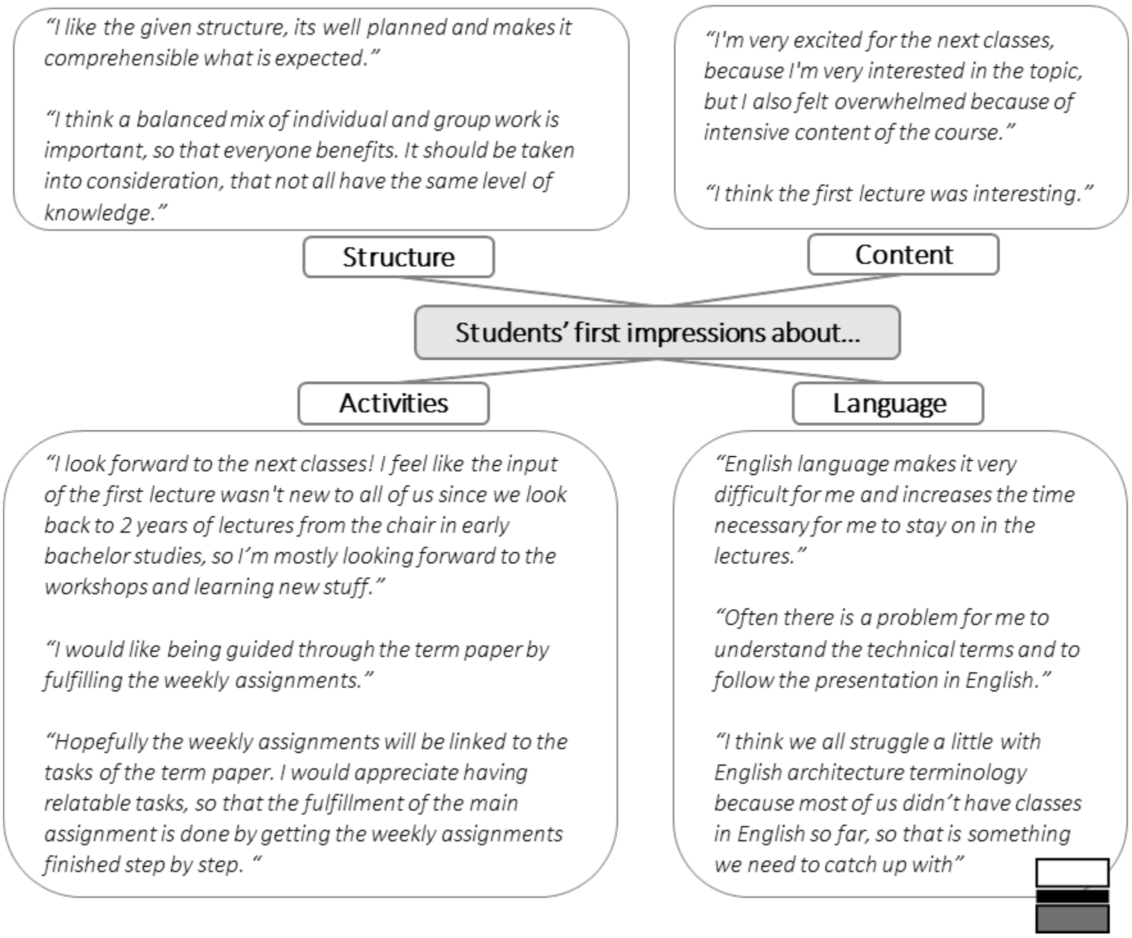



Figure 5. 6: Semi-integrated studio – Students’ first impressions about the course content, structure, activities and language.

It is requested to explain the reasons to take the course and expectation from the course. The comments explaining students’ expectations are presented in Figure 5. 7.

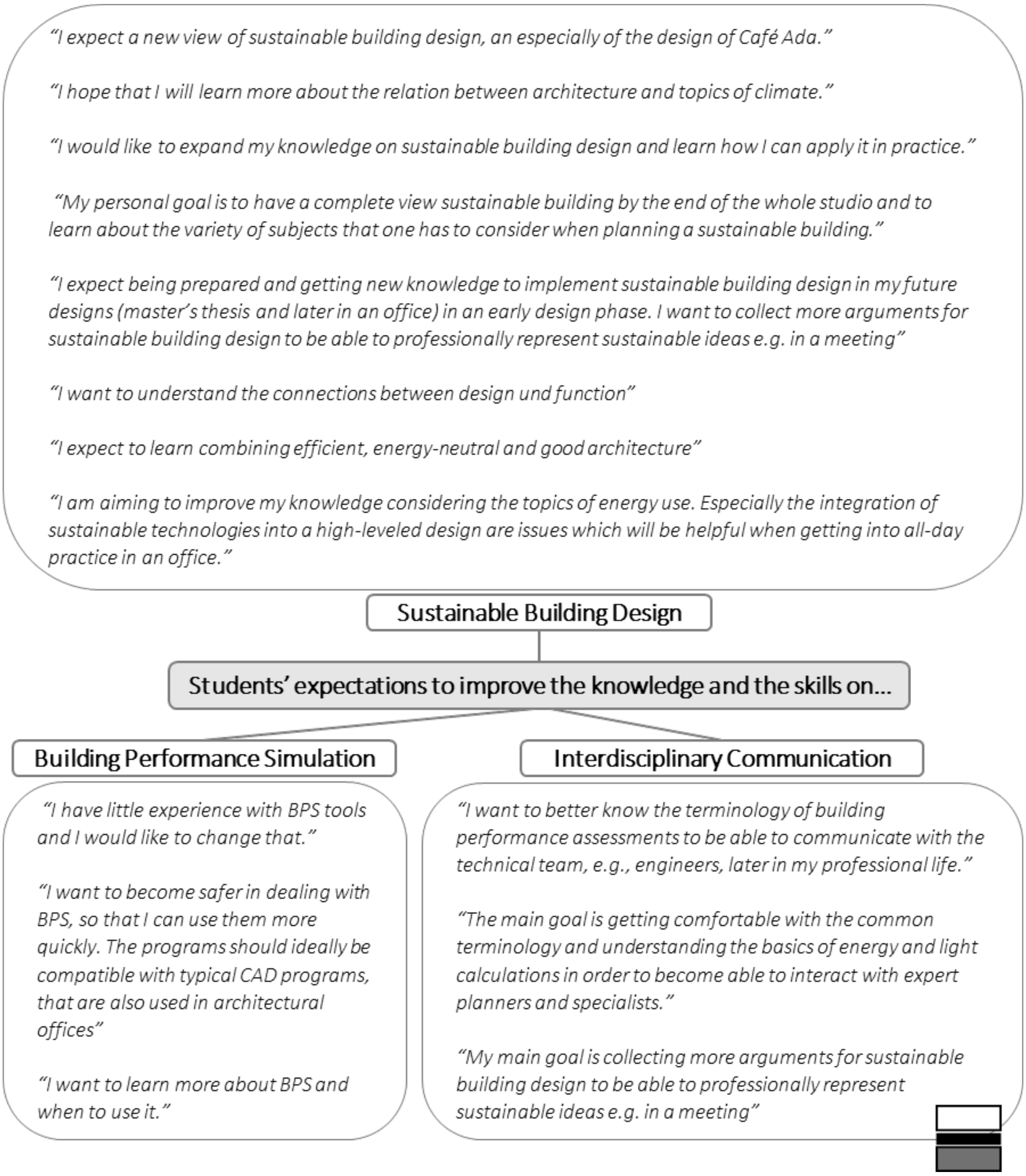



Figure 5. 7: Semi-integrated studio – Students' expectations from the course in order to improve their knowledge and skills on sustainable building design, building performance simulation and interdisciplinary communication.

The students' expectations from the course were centered around three main areas: broadening their perspective on sustainable building design, developing BPS skills, and a solid grasp of building performance assessment terminology, thereby improving their interdisciplinary communication skills with - future professional - project teams.

The evaluation survey showed that the students were already familiar with the topics and had a moderate level of knowledge about BPS. So, there was no need to lower the learning content and level.

Considering that all the students were voted for CAD tools, it was a good decision that the Rhinoceros CAD tool had been chosen as a main digital design tool of the studio.

In general, the entrance survey was very useful to understand the background, interest and expectations of the students. There were no extreme/unexpected results, so only minor adjustments were made to the content and structure as listed below:

- Extra supervision hours were added to the schedule to support the students with lower knowledge and skills of BPS
- To overcome the learning challenges that might be caused by the language barrier, theoretical lectures were supported by German terminology. The students were also welcomed to ask their questions in German, if they needed to. They were allowed to choose either English or German for their presentations, reports, and final papers.

### 5.2.3. Methodology

The performance evaluation in the context of the studio was designed as a continuous workflow: (1) understanding the performance tasks; (2) defining design and performance goals and acknowledging requirements; (3) deciding on constant parameters; (4) detecting of key parameters and testing variations; (5) achieving performance upgrade by combination of high-performing values based on the selected variations, (6) Upgrading. Figure 5. 8 demonstrates the workflows of the studio.

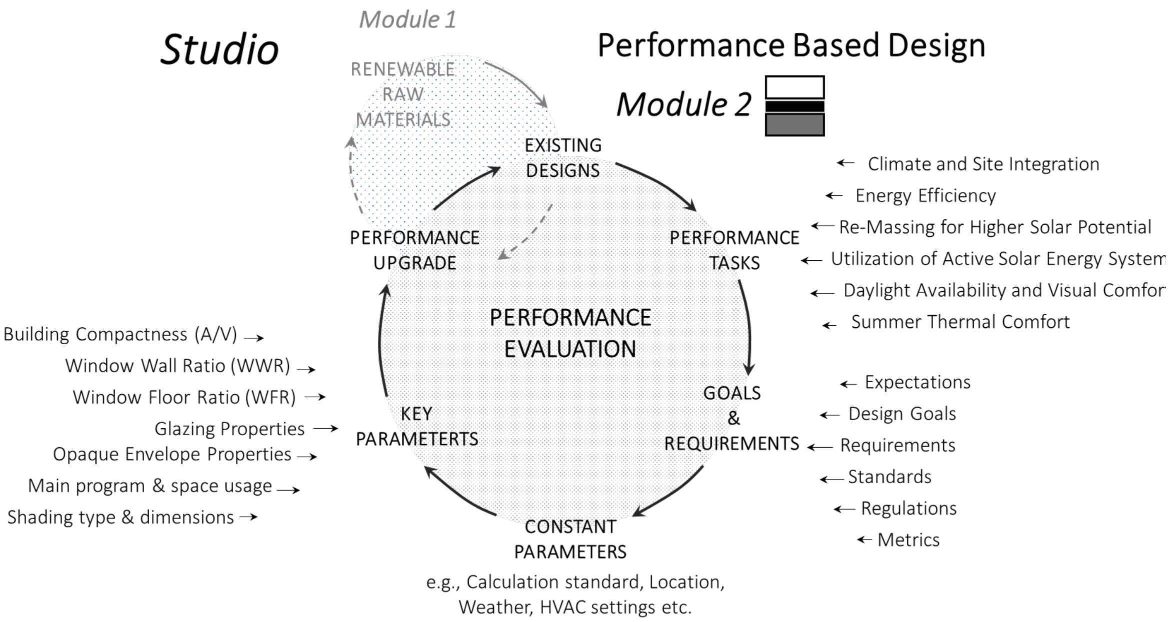



Figure 5. 8: Semi-integrated studio – Workflows.

The above-mentioned workflows were based on a pedagogical method of **"continuous learning cycle"** (Kolb,1984): The method argues that the learning is best when it is a continuous process grounded in experience, and the learning is defined as "*a process whereby the knowledge is created through the transformation of experience*". Teaching and learning activities of the studio that were structured in this respect to enable students to focus, ground, structure, investigate, verify, record, communicate and (re)explore their experiences can be seen in Figure 5. 9.

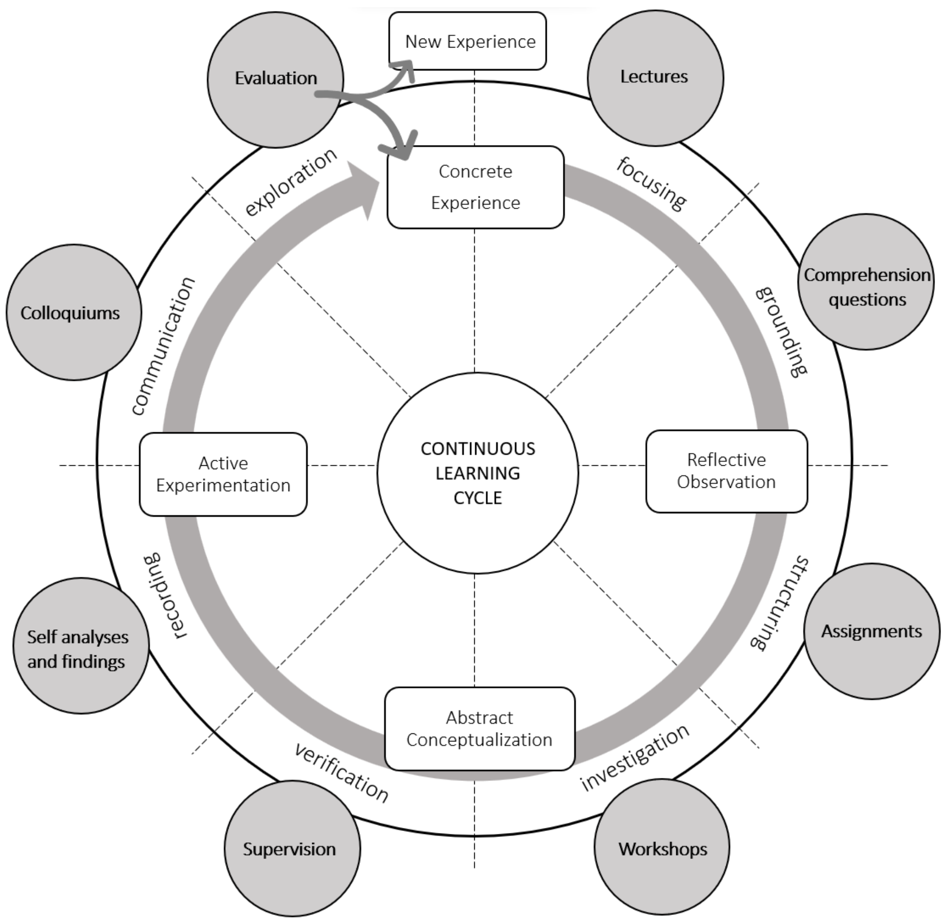



Figure 5. 9: Semi-integrated studio –Teaching activities of the studio structured based-on Kolb's Diagram of Similarities Among Conception of Basic Adaptive Process (Adapter after Kolb [169] and Hopfe [29]).

The main activities of the studio were theoretical lectures, workshops, supervision and colloquiums. Each main topic was introduced by lectures to refresh the theoretical background and to enable the students to focus on the tasks. Workshops and assignments were held in the center of the studio to promote experiential learning. In addition to weekly assignments, comprehension questions were provided to highlight key topics. Figure 5. 10 shows the weight of the main activities as a time percentage over 14 weeks.

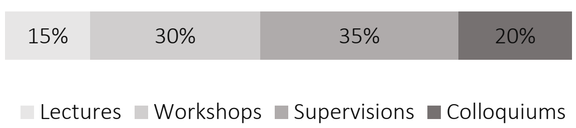



Figure 5. 10: Semi-integrated studio – weight of the studio main activities in semester time of 14 weeks (%).

For each assignment and colloquium, the tasks to be completed and the expectations regarding the content were explained to the students during the class-meetings and delivered them in a written form, namely "Assignment" and "Expectations for Colloquium" documents. (Example documents are included in Appendix CIII and CIV) These documents were prepared with great attention not only to explain the assignment, but also to give the students important hints about the task, to remind them of the tools and resources they might need to complete the task, and sometimes to provide them the basic materials needed for the task, i.e. base 3D model, example simulation files from a previous workshop, etc.

The course outline was given to the students to enable them to focus on the planned studio work through lectures introducing the performance tasks, goals, and requirements. Each lecture was coupled with comprehension questions to ground the information received, eliminate misconceptions, and highlight key learning points. Following this, workshops and assignments were designed to support students in structuring and investigating problems through self-experience. This process is supported by intensive supervision. Students received continuous feedback on their assignments after each submission. Colloquiums were the final activity of each circle where students presented their works and communicated with other students and instructors. In the final step of a circle, students either completed the task and moved on to a new experience, or started over to update the solution based on discussions and feedbacks.

These learning circles were connected to each other through colloquiums, creating a learning spiral that aimed to enable students to deepen their knowledge at the end of each circle. In the scope of this work, the studio had 3 main circles, which is visualized as a continuous learning spiral in Figure 5. 11.

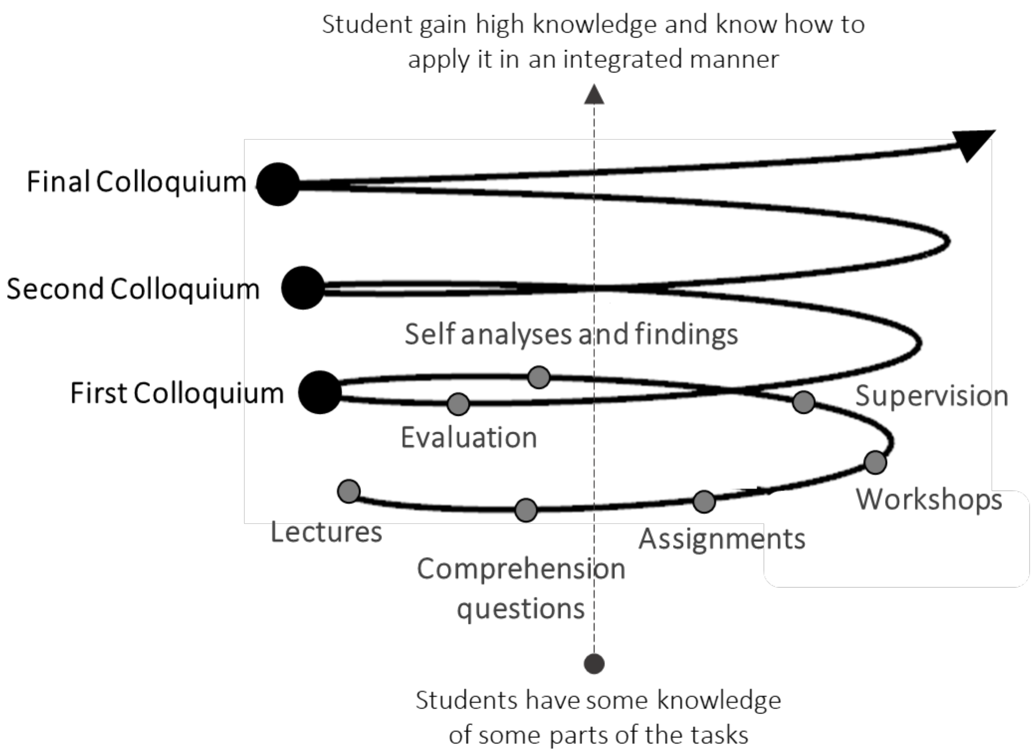



Figure 5. 11: Semi-integrated studio – Conceptual visualization of continuous learning experience.

Another method applied in the studio was starting the evaluations with using "*one-at-a-time*" (OAT) approach [234] to enable students to understand the individual effects of changing values of key parameters on a performance task. Later, combinations of selected parameters – nested OATs - were also tested. Figure 5. 12 demonstrates the OAT method applied.

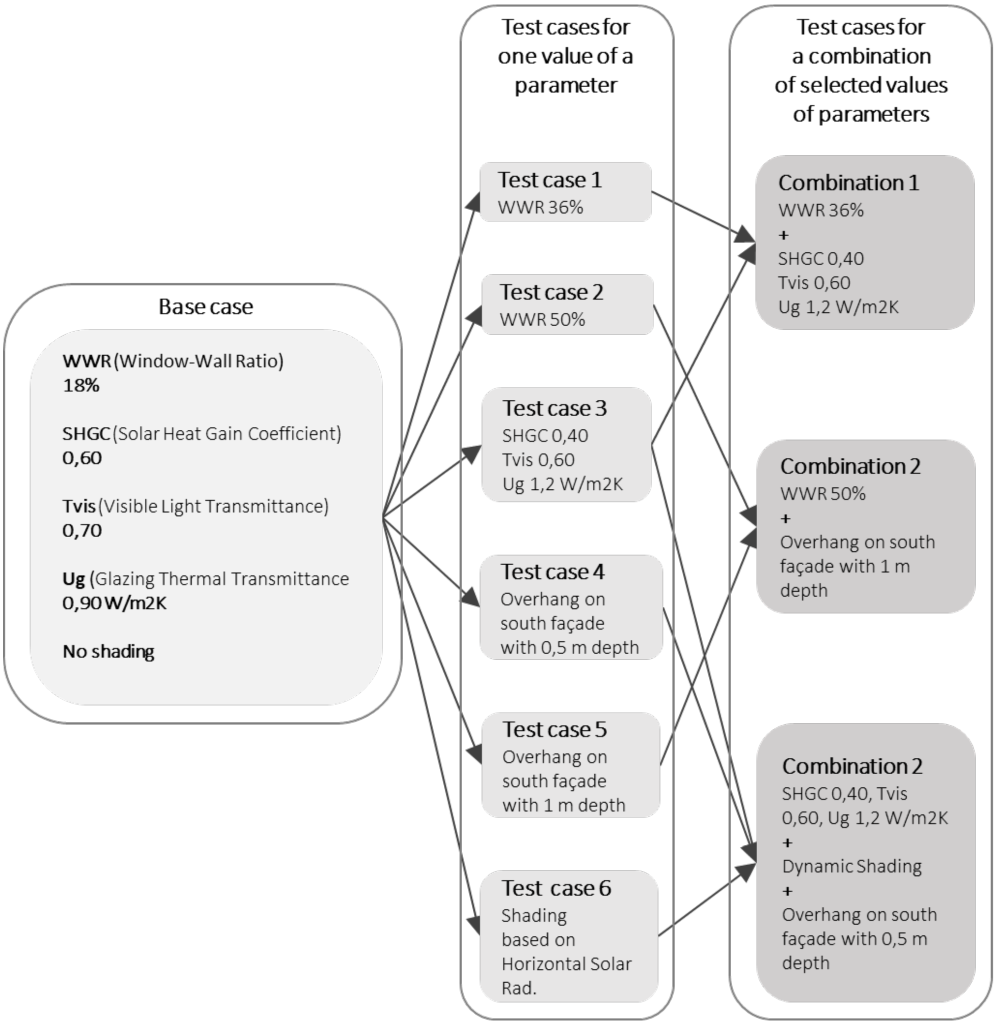



Figure 5. 12: Semi-integrated studio - Method of "one- *value of a parameter*- at-a-time" applied in the studio.

BPS was the main assessment method of the performance evaluation. In addition to simulations, other methods such as design guidelines, standards and rules of thumb were used. To make the BPS studies easier for the students, some theoretical simplifications were also applied. For example, simulation templates including the base-settings, i.e. use type, conditioning and ventilation scenarios, optical and thermal-physical properties of building elements, and schedules of occupancy, lighting, equipment, ventilation were provided for a start of simulation studies.

## 5.2.4 Students' works

The students started with site and climate analyses in order to explore their existing design in relation to the climate and to determine the performance requirements in the context of the investigated climate. Precipitation, radiation, temperature, sun-path and shadow analyses were conducted.

To provide a baseline for energy upgrades, the energy demands of the existing design from previous module were analyzed. Then, keeping the geometry-related parameters the same, design alternatives were evaluated for higher energy-efficiency by testing variables related only to non-geometric parameters such as thermal transmittance (U-value), solar energy transmittance (g-value), thermal mass capacity, infiltration, lighting control, occupancy, etc. Figure 5. 13 presents an example student works for an energy upgrade with less energy demand for conditioning, domestic hot water (DHW) heating and lighting.

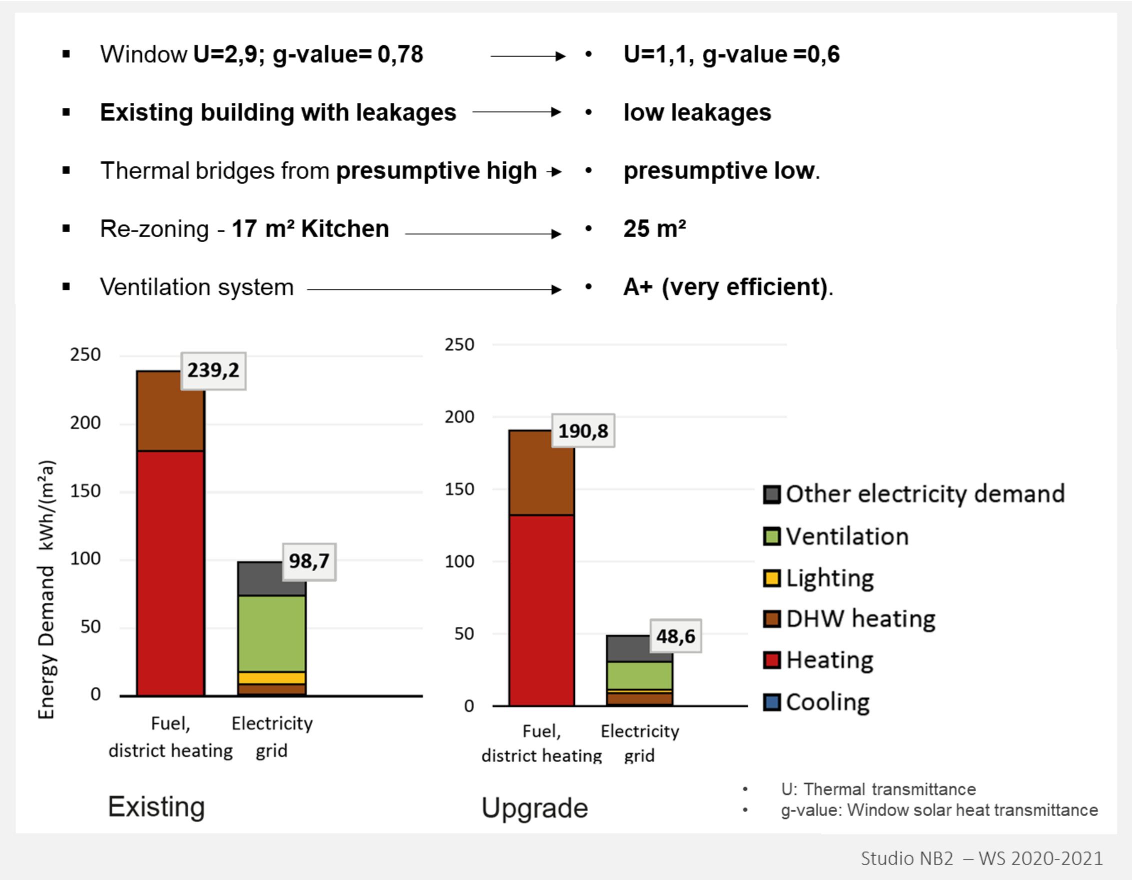



Figure 5. 13: Semi-integrated studio – Student work – Upgrade for energy efficiency.

After the students found more energy efficient alternatives of their existing designs, shading and radiation analyses were included in the energy assessments in order to explore the potential envelope areas of the designs for the use of active solar systems. In this step, they were asked to re-evaluate the cubature and investigate the other forms possible for higher solar radiation. The assessment started with the whole building envelope including walls, roof, terrace, etc. The parts of the envelopes with higher solar potential were investigated in detail for PV use. Figure 5. 14 shows an example student work for re-forming for higher solar energy utilization, and Figure 5. 15 for balancing energy demand combining energy upgrade and PV use.

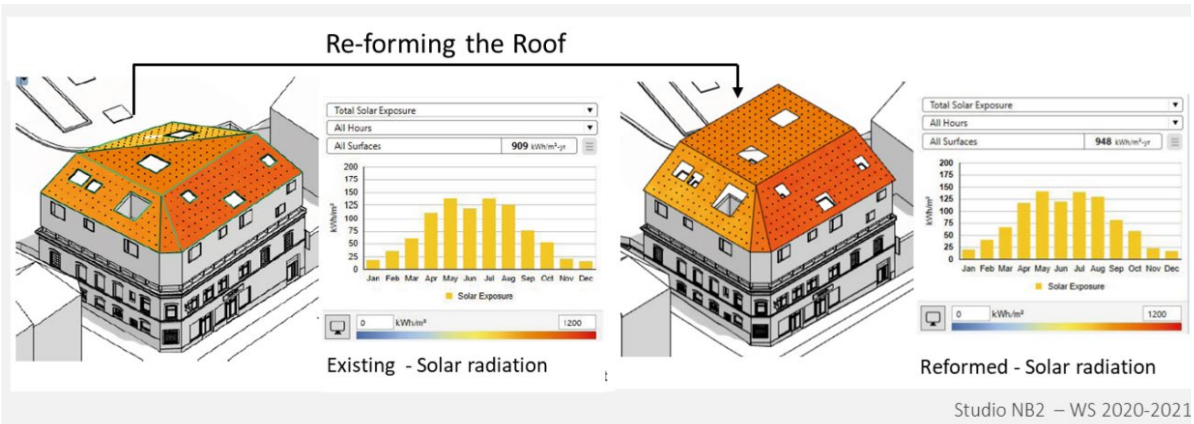



Figure 5. 14: Semi-integrated studio – Student work – Re-forming for higher solar energy utilization.

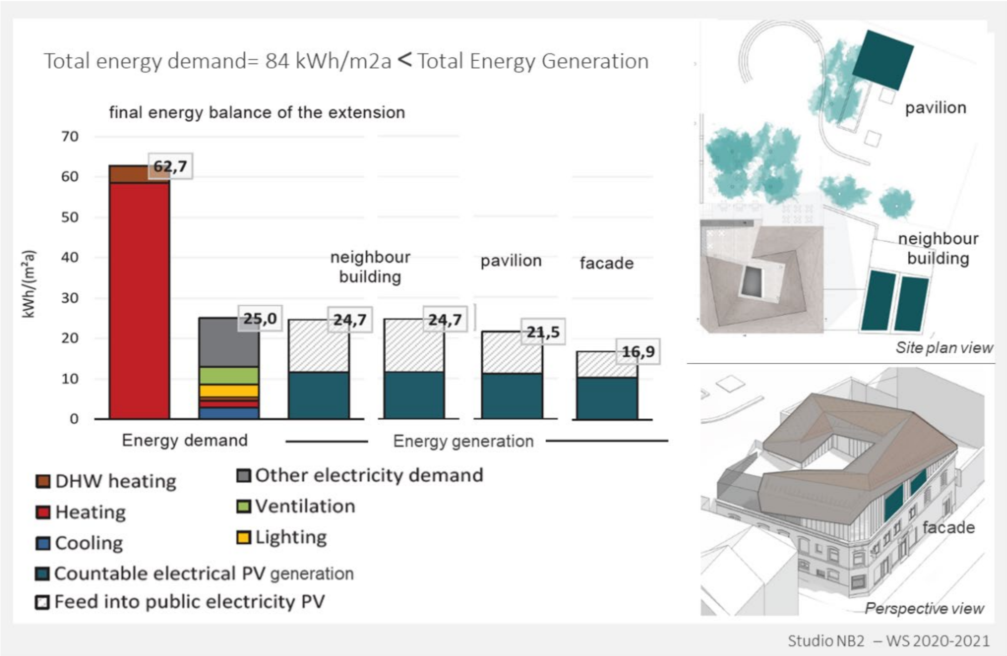



Figure 5. 15: Semi-integrated studio – Student work – for energy positive building through energy efficiency upgrades and utilization of active solar energy.

For the daylight analyses, the task was to achieve adequate daylight availability with good visual comfort, furthermore, to reduce the need for artificial lighting by efficient use of daylight, but also, to maintain the summer thermal comfort without active cooling. For daylight availability, the metrics of daylight factor (df), spatial daylight autonomy (sDA), average useful daylight illuminance - autonomous (avgUDIa) and Annual Sunlight Exposure (ASE) were used. The challenge of achieving the summer thermal comfort while providing a visually comfortable space was deliberately given for didactive purposes. The aim was to enable the student to control conflicting performance objectives, where one performs best at high values of a parameter and the other at low values, and in general to enable them to identify the relations between different aspects of building performance. An example student work for the parameter investigation for visual and thermal comfort can be seen in Figure 5. 16.

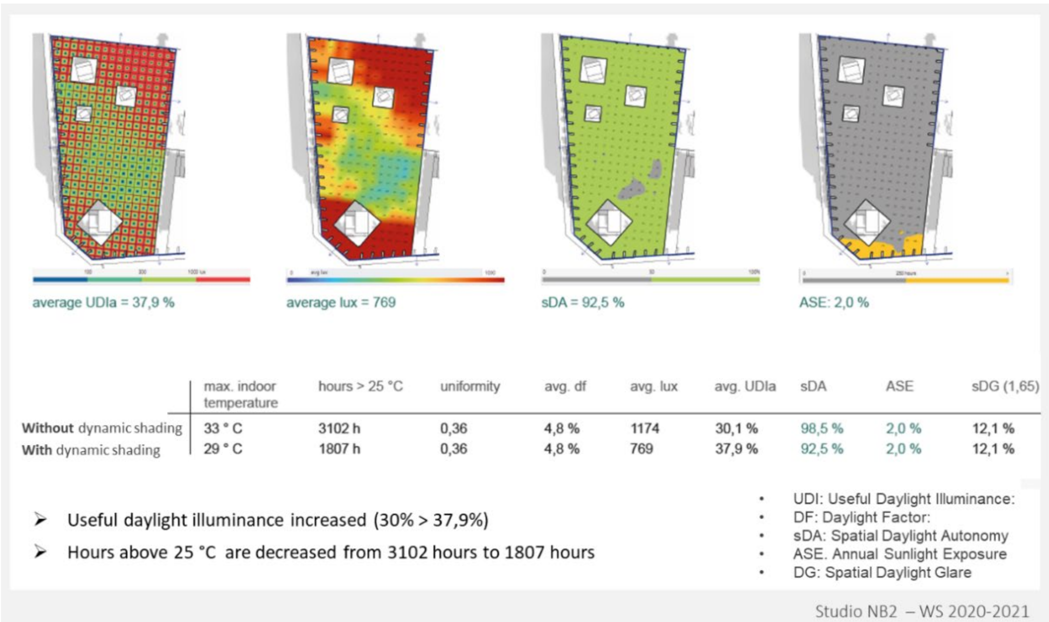



Figure 5. 16: Semi-integrated studio – Student work – Parameter investigation for visual and thermal comfort: Test of Dynamic Shading.

Each main task was investigated separately by defining task-oriented goals, requirements and parameters. The key parameters were defined throughout the AOT, and later nested AOT methods. After the evaluation of high number of parameters, each student decided on an "optimum" combination of variables for the final upgrade. The rich variety of performance upgrades was achieved by the end of the studio.

As the final work of the studio, the students summarized their works and presented them in a booklet format. This was a didactic approach that, in addition to underlining key learning points, enabled students to develop their skills in writing and communicating the results of their work with precision.

### 5.2.5. Students' feedback

An anonymous studio evaluation survey was conducted to capture the students' views about the studio experience via the online learning platform of the university.  Eight of the 13 students of the studio participated.  The evaluation survey questions are included in Appendix CV.

Workshops and colloquiums were found as the most useful activities, and this is followed by weekly assignments. The rates between 0 (not useful) and 4 (very useful) are averaged for each activity and presented in Figure 5. 17. The average rating of all activities (2,3) showed that they were found to be moderately useful.

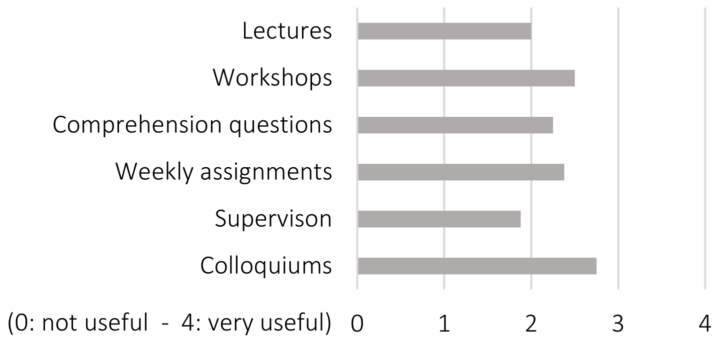



Figure 5. 17: Semi-integrated studio – Rating for the studio activities.

The most attractive task was daylighting and visual comfort, rated by 6 students. Two students found the optimization for overall performance more attractive than the other topics. The topic of thermal comfort is rated as the most difficult by 4 students, and integrated approach for sustainable building design by 3 students, where manual optimization was applied, and site and climate analysis by 1 student. Abstracting their architectural models to create a thermal model and thermal model settings are mentioned as the most challenging steps of thermal comfort evaluation.

The most rated features of the BPS tool – ClimateStudio were its integration with the 3D design tool – Rhino, its rich material library and ease of use/get in (Figure 5. 18). The level of satisfaction, which is an averaged value based on the rating of the features, was higher than medium.

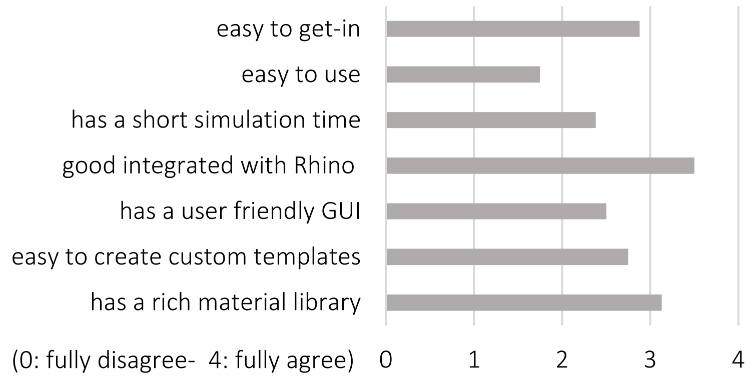



Figure 5. 18: Semi-integrated studio – Comments on BPS Tool – ClimateStudio.

The average level of improvement in skills and self-confidence for using BPS Tools, which is stated by the students, was between medium and high (2,5), in the range of no improvement (0) and very high improvement (4).

The students are provided a range between 0 (fully disagree) and 5 (fully agree) for selecting how much they agree with the phrases of “*BPS tools raised confidence for taking architectonic decisions*?” and “*BPS supported creativity during the design process*”. The average rating for confidence was between neutral and agree (2,5) and for creativity almost neutral (1,75).

Except one, all students agreed on a quote that “The whole evaluation through the application of BPS, showed me something new, I got some results different than my presumptions, but not much different than my expectations.”. Only one selected a quote that “*the whole investigation showed me completely different picture than I expected. I got simulation results far from my presumption*”.

It is asked that if they plan to use BPS in their future studies, i.e. master’s thesis. The half of the students selected “YES”, and the half “NO”. *Reasons not to* plan to use BPS are quoted in Table 5. 2.

Table 5. 2: Semi-integrated Studio – Comments explaining reasons *not to plan* to use BPS are quoted.

| |
|---|
| *“BPST limits me mentally when designing and makes me feel very insecure and overwhelmed.”* |
| *“Since I don't use Rhino, the effort to create my own 3d model for the simulation would be too great.”* |
| *“Simulations in detail take too much time!”* |
| *“I don't know yet, what I want to focus on with my master thesis, On the other hand, usually there is limited time for the submissions and handling new software always is quite time-consuming, brief evaluations may cause very wrong conclusions”* |

The students’ final comments and suggestions on the workload, structure, lecturer, language and the content and methods of the semi-integrated studio are presented in Figure 5. 19.

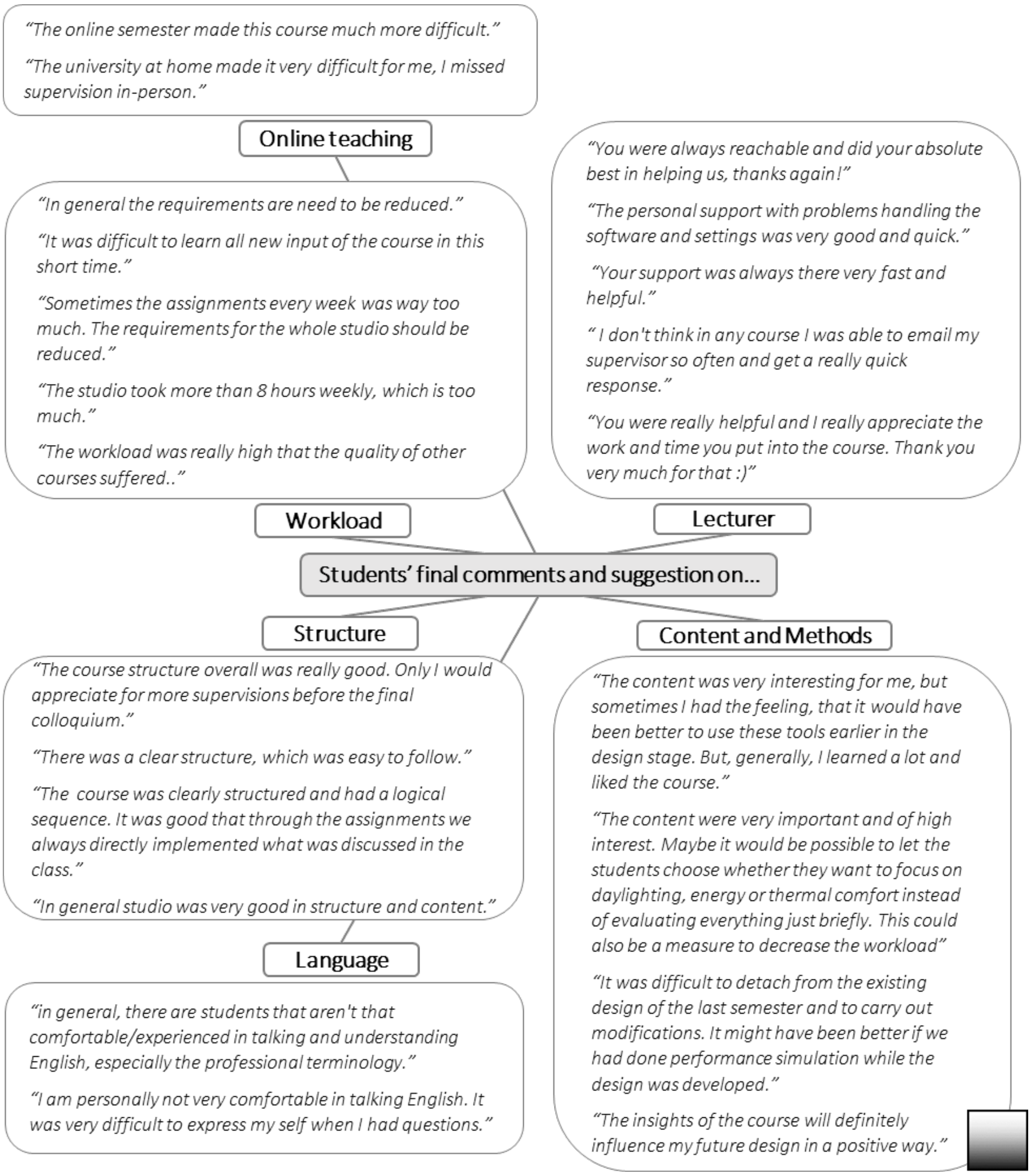



Figure 5. 19: Semi-integrated studio – Students' final comments and suggestions on the workload, structure, lecturer, language and content and methods of the semi-integrated studio.

A review of the entrance and evaluation surveys was useful to plan the next studio. Some of the decisions made for the next studio experience in line with the feedback of the students are listed below:

- Workshops, which were rated as the most attractive activity at the entrance survey and as the most useful activity at the evaluation survey. Thus, the weight of workshops was decided to be increased.
- Weekly assignments were also highly rated at the evaluation survey, so this proved that they were useful steps on the way to accomplishing the final assignment as requested by the students, so this was one of the reasons to remain this activity in the next experience. On the other hand, in order to reduce the workload, it was planned to give assignments every two weeks instead of weekly.
- Comprehension questions and supervision were rated relatively lower than the other activities. Therefore, comprehension questions were planned to be carried to the next experience as

blended within supervision hours, and the supervisions in a way that the group and individual times were balanced.

- The task of daylighting and visual comfort was rated as the most attractive, and the thermal comfort task as the most difficult. It was therefore decided to spend more time on thermal comfort simulations.
- Satisfaction with the BPS tool was high, and the integration of the BPS tool into a design environment was the most rated feature. So, the same design and BPS tools were decided to be used in the next step.
- A plan of applying BPS in earlier design stage was also proposed by students, stating that it was not easy for them to detach themselves from their design to respond to the performance results, and it would be more efficient to apply performance investigation in parallel with the design development.
- Online learning & teaching environment was found challenging for decreasing the quality of communication and the efficiency of supervision.
- To reduce the workload, more group studies were planned for the next studio.
- In general, the availability and the support of the lecturer was highly appreciated and helped the students to progress, which was important to be maintained for the next studio.

## 5.3. Studio Prototype 2: "Integrated Studio"

In the previous experience - "semi-integrated studio", BPS tools were used in an integrated manner with a design tool to evaluate existing designs and it was observed that the use of BPS integrated with the design tool had a high potential for the integrated teaching, but higher flexibility, variety and efficiency were needed. Besides the revisions made in line with the students' feedback from the semi-integrated studio, two major upgrades were made in the integrated studio:

(1) **BPS integration at an early stage** - The aim was to achieve greater diversity by exploring possible design solutions at the intersection of design and performance at an early stage, as well as greater flexibility in form exploration based on the experience that a design form is more easily changed at an early stage compared to later stages of a design process.

(2) **Adoption of parametric design and simulation and optimization** - It is aimed a higher efficiency by achieving a higher number of design alternatives and performance iterations.

Being so, this studio prototype is referred as the "integrated studio" in the scope of this chapter.

As in the previous modules, in the summer semester 2021, module 1 was again carried out by the Chair of Building Construction, Design and Materials Science, and in the winter semester 2021-2022, module 2 was carried out by the Chair of Building Physics and Technical Building Services.

The content of the first module included research on the massive and half-timber structures of the Founder's Era (org. in German, *Gründerzeit*) in the City of Wuppertal, Germany and investigations on embodied energy, life cycle assessment and summer thermal performance of these specific buildings, but no design activity. The module 2 brought a new design challenge in an urban context: "*a space between"* - *Gründerzeit* houses. "Performance-based early design" investigations created the main theme of the studio. Performance indicators for daylight availability, thermal comfort and energy balance with active solar energy utilization were used as guiding parameters for the design investigations. Climate change scenarios were included in the process to see how design alternatives would respond to different climate scenarios. A special focus was placed on the utilization of BPS in the early design phase to see if this would stimulate and inspire design investigations.

The language of the studio was English. With the reduction of the restrictions caused by the worldwide COVID-19 pandemic, the studio took place face-to-face.

The descriptions in section 5.3. refer only to the second module in the winter semester 2021-2022, where the second prototyping took place, the so-called " integrated studio”.

### 5.3.1. Content and structure and tools

The content of the integrated studio was structured based on the teaching methods of case study, parametrization and optimization. The content and schedule of the studio is presented in Figure 5. 20.

| Semester Weeks | Course Phase | Phase Content |
|---|---|---|
| 1<br>2<br>3<br>4 | I | **A Case Study: Building 2226**<br>Understanding building performance on the edge of climate change |
| 5 | First Colloquium | |
| 6<br>7<br>8<br>9 | II | **Parametric design and simulation**<br>Investigating design and performance interaction at early design phase |
| 10 | Second Colloquium | |
| 11<br>12<br>13 | III | **Optimization**<br>Design for Performance |
| 14 | Final Colloquium | |

Figure 5. 20: Integrated studio – Content and structure of the integrated studio.

The learning goals of developing the skills and knowledge for design integrated building performance simulation and gaining a broader perspective on sustainable building design were the same as in the semi-integrated studio. In contrast, students in the integrated studio were introduced to a new design problem rather than an evaluation of an existing design. The additional goal was to encourage studio students to acquire the skills to integrate BPS into early design workflows.

Alongside the design tool – Rhinoceros [106], Grasshopper [97], which is a graphical algorithm editor in Rhino, is adopted for parametric modeling and simulation. The BPS tool – ClimateStudio [115] is again preferred because it is also available in GH. The model-based optimization tool Opossum [235], which is available for GH, was used for multi-objective optimization (MOO). The tool, which is based on a machine learning optimization strategy, was chosen because it is suitable for time-intensive performance simulations. While parametric modeling was useful for fast and flexible generation of design alternatives, the model-based optimization provided support for finding well-performing variants based on defined performance objectives. Present and future weather data sets were provided by Meteonorm [236], which is a meteorological database and calculation tool. The tools can be seen in Figure 5. 21.

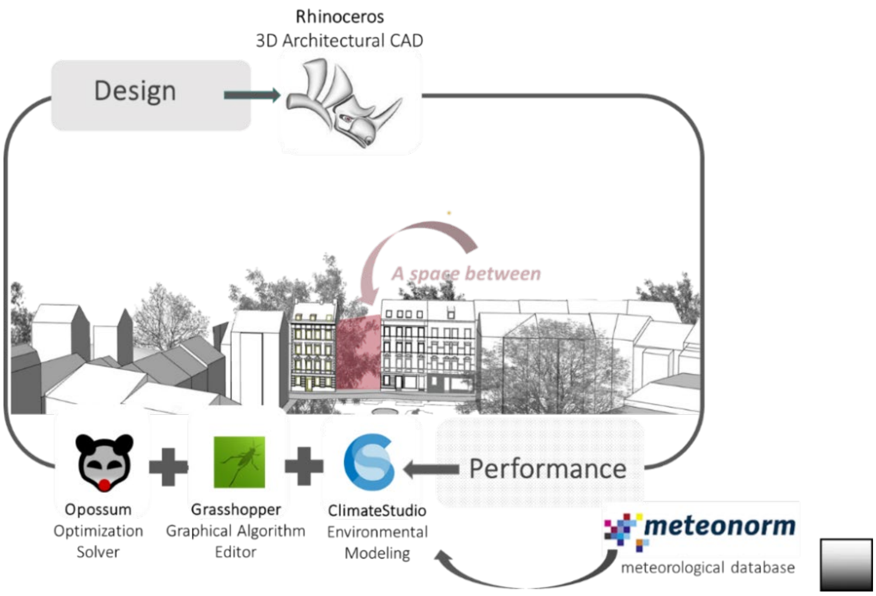



Figure 5. 21: Integrated studio – Digital tools of design and BPS.

The syllabus of the integrated studio, which describes the course content, structure, activities and schedule was provided at the beginning of the semester. It is presented in Appendix CVI.

### 5.3.2. Studio entrance survey

The entrance survey of semi-integrated studio was quite useful to learn about students' backgrounds, interests, and motivations, therefore, to tailor the studio in this respect. Building on this positive experience, an entrance survey was also conducted at the launch of the integrated studio, but this time in an anonymous format to increase the comfort of free comments. Questions were asked in form of online survey via online learning platform of the university. Seven of the 10 students of the studio participated. The survey questions are shared in Appendix CVII.

The students were given some predefined sentences explaining the first possible impressions after the studio introduction lecture, and they were requested to choose the closest one to their first impression. Seven students' selections are presented in Table 5. 3 with the number of students who selected the phrase.

Table 5. 3: Integrated studio – First impression on the course content.

| | |
|---|---|
| **3** | **I felt excited and looking forward for the next classes.** |
| 0 | I felt satisfied with the content of the course, which was what I expected |
| **3** | **I felt neutral after first lecture, I will consider it in coming lectures** |
| 0 | I was surprised with the content of the course, which is not what I expected |
| **1** | **I felt overwhelmed because of the intensive and heavy content of the course** |

Two students commented on the studio structure and schedule (Figure 5. 22). The first impressions showed that the structure and schedule were clear, which was appreciated by the students.

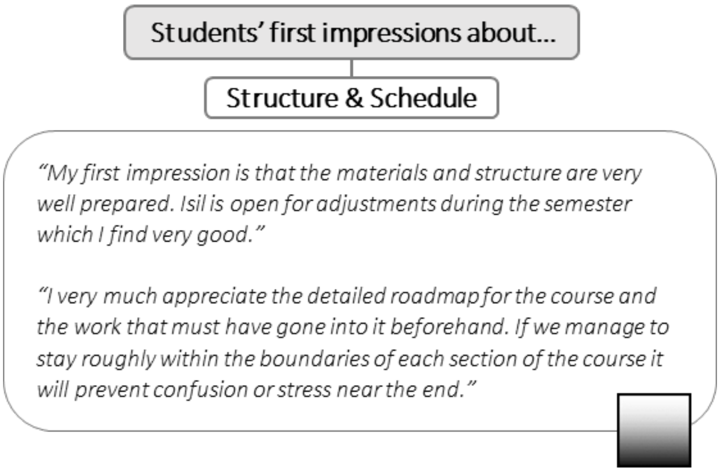



Figure 5. 22: Integrated studio – First impression about the course structure and schedule are quoted.

A range between 0 (not at all familiar & low knowledge) - 4 (extremely familiar & excellent knowledge) was given to the participants to indicate their familiarity with the topics and their knowledge of BPS: 1 student selected "very familiar", 4 students selected "somewhat familiar", and 2 students selected "slightly familiar". The average of the selections (1.86) demonstrated that the students were somewhat familiar with the topics. One student stated his/her knowledge of BPS as "low", 3 students as "little", and 3 students as "good". The average value of the students' knowledge was 1.3, which is between low and medium. Their experiences with the BPS tools were mainly limited to the tools taught in previous master seminars, i.e. EnerCalc, Simroom. Only 2 students had experience with the design-integrated BPS tools of ClimateStudio.

The students found the topics of the course very important: 1 student selected "moderately important", 3 "very important" and 3 "extremely important" in a range between 0 (not important at all) and 4 (extremely important). The average value was 3,15. Workshops were rated as the most attractive activity, and this is followed by lectures. Phase 2, where the investigation of the design and performance interaction was planned to be investigated via parametric modeling and simulation, was rated as the most attractive phase.

They were requested to explain the reasons to take the course and explain their expectations from the course considering the skill and knowledge they wanted to gain. The comments explaining students' expectations are presented in Figure 5. 23.

The students' expectations centered on gaining a broader perspective on sustainable building design and developing skills in building performance simulation. In particular, they were interested in better understanding the relationships between design and performance and in applying this knowledge to the design process.

In general, the survey showed that the planned course content and the structure were compliant with the students' level and expectations. No revisions were applied.


Figure 5. 23: Integrated studio – Expectations from the course in order to improve their knowledge and skills on sustainable building design, building performance simulation and interdisciplinary communication are quoted.

### 5.3.3. Methodology

The same "continuous learning cycle" workflow used in the semi-integrated studio was adopted in the integrated studio. The flow includes the learning steps aimed at (1) understanding of performance tasks; (2) defining design and performance goals and acknowledging requirements; (3) deciding on constant parameters; (4) identifying key parameters and testing variations; (5) finding solution alternatives at the intersection of design and performance requirements, and (6) deciding on a final design proposal. Figure 5. 24 demonstrates the workflows of the integrated studio.

Theoretical lectures, workshops, supervision and colloquiums remained as the main activities. Based on the experiences gained during the semi-integrated studio, the weight of the workshops in the semester schedule was increased from 30% to 40% by reducing the number of theoretical lectures. Figure 5. 25 shows the weight of the main activities of the integrated studio as a percentage of time over 14 weeks.

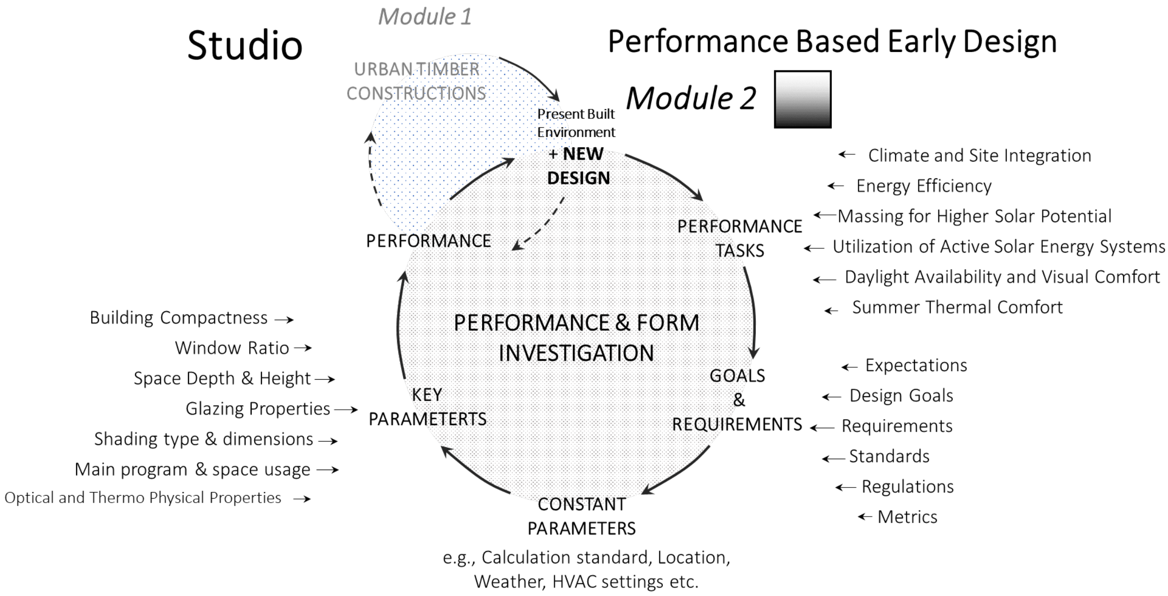



Figure 5. 24: Integrated studio – Workflows.

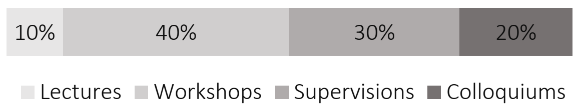



Figure 5. 25: Integrated Studio – Weight of the main studio activities in 14-week semester time (%).

A case study was chosen as the entry-point of the studio to refresh the students' knowledge on the studio topics and to introduce them to the studio tools of design and BPS.

Weekly assignments continued, emphasizing key learning topics and allowing students to experience each major step toward the final assignment on their own. Again, the expectations for the content of the assignments, as well as for the colloquiums, were explained to the students during class meetings and delivered in written form, namely the "Assignment" and "Expectations for Colloquium" documents (Example documents are included in Appendix CVIII and CIX).

The one-at-a-time (OAT) method remained. Unlike the semi-integrated studio, the integrated studio simulations started with only geometry-related parameters, e.g. building form, compactness, space dimension, window ratio, shading form and dimensions, and so on. This was done to attract students' attention to BPS without overwhelming them with a large number of optical and thermo-physical property inputs required for BPS. To facilitate this "easy and attractive" start, pre-defined templates of building use, occupancy, lighting, equipment, ventilation, and conditioning schedules were tailored by the studio instructors in advance.

Addition to BPS as the main performance assessment method, parametrization and optimization were adopted, acknowledging that the methods, and hence the tools, used during a design process have a significant impact on the number of iterations that can be performed during design exploration.

As stated by Hovestadt at. all [237]: "*Designing in and working with space means manipulating (adapting, changing, evolving) the objects and their attributes…*". Therefore, the aim was to increase the solution alternatives through the manipulation of the objects of the studied spaces for design and performance challenges. Parametric modeling, which is a modeling process with the ability to change the shape of model geometry as soon as the dimension value is modified [238], sought to speed up the investigation by enabling easy creation and modification of a design form, while parametric simulation, which can be defined based on parametric modeling as the ability to easily change the simulation inputs using parametric models, attempted to enable rapid testing of design alternatives.

Optimization, according to the basic dictionary definition, is "the act of making something as good as possible". In the context of the prototype studios, it refers to the search for design variants for better performance. Optimization, as both a manual and an automated method, was applied to provide a systematic approach to analyzing and understanding trade-offs between contradicting objectives. The automated optimization technique using surrogate-based methods was preferred, because of that *"model-based methods are proven to be more suitable than genetic algorithms for architectural design optimization, where design problems are often complex and time intensive."* [239].

In order to introduce these methods to the students and to provide them with examples that they can adapt to their own workflows, parametric modeling and simulation and then optimization sample workflows were provided to the students when starting their design studies.

### 5.3.4. Students' works

Research from the previous module on the Founders' Era buildings about their structure, materials and embodied energy in this respect was used as the base for a new design challenge. And so, the "*Performance-based early design*" investigations began "*in a space between*" the Founders' Era houses.

The integrated studio had 3 main phases: (1) Understanding the performance at the edge of climate change via a case study of Building 2226, (2) Investigating design and performance interactions for a new design by methods of parametric design and simulation and (3) Investigations of design alternatives through optimization. The phases and content of the integrated studio are presented in Figure 5. 26.

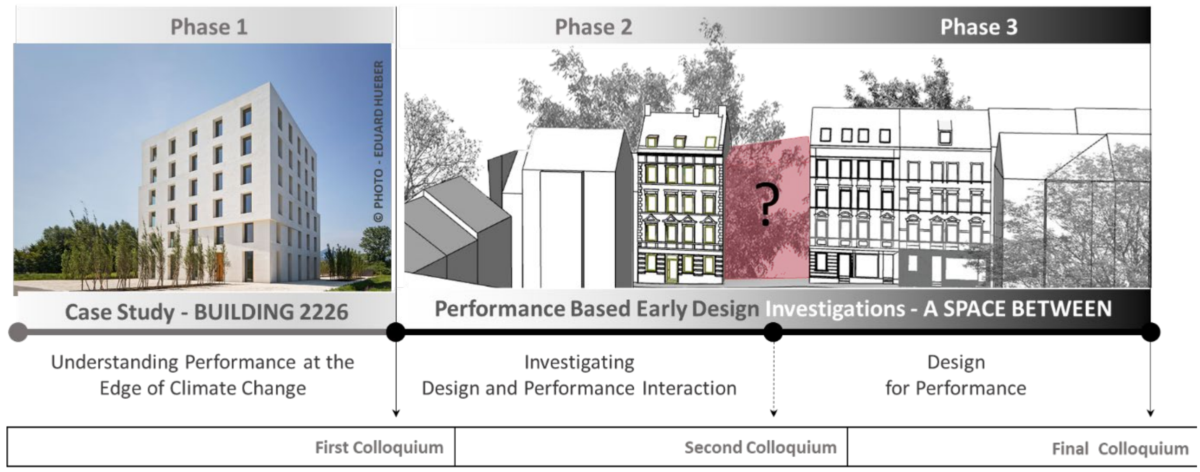



Figure 5. 26: Integrated Studio – Phases and content - © Building 2226 Photo credit: Eduard Hueber.

The phase 1 began with an investigation of Baumschlager Eberle's Building 2226 [240,241], which is a well-known recent architectural work with its low-tech and passive approach. In the integrated studio there had been no existing designs from the previous module, being so, a case was needed to provide students hands-on experience on the studio tools and tasks before starting their own design studies. This phase aimed to enable students to understand the impact of the climate change on design and performance, in the meantime to refresh the basic knowledge regarding selected main performance tasks, which are solar energy utilization, daylight availability and summer thermal comfort. The five-week long phase 1 included 2 workshops as an introduction for the use of tools and for the main performance tasks of the studio, and ended with the first colloquium. The student' work was conducted as a group study for each location, which were pre-selected by lectures for didactic reasons, in order to provide extreme examples with a broad range of climatic conditions.

The students assessed their works first to answer the questions of "How does Building 2226 perform in different climates?". The present and future climate patterns were analyzed to see how the outside temperature and solar radiation change in these different locations. The future climate data sets of the locations were created based on the Intergovernmental Panel on Climate Change (IPCC) A2 Scenario for the year 2100 [242]. For daylight availability, the metrics of avgUDIa and sDA were used. Neutral hours, which is a simplified method for defining the potential of running a building fully passive, was used. Annual thermal comfort indicators were used as a percentage of hours in the free-floating mode: heating hours (%) (T operative < 20°C), neutral hours (%) (20°C ≤ T operative ≤ 26°C), cooling hours (%) (T operative > 26°C). "Neutral hours" was applied as a simplified approach to give students an insight about thermal comfort rather than a definitive method of a building's cooling and heating demand. The students' works investigating solar radiation and outside temperature, and assessing the daylight and thermal comfort performance of the Building 2226 in different location can be seen in Figure 5. 27.

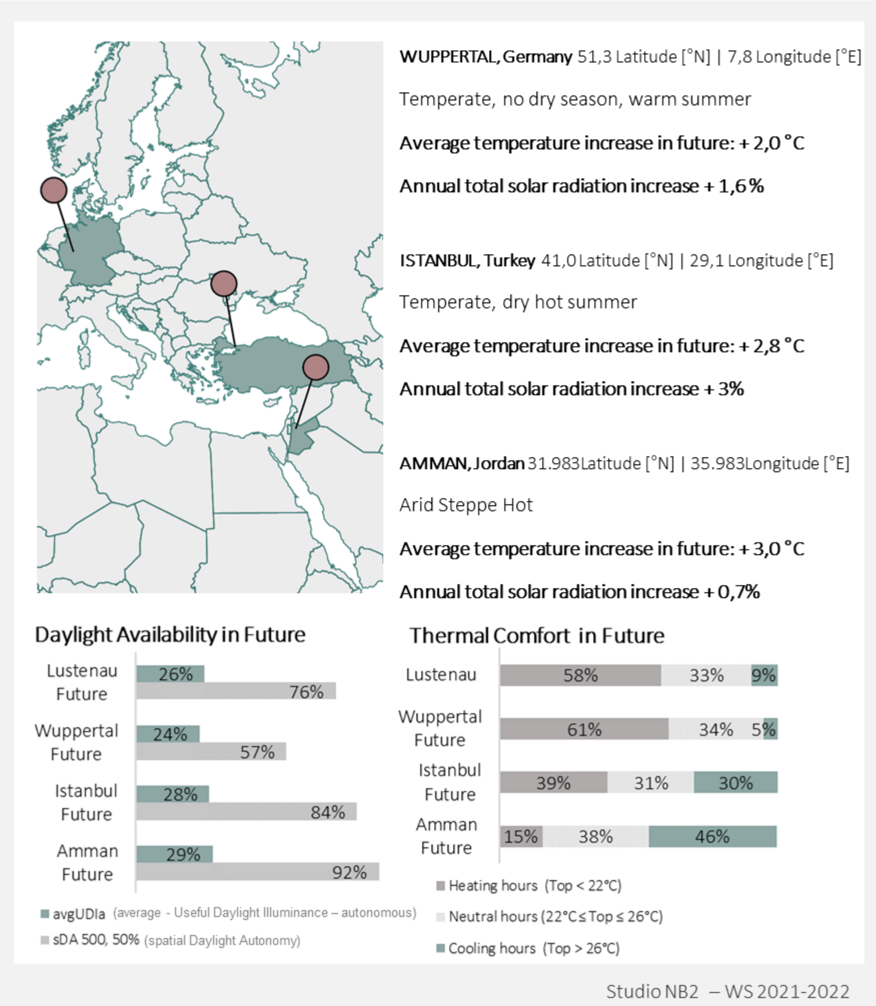



Figure 5. 27: Integrated studio – Students' work – Investigation of the climate patterns for the present and the future worst-case climate scenario, according to IPCC A2 for 2100 over the case study of Building 2226, in cities of Lustenau, Wuppertal, Istanbul and Amman.

The final output of this phase was the upgrade proposals from each group to increase the daylight availability and thermal comfort of the Building 2226 for the investigated locations for future climate scenario. The students went through the geometric and non-geometric parameters by testing a "one-single value of a parameter- at-a time" (OAT), later, the combinations of the selected parameters –

(nested OAT) - were also tested, and the best performing combinations were selected as final upgrades. Figure 5. 28 shows the example student work for testing single values and combinations.

The phase 2 started with a new design challenge in a space located between two buildings from Founders' Era. The aim of this phase was the investigation of the solution space at the intersection of design and performance. The use of the space was flexible under the main use of residential. The design was limited to a total gross floor area of 600 $m^2$ (±10%). The seven-week long phase 2 included three workshops, which provided further details about the use of tools and introduced parametric design and simulation methods for each performance task. Each workshop was followed by a week of supervision, including hands-on sessions, discussions and consultations. The second colloquium was the conclusion for this phase. The students conducted their works to answer the question of "How much does a form matter for performance?". Climate groups of students were formed based on the climates discussed at the phase 1. Massing studies for building volumes were done through radiation and daylighting simulations, by considering only geometry related parameters such as compactness, height, depth. Example massing studies of the students by solar exposure and daylighting can be seen in Figure 5. 29.

Later, the best performing volumes were tested for the thermal comfort, including also non-geometric parameters to find better performing variations of this volumes. At the end of the second phase, the students presented pre-design proposals for overall performance of high solar energy utilization, daylight availability and thermal comfort. Figure 5. 30 shows example work of students for analyzing a volume for thermal comfort by applying AOT and nested AOT methods.

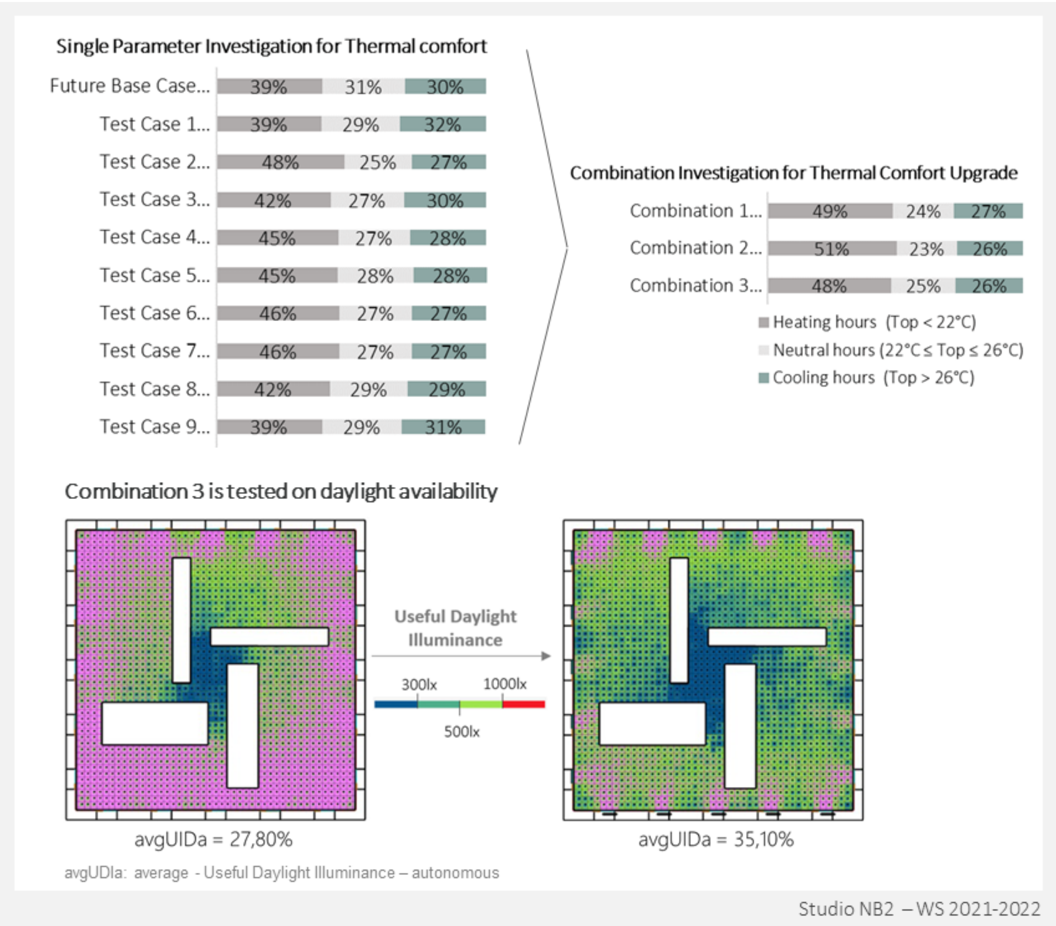



Figure 5. 28: Integrated studio – Students' work - Parameter investigation for better thermal comfort and daylight availability: Upgrading Building 2226 for Istanbul, Turkey, for future based on IPCC Scenario A2 for 2100.

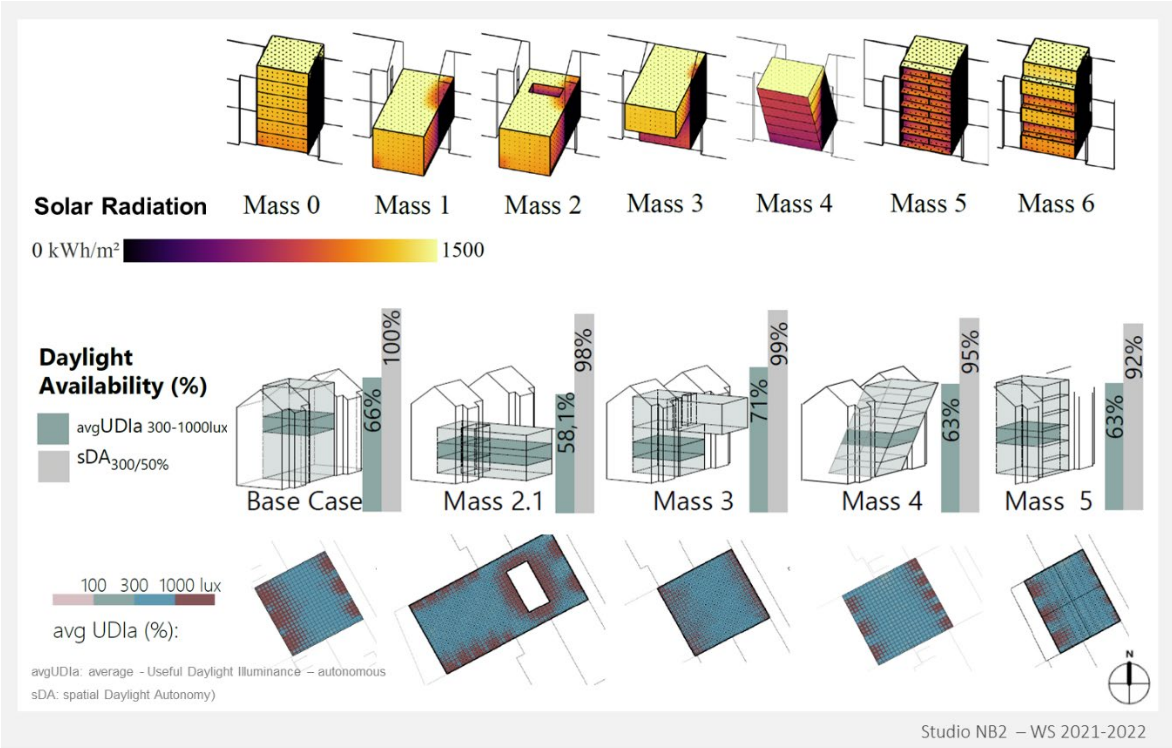



Figure 5. 29: Integrated studio – Students' work – Massing studies for maximum solar energy utilization by using solar radiation analysis and for maximum daylight availability by using avgUDIa and sDA metrics.

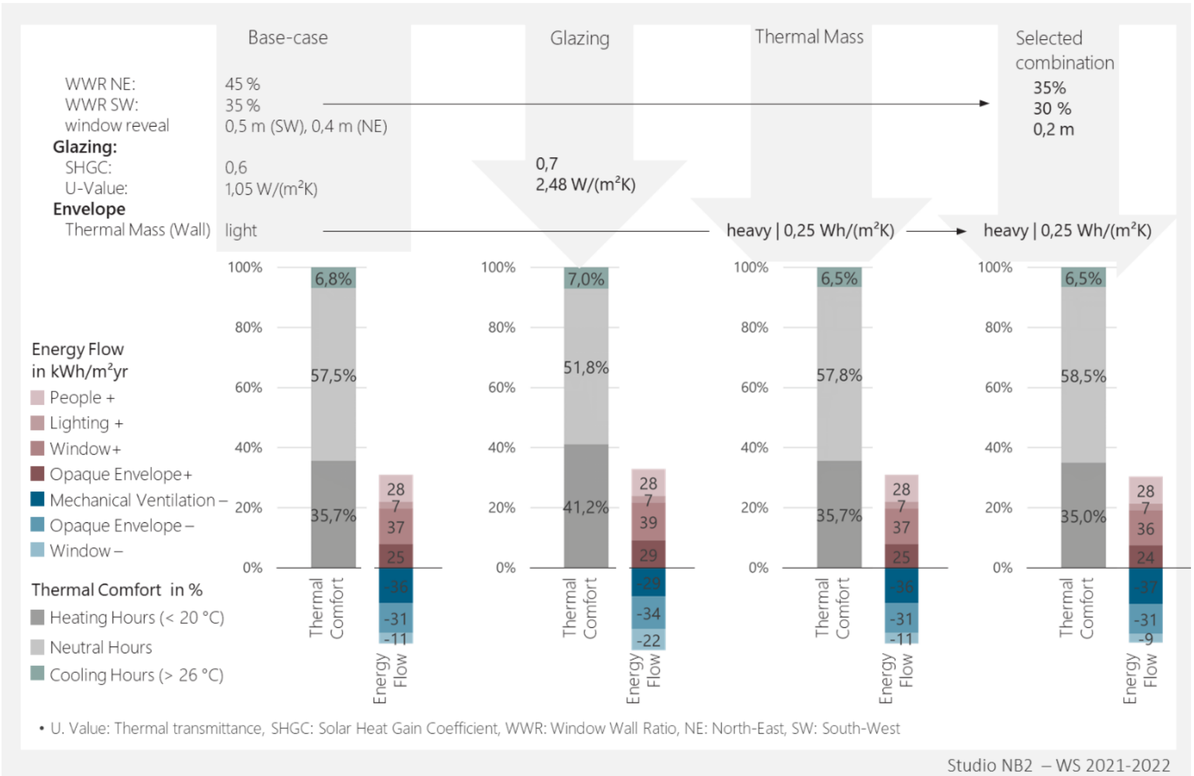



Figure 5. 30: Integrated studio – Students' work - Analyzing a selected volume from massing studies for thermal comfort by parameter investigation, as an example for OAT and nested-OAT method.

The phase 3 was about learning how to manage contradicting objectives of different performance goals for a final design proposal. Addition to parametrization, in this phase, the optimization method was adopted to make the investigation more attractive and less time consuming, as well as the investigation space larger. The optimizations in the phase 2 had been deliberately continued manually, so that the students became familiar with the basic parameters and optimization objectives and thus understood the optimization logic before using the automated optimization methods in the phase 3. Therefore, investigations in the phase 3 could be fully automated adopting parametric modeling, simulation and optimization. The three-week long phase 3 included 2 workshops. After an introduction lecture and a workshop on the optimization theory and tool, the students were assisted in creating their own optimization workflows linked to their parametric model and simulation workflows. As a starting point, they were requested to come up with specific challenges for their designs, in other words to define an optimization scenario including challenges, parameters and objectives for the investigated performance issues. To become familiar with the optimization tool, learn how to set up workflows and read the results, they started with single-objective optimization (SOO), which means finding the best-performing values of the investigated parameters for only one objective, for example, investigating the range of values for glazing ratio (e.g. between 20% - 100%) and structural shading depth (e.g. between 0.2 - 0.5 meters) for the objective of UDI.  Some of the students kept the approach of "one-parameters-at-a-time" to compare their manual investigations to tool-based (automated) investigation and to see if the key parameters had been correctly identified earlier. Multi-Objective Optimization (MOO) workflows were then carried out by incorporating other objectives, for example, better summer thermal comfort and higher energy production (through active solar systems). Achieving summer thermal comfort while providing a visually comfortable space, as was done in the semi-integrated studio, was a challenge deliberately given to the students. The didactive aim of the approach was to make the students aware of the conflicting objectives, one of which works best at high values of a parameter and the other at low values. For example, high glazing ratios favored the daylight availability but reduced summer thermal comfort due to high solar gains, therefore the glazing ratio had to be optimized to reach the objectives of daylight availability and summer thermal comfort.  This was intended to help them see the links between different performance objectives through parameters and to practice how to make decisions in such a conflicting situation; for example, to identify the performance of primary importance, but to stay within the boundaries for the performance of secondary importance. Example student works for defining the optimization objectives, i.e., increasing UDI and neutral hours while decreasing the ASE and cooling hours, and the parameters, i.e. glazing ratio, shading depth (i.e. overhangs and fins) and PV panel angle, are presented in Figure 5. 31.

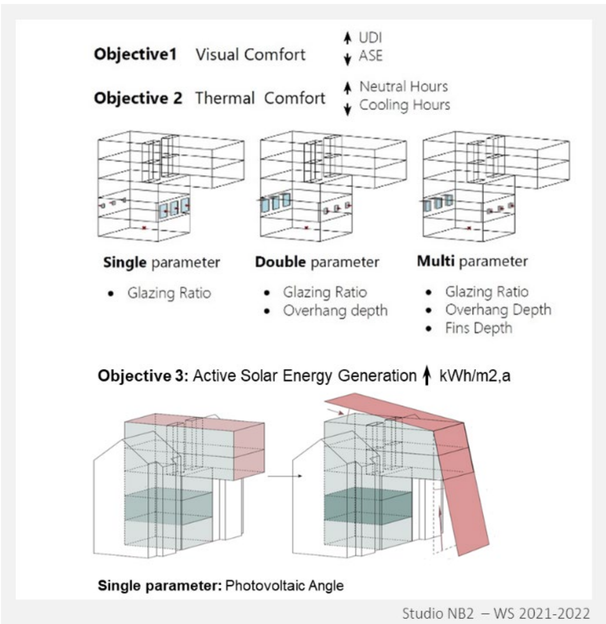



Figure 5. 31: Integrated studio – Students' work -Defining an optimization problem: objectives and parameters.

The students worked on a final design proposal that was expected to meet all performance goals studied. Figure 5. 32 shows an example final work of students, which was developed in the phase 3 through the fully automated process of parametrization and optimization.

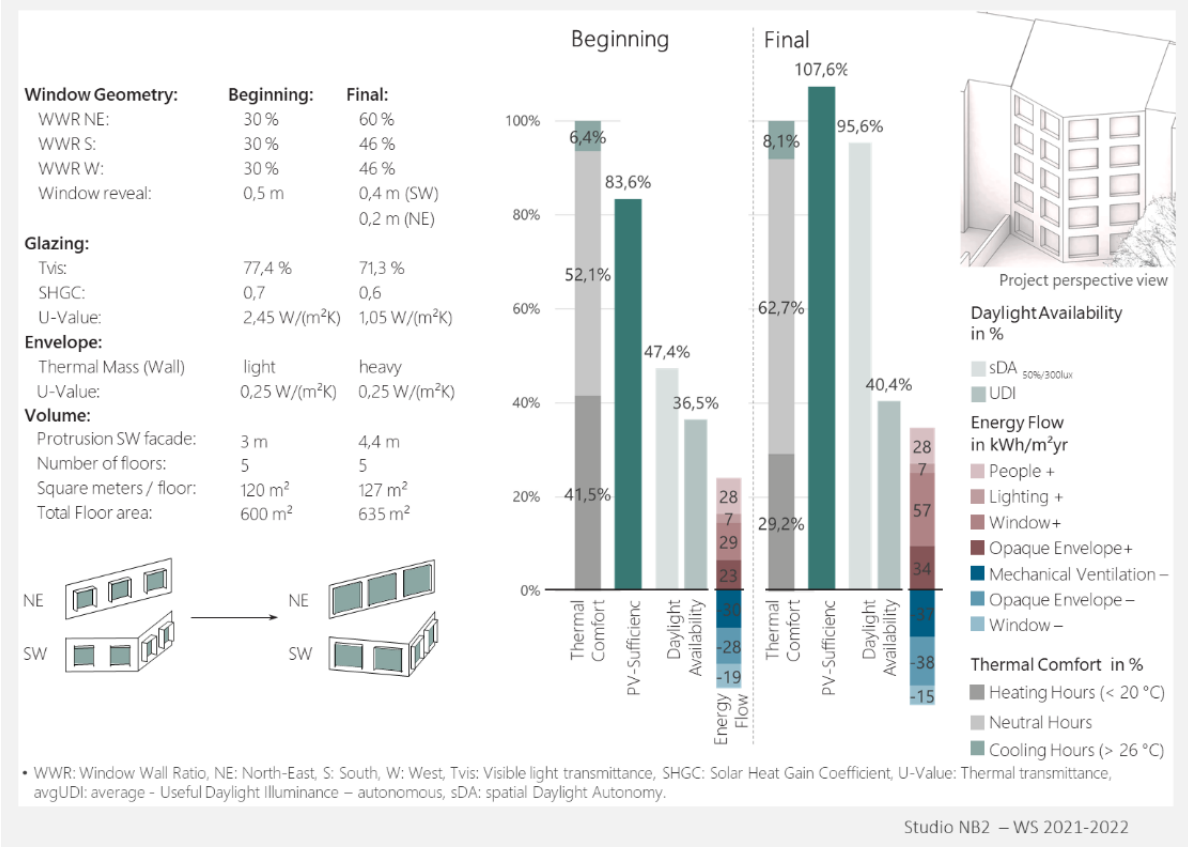



Figure 5. 32: Integrated studio – Students' work – Final proposal developed during the phase 3: Final proposal for Wuppertal, Germany - from the beginning of optimization to the final proposal.

As the final work of the studio, in addition to the final reports and colloquium presentations, the students summarized their works and presented them in a poster format. Each group prepared their works of exhibition, explaining their investigation and presenting their final design proposal, with a special focus on one of the main tasks of the studio, i.e., (1) solar energy (2) daylight availability and visual comfort, (3) thermal comfort and (4) building integrated photovoltaic system. The posters are included in Appendix CX.

## 5.3.5. Students' feedback

As was done for the semi-integrated studio, an anonymous online evaluation survey was conducted also for the integrated studio. The survey is included in Appendix CXI. Eight of the 10 students of the studio participated. Lectures, workshops, supervision and colloquiums are rated as the most useful activities with the average rate of 3,38 between 0 (not useful) and 4 (very useful). The average rating of all activities (3,23) showed that they were found to be useful. The rates between 0 (not useful) and 4 (very useful) are averaged for each activity and presented in comparison to the semi-integrated studio results in Figure 5. 33.

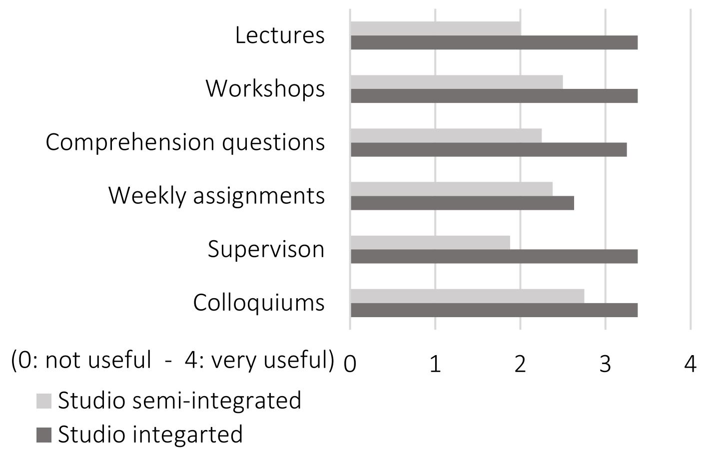



Figure 5. 33: Students' ratings for the activities the studios.

Half of the students rated for the phase 2, where manual investigations were conducted for optimum performance, as the most attractive phase, while the other half rated for the phase 3, which was fully automated. The most attractive task was the design and integration of PV system, which was fully automated process by the use of parametrization and optimization techniques. The task is rated by 6 students as a very attractive and by 2 students attractive. This is followed by thermal comfort, daylight availability, sunlight exposure and climate analyses, respectively. As in the semi-integrated studio, the thermal comfort topic was rated as the most difficult topic.

Almost all of the phrases quoted for the features of the BPS tool – Climate Studio were rated between neutral (2) and agreed (3). On the other hand, the average level of satisfaction was same as it was in the semi-integrated studio (2,7 out of 4). The ratings for the BPS tool are presented in comparison to the semi-integrated studio in Figure 5. 34.

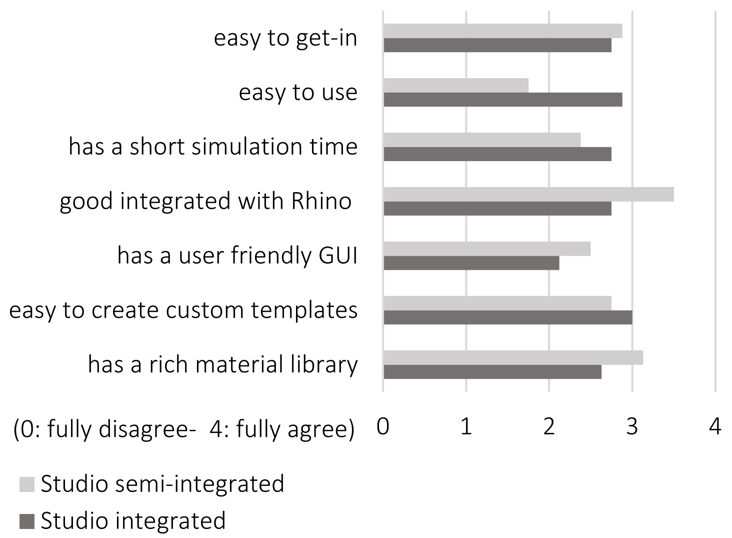



Figure 5. 34: Students' comments on BPS Tool of the studios.

An average level of improvement of the skills and the self-confidence for using BPS tools was stated to be very high (3,88), which was only higher than medium (2,5) in the semi-integrated studio. Figure 5. 35 shows how many students voted for which degree of improvement in the studios.

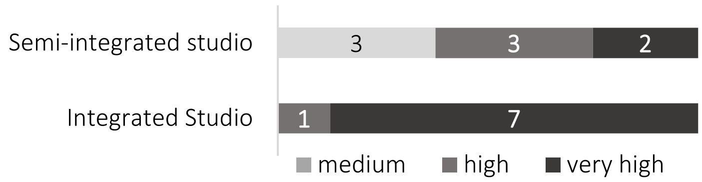



Figure 5. 35: Students' rating for the level of improvement of their skills at the studios.

To assess the impact of BPS on the design process in terms of raising confidence in making design decisions and supporting creativity, same phrases from the semi-integrated studio are shared with the integrated studio students, and they are requested to state how much they agree with them. The results are presented in comparison to the semi-integrated studio in Figure 5. 36.


Figure 5. 36: Students' comments on BPS impact of the studios.

Six students agreed on a quote that "The whole evaluation through the application of BPS, showed me something new, I got some results different than my presumptions, but not much different than my expectations.". Two selected a quote that "the whole investigation showed me a completely different picture than I expected. I got simulation results that were far from my presumption.".

A question for the integrated studio is asked to learn about how attractive were the methods of the design and BPS applied in the studio. The average rating for all methods was between attractive and very attractive (3,35). Figure 5. 37 shows the ratings for each method with the number of students for a level of attractiveness of a method.

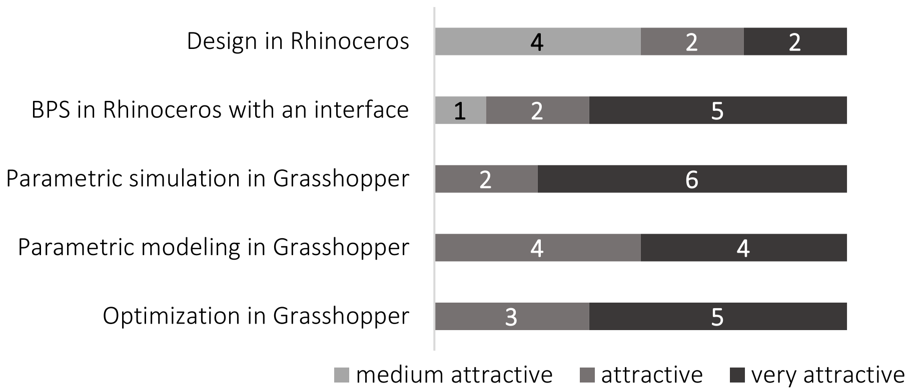



Figure 5. 37: Students' ratings for the attractiveness of the design and simulation methods applied in the integrated studio. Numbers on the bars refer to the number of students rated for a level.

Except for one student, who said he/she had no concrete plans for the future, all student in the integrated studio stated that they plan to use BPS in their future studies, i.e. in their master's thesis., which was only half of the students in the semi-integrated studio.

The average satisfaction of the student in the integrated studio and the possibility to recommend it to the prospective students was between high and very high (3,36) in a range of low (0) and very high (4). Figure 5. 38 shows the ratings for the level of satisfaction and recommendation.

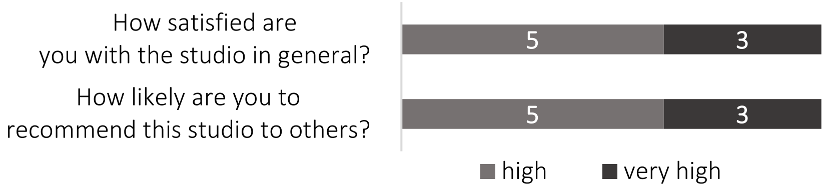



Figure 5. 38: Students' ratings for the level of satisfaction and recommendation of the integrated studio. Numbers on the bars refer to the number of students rated for a level.

The students' final comments and suggestions are presented in Figure 5. 39.

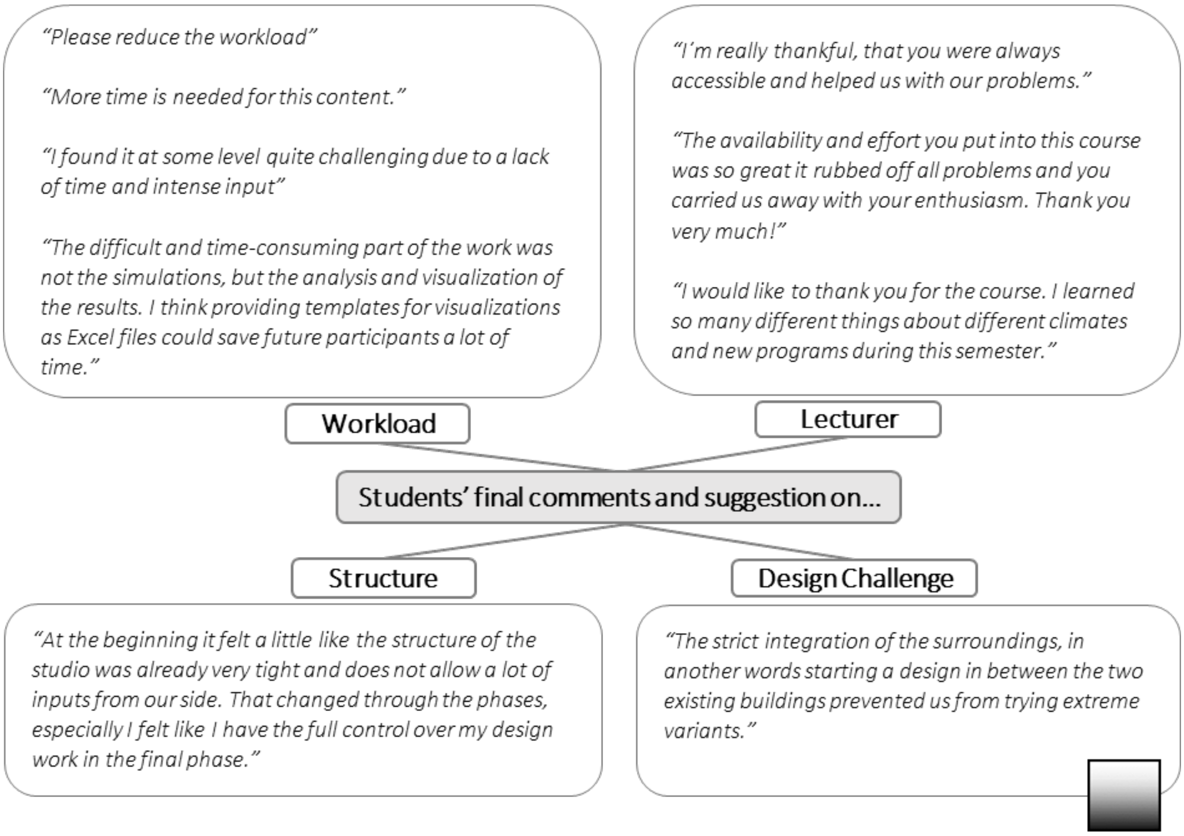



Figure 5. 39: Students' final comments and suggestions on the workload, structure, lecturer and the design challenge of the integrated studio.

## 5.4. Educators' Feedback on the Studios – Interviews

The studio prototypes (semi-integrated & integrated) were presented to the same group of educators mentioned in Chapter 3 as a part of the interviews. The presentation is included in Appendix CXII. Following the presentation, they were asked for their comments on the pros and cons of the prototypes and how they could be improved.

The comments (in Table 5. 4) and the suggestion (in Table 5. 5) of the interviewees on the studios are presented as it is noted during the interviews.

Table 5. 4: Interviewees' comments on the studios.

| Pros (+) and Cons (-)<br>stated by the Interviewees (A, B, C, D, E) | |
|---|---|
| Semi-integrated Studio | Integrated Studio |
| **(A+)** There was a time for architectural design, so more discussions on qualitative aspects of the design.<br>**(B+)** For the design aspects were already discussed in the previous module of the studio, there was enough time to learn the tool and to investigate the performance.<br>**(B+)** It is more applicable for the performance evaluation / renovation of an existing design.<br>**(B-)** Since the designs were already developed, there was not much room for design optimization. | **(A+)** Starting with case studies is a good method to teach the tool and refresh students' knowledge on performance topics and simulation.<br>**(A-)** The design phase is missing in the integrated studio: there is kind of direct jump to the performance topic. Other qualitative design aspects should be considered in early design.<br>**(B+)** The feedback loop between design and performance is strong. Therefore, the studio approach is good for new designs.<br>**(B-)** The design pillar is somewhat missing, i.e., other aspects such as economy, sociology etc.<br>**(C+)** Starting with daylight and radiation analysis is strong, because compared to energy analysis, these are better form givers.<br>**(C+)** The relationship between non-geometric (template) and geometric (form related) inputs is well defined.<br>**(D+)** Starting with very basic examples (i.e., case studies) is helpful for students in understanding performance tasks and related workflows<br>**(D+)** Gradually increasing level of challenge is good for better understanding.<br>**(D-)** Pre-structured works (i.e., parametric modeling and simulation workflows) guide students to certain directions. Perhaps students learn better when they do this by discussing and perhaps failing.<br>**(E-)** There needs to be more design-related questions, but apparently one semester is not enough to build a course that balances design and performance discussions. |
| Semi-integrated Studio and Integrated Studio | |
| **(A+/+)** In general studios have different structures that make them incomparable.<br>**(B-/+)** In the semi-integrated studio there is only one learning curve, which is design renovation. But in the integrated studio, there are several learning curves, i.e., design, performance, parametrization, optimization.<br>**(C+/+)** the methods and the approach for teaching building physics are strong in both studios.<br>**(C+/+)** Example models and workflows introduced to students at the beginning of the studios are useful.<br>**(C+/+)** Using tailored templates is strong, as they provide an easy start in early design considering uncertainties, and also allow for an initial focus on geometry-related inputs.<br>**(D+/+)** In the both studios, the methods are applicable and efficient.<br>**(E-/+)** Progress in the integrated studio is more controlled than in the semi-integrated studio, which might lead the students directly to the solution space at the intersection of design and performance. | |

Table 5. 5: Suggestions quoted from interviewees.

| | |
|---|---|
| A | *"Referring to the shared experiences, Studio Part 1 and Part 2 should be integrated. I would recommend bringing the design and performance topics together for two semesters within continuous feedback to balance the quantitative and qualitative aspects of design."* |
| B | *"Strong sides of the Studio A and B methods can be combined for the future steps."* |
| C | *"Knowledge of design and performance should be fed into design studio to be able to achieve performance-based design"* |
| D | *"Design studio seems to be useful method to integrate BPS into design education but needs two semester time."* |
| E | *"For early design integrated performance, it would be more efficient if the studio is applied through 2 semesters."* |

## 5.5. Discussion

This chapter aimed to find out how the integration of design and BPS can be enhanced with the help of design studio. The usefulness of the design studio as a method and its main features for a performance-based early design teaching are explored through studio prototyping, student surveys and educator interviews.

### 5.5.1. Observations during the tests of the studio prototypes

The observations made during the testing of the studio prototypes with students indicate that special attention should be paid to the following points when planning a design studio aimed at integrating BPS into the design process in architectural education:

- **Recognizing the student profile and understanding expectations**

No matter how detailed and well designed the studio is, it can fail, if the planned structure is not compatible with the students' expectations, backgrounds, skills and knowledge levels.

To avoid failure, **an anonymous studio entrance survey** after an introduction session can be useful to learn about students first impressions, expectations, levels of knowledge and skills, to identify possible incompatibilities and to adapt the course accordingly.

- **Promoting experiential learning**

**Direct interaction with tools and methods** of design and performance, e.g., modeling, simulating, testing, measuring, is important to ground and internalize the knowledge gained through theoretical lectures.

To provide an experiential learning environment, **the role of studio activities** (e.g. lectures, assignments, workshops, supervision, colloquia, etc.) in the learning experience (e.g., focusing, grounding, structuring, verifying, communicating, exploring knowledge) should be well defined, and the activities should be designed to feed into each other and support a continuous learning cycle. Firstly, **workshops**, and secondly, **assignments** and **colloquia** have a high potential for promoting experiential learning and tracking learning performance.

- **Balancing design and performance**

If performance and balance inquiries are not balanced, it means that full integration fails. In case of imbalance, design studio can result in either very high performance and low quality or aesthetically pleasing but low performance designs.

In order to achieve the balance, the following points should be considered: **(1) Providing sufficient time**: A one-semester studio session may not allow sufficient time to discuss performance and design issues, and even if achieved in one semester, the workload may have a negative impact on students' interest and motivation; **(2) Providing continuous guidance and interdisciplinary feedback:** In order to achieve the goals of a studio, it is important to communicate them clearly to students from the outset through a well-structured studio syllabus that defines content, activities, tools, objectives and includes a timeline. Intermediate guides can also be useful when needed during the studio, such as for colloquiums. An integrated studio requires continuous, high quality and interdisciplinary feedback and this requires collaboration between teaching chairs/institutions. To achieve balance, a balanced involvement of chairs teaching design and building performance in a continuous feedback process throughout the entire duration of the studio seems ideal; and **(3) Providing adequate level of design and performance challenge**: If the focus of a studio is more on one dimension, either design or performance, the less focused dimension may be missing in the final design and the integrated approach may not be fully realized. To avoid this, in addition to the feedback from different disciplines, a balance needs to be struck between the challenges presented to students. For example, even if the focus is on a performance-oriented renovation of an existing building, students may be given the opportunity to design an extension that meets the design challenges. This is also valuable in ensuring that the BPS is experienced not only as an assessment tool, but also as a tool for new design explorations.

- **Integrating BPS into design process as early as possible**

As the design stage progresses, the willingness of the designers (in the scope of the study, designers are referred to as students) to respond to BPS results may decrease – they may become too attached to their design due to the advanced stage reached in the design process. If no BPS feedback is received at the early stage, it becomes more burdensome to revise the design. BPS becomes merely a performance evaluation tool, and many design alternatives that could be explored at the intersection of design and performance with the stimulation of BPS in the early stages are missed. When planning the major functions, form, and program of a building, it is critical to include performance questions early on; for example, to achieve thermal and visual comfort with minimal or no mechanical installation and thus take an early step towards an energy-efficient design and/or to achieve good integration of renewable energy systems, especially PV/PVT systems, which have a major impact on aesthetics, comfort and energy performance. Furthermore, especially from an educational point of view, performance inquiries initiated at an early stage are valuable in that they provide students with a broader and more gradual experience.

In order to achieve the integration, the following points can be helpful: **(1) Utilization of BPS tools, with an architect friendly interface, suitable for early design use, integrated into a design tool**, which is to eliminate the error-prone and time-consuming process of data exchange between design and BPS tools, thus allowing simultaneous design and performance exploration; **(2) Gradual interaction with BPS** to introduce the basic workflow and refresh the students' knowledge, i.e., starting with a simple shoe-box model, or/and a case study. In addition, especially for early design integration, starting with geometry related inputs during form investigations and later extending the scope towards non-geometric inputs; **(3) Technical simplifications** for the design integrated BPS workflow, i.e., custom templates and pre-defined workflows to overcome some of the uncertainties about the inputs needed for BPS that are stemming from the nature of early design; **(4) Theoretical simplification**, noting that simplifications need to be approached more critically, especially in the advanced design stages, to introduce topics of BPS in the early design. For example, "Neutral hours" approach, "which is more of a simplified approach to give students an insight into thermal comfort without delving into the calculation of conditioning loads. The use of daylight availability metrics to investigate the form and dimensions of a space, radiation analyses as a form giver to a design while searching for maximum active solar energy utilization.

In a parenthesis at this point, it can be said that lighting, energy and thermal comfort are the main domains of the building performance teaching in architecture education. Some approaches and methods are more prominent than others because of their potential to be adopted during the creation of design alternatives. Considering early design phases and novices in design process, and being them architecture students, the methods relating architectural form and material with the domains of performance, without delving into the details of technical and mechanical elements and their design at least at the early steps of the design process, have a high potential.

In this regard, daylight analyses during the exploration of the cubature and layout of spaces (i.e., use of DF and sDA metrics); energy use analyses, focusing on efficiency only by alterations of form and material, excluding active heating and cooling systems; and energy balance analyses by comparison of energy use and possible energy production via integration of active solar energy system, understanding possible daily and/or seasonal mismatch between need and production depending on the climate and solar energy system chosen, are appropriate approaches to integrate performance topics into early design process in architectural education.

When it comes to **thermal comfort**, especially for performance investigation in early design, it is important to focus on the performance of a design, leaving the consideration of mechanical systems out of the picture to be investigated after the architectural project has achieved the best possible performance as a pure design product. At this point, based on the experiences gained through the studio teaching, the "neutral hours approach" stands out among many, as it can help to think about "comfort" in relation to "form and material" and inform the design process about how autonomous the project is as a design work, and what the possible dependency/need for active systems is.

Another example for simplifications is "**one-*value of a parameter*-at-a time",** which is useful not only for providing an easy start, but also for recognizing the effect of a single parameter; but noting that it is only applicable for a very early start with relatively small number of basic parameters; additionally, **investigating extremes** can have a positive impact on students' learning curve. Trying very opposite forms, e.g. comparing a form that expands extra-normally horizontally with another form that expands extra-normally vertically, or testing unusual values of thermos-physical parameters (e.g. thermal transmittance > 5W/m$^2$K, infiltration > 15 1/h), or also, testing the performance of a case in extremely contrasting climates, e.g. hot-arid and cold-humid, may help to better understand the effects of parameters in questions, i.e. geometric, non-geometric and climatic; and others can be categorized as **(5) pedagogical simplifications,** i.e. applying **"continuous learning circle",** which is important for tracking and connecting each learning step to achieve a concrete learning experience.

- Use of intelligent techniques

Parametrization and optimization methods have the potential to make the investigation more attractive and less time consuming, as well as to extend the investigation space. To achieve this, it is better to provide basic theoretical knowledge of the process of these techniques before using digital parameterization and optimization tools. This will allow students to internalize the process and use the tools more effectively. Using sample workflows when introducing digital tools to students and allowing them to experience these workflows through workshops are very important to fill possible gaps in the learning process. In addition, it is extremely important to provide students with continuous and intensive supervision, especially if they are experiencing these tools for the first time.

- Takin into account students’ experiences

Students' comments and evaluations, as those who directly experience the study, are an important resource for understanding how far the intended integration has been achieved and how far the learning objectives have been met, therefore for assessing which elements should be retained and which should be revised for improvement.

In addition, a student-centered approach, which can give students more space and thus can involve them in the process, and which emphasizes the importance of their role in terms of mutual learning and teaching, has the potential to encourage them to comment on their experiences.

### 5.5.2. Students’ feedback on the studio prototypes

The surveys conducted with students about the prototype studios aimed to evaluate the effectiveness of the studios through students' experiences and comments. The survey results of the semi-integrated studio are presented in Section 5.2.5, and the results of the integrated studio in comparison with the semi-integrated studio are presented in Section 5.3.5. To facilitate the evaluation of the results, the main differences between the prototypes are listed in Table 5. 6.

Table 5. 6: Main differences between the semi-integrated and integrated studio prototypes.

| | Semi-integrated Studio | Integrated Studio |
|---|---|---|
| Number of students | 13<br>(8 of 13 participated to the evaluation survey) | 10<br>(8 of 10 participated to the evaluation survey) |
| Face-to-face or online | online | face-to-face |
| Studio schedule | **Based on BPS topics**, i.e., daylight availability, thermal comfort, solar energy utilization. | Same topics were included in the content, but the studio schedule is **based on design and BPS methods,** i.e., case-studies, parametric modeling and simulation and optimization. |
| BPS integration | **In the design development phase** for the evaluation of the existing design of the students from previous module. | **In the early design phase** for the investigation of design alternatives. |
| Course activities | **Lectures, comprehension questions, assignments, workshops, supervision, colloquiums** | Same studio activities, but **less theoretical lectures and more workshops** |
| Design and BPS tools and methods | ▪ RhinoCeros (design)<br>▪ ClimateStudio for Rhino (BPS)<br>▪ EnerCalc (BPS) | Except the EnerCalc (BPS), the same tools were used, and additionally:<br>▪ **ClimateStudio for Grasshopper (parametric modeling and simulation - BPS)**<br>▪ **Opossum (Optimization)** |
| Interaction with BPS | Relatively a **steep start** considering all geometric and non-geometric inputs | **Gradual interaction** with BPS inputs starting only with the consideration of geometry related inputs |
| Final assignment | **A design upgrade** for an overall performance while remaining the aesthetic quality | **An early design proposal** considering both design and building performance elements |

Given the differences listed above, it is acknowledged that a direct one-to-one comparison is not possible due to too many variables. Nevertheless, it is important to consider the students' feedback on the prototypes together in order to understand how successful the development from semi-integrated to integrated was, how useful the methods and techniques used were, and thus to gain insight into how an integrated design studio should be structured.

The survey results support many of the points listed above that were observed during the studio prototyping and testing:

- Usefulness of studio activities

It was clearly seen that **workshops**, which allowed students to experience the methods and techniques related to practical sessions, and **colloquiums**, which allowed for the communication and evaluation of acquired knowledge, stood out for an integrated studio. The average rating for the overall usefulness of all studio activities in the integrated studio (3,23) was higher than the semi-integrated studio (2,29). The increased weight of the workshops in the integrated studio may have balanced the information input and internalization and application of information, thus making all activities more useful and attractive. On the other hand, this could be partially related to the moderate communication comfort of the online teaching in the semi-integrated studio compared to the face-to-face (in person) teaching in the integrated studio.

- Difficulty and attractiveness of BPS Topics

In the semi-integrated studio, **daylighting and visual comfort** tasks were rated as the most attractive, and **thermal comfort** as the most difficult. Similarly, in the integrated studio, thermal comfort was rated as the most difficult, but differently, it was also rated almost as attractive as the daylight and visual comfort.

The daylight simulation requires relatively less input and the representation of results is more integrated with the 3D model. Also, students can directly use their architecture models in order to run daylight simulations, but they need to create a new **abstracted version of an architectural model as an energy model to be able to run thermal comfort simulations**. Finally, it is well known that **interpreting the results of a thermal comfort simulation** requires more knowledge of building physics than **interpreting the results of a daylight simulation**.

It was therefore decided to devote more time to thermal comfort simulation by adding **special lectures on the abstraction of architectural models** in the integrated studio. Add the top of this, the **theoretical simplification**, the **gradual interaction with the BPS inputs**, the **adoption of intelligent techniques** could be counted for the increased attractiveness of the thermal comfort topic in the integrated studio. Above all, the **use of BPS at the very early stage of the designs** in the integrated study, as opposed to its use only for the evaluation of existing designs in the semi-integrated study, may have contributed to an easier understanding of even the difficult topics of BPS, which supports the argument for including BPS as early as possible in the process of integrated design teaching.

- Level of satisfaction with the BPS tool ClimateStudio

The students of the integrated studio, who were **introduced to CS with a gradual approach**, **using case-studies** and who **had more workshops** than the semi-integrated studio, found the CS **much easier to use**. This supports the effectiveness of the above-mentioned methods for introducing a new BPS tool to students.

On the other hand, the integrated studio students who were introduced to "CS for Grasshopper", which does not have a **separate GUI** in Grasshopper and has a more complex interface than "CS for Rhino", found the user interface of CS generally less user-friendly than the semi-integrated studio students who had only experienced "CS for Rhino".

- **Improvement of BPS skills**

The fact that the integrated studio **students' skills and self-confidence in using the BPS tools** at the end of the studio, compared to the semi-integrated studio, developed at a higher level, can be considered as another evidence that integrated studio methods were more effective in teaching BPS.

- **BPS impact**

The high level of agreement among students of both studios that ***BPS increases confidence in making design decisions*** supports the argument for the necessity of early integration of BPS into the design process. This is reinforced by the fact that the level of students' agreement, not only in terms of increasing confidence but also in terms of **supporting creativity**, was higher in the integrated studio where BPS was adopted at an early stage.

- **Attractiveness of parametric modeling and simulation and automated optimization**

The **optimization process** was found to be less difficult and more attractive in the integrated studio; this holds with the argument that the use of automated optimization techniques can make performance studies/evaluations **much more efficient and attractive, by reducing the workload and expanding the investigated solution space. The parametric BPS simulation** conducted with BPS tool - *CS for Grasshopper*, was found to be more attractive than the non-parametric BPS simulation conducted with *CS for Rhino*. This result can be interpreted as the speed and convenience provided by parametrized simulation workflows may be more important than the comfort provided by the user interface. Although *CS for Rhino* allows simulation results to be entered more easily with a specially designed user interface that opens in a separate window, it was possible to test many parameters at once with automated workflows using CS for Grasshopper, which does not have a dedicated interface, in other words, it was possible to run many simulations with a single simulation setup.

- **Embracing the integrated design and simulation approach and plan to use BPS in future**

The students' acceptance of the integrated design and simulation approach and the likelihood of applying it in future design workflows is almost twice as high in the integrated studio than in the semi integrated, which is another finding that demonstrates the success of the integrated studio.

- **Final comments of the students**

Final comments of the students were in line with the key points identified from the studio experience, such as;

  - Providing sufficient time to reduce the workload by extending the studio period to two semesters
  - Continuous and intensive guidance/supervision provided by competent and committed lecturers
  - Introducing and communicating the studio content to students in a well-structured and clear way that defines activities, tools, methods, objectives and includes a timetable.
  - Incorporating BPS into the design as early as possible

### 5.5.3. Educators' comments on the studio prototypes

The interviews aimed to collect feedback on the feasibility and effectiveness of the course prototypes structured in this thesis for performance integrated design teaching. The views of the educators show a clear consensus that a design studio is a significant method for integrating building performance teaching and design teaching in architectural education. The general impression of the educators was positive about the general framework of the prototype studios. Their views are closely aligned with the experiences gained during the implementation of the prototypes and the results of the surveys conducted with the studio students.

- **Early stage, but in a timely manner and without interruption**

The common opinion of the interviewees was that integration is needed early, but in a timely and uninterrupted manner; one semester is not enough to cover all the design and performance-related aspects of a focused performance-based design studio, but a studio divided into design and performance semesters can also lead to an interruption in the design process.

A **block** – **two-semester-long studio** – was claimed to be an appropriate structure for an efficient integration, **balancing all qualitative and quantitative aspects** of the design process in a **simultaneous feedback loop that remained continuous and** supported by the **collaborations of design and performance educators**.

The integrated studio was found to be effective in i**nitiating performance inquiries** and directing students **early** to a solution space at the intersection of design and performance. The use of **case studies** was found to be useful at the beginning of a course to teach a new tool and to refresh students' knowledge on related topics. The importance of the **templates** as well as the **example workflows** of design, simulation, parametrization, and optimization were highlighted for their ability to provide an easy start in early design against the uncertainties of the phase.

On the other hand, it was reminded that use of pre-defined templates and workflows should be critically and precisely approached for it might lead to an over-guided and /or too controlled design process. It is stated that this is prone to two risks, (1) less flexible design and performance investigation, and (2) less "learning by making mistakes", because learning over discussions and mistakes was claimed to be also an important way of learning. These concerns are understandable, but when the process is managed not as an unchanged reuse of sample workflows, but as a process that focuses on explaining the flows at the outset and then helping students acquire the knowledge and skills necessary to create their own workflows, and when critical thinking is incorporated into this process, both the sample workflows and the risks posed by simplifications can be eliminated. However, the necessity of templates and personalized workflows was confirmed, noting the need to pay close attention to where to apply them and where to leave them, following the students' learning curve carefully.

- **With balance, not only for performance, but also for design exploration**

The interviewees highly expressed that a **continuous feedback loop between design and performance** should be provided by professionals in respective fields to **balance the qualitative and quantitative aspects of a design process**.

The semi-integrated studio was found to be more successful in balancing design and performance processes, because it had a previous semester work (module 1) with more design-oriented investigations, and thus, focusing fully on performance evaluations in the second module was acceptable. In this regard, the integrated studio was seen to be too performance-oriented and missing some design questions, leading the discussion to the view that the studio time should be longer with a continuous and simultaneous feedback loop involving together the performance and design inquiries.

The seamless workflow between design and performance, and the use of parametric design, simulation and optimization techniques that contribute to the feedback loop between design and performance research for an early design, were stated to be strong in the integrated studio. In the semi-integrated studio, the existing designs which had been developed missing an early performance feedback, had been introduced to the performance requirements in the middle of design process, and asked to be revised to respond the BPS results. Therefore, the likely interruption in design process and the limitations for the optimization of existing design in the semi-integrated studio were recognized in this regard. It was a common idea that the integration of performance into a design process as early as possible is important to be a part of the process rather than a reason for a revision.

And the final remarks for the presented work were on the gradually increasing level in the integrated studio, i.e., starting with only geometry related BPS inputs, using performance indicators through the form finding / massing studies, in other words balancing the strong definition of the relationship between non-geometric (template) and geometric (form related) inputs. The potential of using radiation and daylight simulations for massing studies was highlighted and the method of starting with daylight and active solar energy utilization evaluations as better form givers compared to energy analyses (excluding active solar energy analyses) was supported.

- Within a design tool

Both studio prototypes were considered to be strong for providing a BPS experience within a design ecosystem, i.e., in a design tool that students are already familiar and using for design investigations, so the BPS can be simply incorporated to the process. This was mentioned as noteworthy for eliminating the complexity of file exchanges between design and performance tools, providing an interface for BPS within a design environment, enabling transitions from a zone scale to a building scale while remaining within the holistic picture of the design and without losing the site context, as well as integrated visualization and interpretation of BPS results.

## 5.6. A Framework for Performance Based Early Design Teaching

When evaluating the main findings of all the major research steps, including the literature review, surveys, interviews, platform and course prototyping, the main conclusion points to the fact that a more systematic approach is needed for the integration of performance assessments, especially BPS, in architectural design education. In response, this study outlines a framework that can guide the aimed integration. The framework is illustrated in Figure 5. 40.

This framework first defines a linear sequence of theoretical and practical knowledge of design and building performance to achieve the performance-based based early design learning & teaching in architectural education. Theoretical basic knowledge in design, building physics and environmental design, and computational skills for design, documentation and BPS need to be sequentially incorporated into the students' learning curriculum. If basic design knowledge is not established, it may be very difficult for students to understand environmental design and/or to integrate basic building physics knowledge into design. The thesis author's teaching experiences and the experiences of other educators obtained through the literature review, questionnaires and interviews suggest that 2 to 3 credits of courses, which can be interpreted as at least 60 to 80 hours of learning for each core knowledge area (i.e. design, building physics, BPS and computational design) are required to establish a foundation prior to teaching performance-based design.

All the research conducted in this thesis indicates that when this sequence is broken, for example, when computational techniques are used without basic design knowledge, or when building performance tools are used without basic building physics knowledge, the intended learning objectives may not be achieved and, moreover, students may feel demotivated to learn.

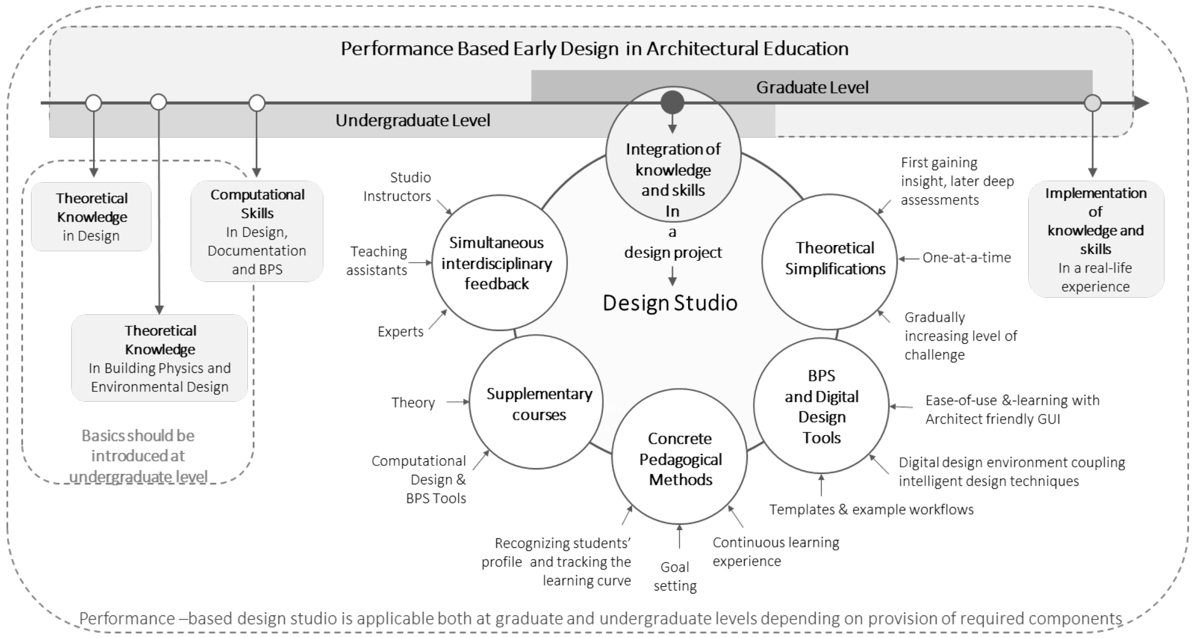



Figure 5. 40: Illustration of the proposed framework for performance based early design teaching in architectural education.

Second, the framework places the design studio at the very center of this sequence, recognizing the importance for students to internalize these foundational knowledge and skills in the context of a design project. The research conducted in this thesis has shown that a performance-based design studio works best at the graduate level, but it is possible to offer such a studio at the undergraduate level if the necessary knowledge and other related components, i.e. basic knowledge and skills in both technique and practice, are provided. However, one risk at the undergraduate level is that if the acquisition of all this basic knowledge and the design project are carried out at the same time, the enormous learning input is likely to overwhelm students due to the lack of time for them to digest this knowledge, process the input and transfer it to the design. At this point, as shown in the framework, supplementary courses are important components to reduce some of the learning load by shifting it to another course. However, it is important that the supplementary courses take place at the same time as the studio, otherwise there is a risk that the knowledge acquired in the previous semester becomes stale and additional hours are required to refresh the knowledge.

In the illustration of the framework, the interconnected circles on the design studio ring represent the 6 main components of the performance-based early design studio, which are **(1) design project** - as a base for the design studio; **(2) simultaneous interdisciplinary feedback** - from many sources as possible including studio tutors, but also additional teaching assistance especially if new tools and methods are introduced, as well as the experts from the practice to be able to maintain the links with real-word cases; **(3) supplementary courses** – to improve and reinforce the basic knowledge and skills, which requires collaboration for creating of learning modules in curricula; **(4) concrete pedagogical methods** – to define the learning goals, to recognize the students' profile and track their learning curve, as well as to provide a continuous learning experience through the well-structured studio activities balancing theory and active experimentation; **(5) BPS and digital design tools** – easy to learn and use, integrated, and introduced with the use of tailored templates and example workflows through case studies in advance of project start; and **(6) theoretical simplification** – providing a gradually increasing level of challenge, introducing parameters with a one-at-a-time approach, and moving to detailed evaluations with advanced methods after gaining insight in a subject area. The simplifications are important given that architectural design projects are a complex puzzle of system in which a large amount of information must be combined and interpreted together to arrive at design solutions, the study of parameters of these complex systems requires specific methods that are adequately simplified for each phase of a design process in order to prevent students from getting lost in the complexity of the work.

As expected in a design studio, while keeping design at the center of the work, it is crucial that educators with backgrounds in related fields conduct the design studio together so that the aesthetic performance of the design as an architectural product, as well as structural, environmental, comfort, energy, etc. performance considerations, can be incorporated into the design development process in a balanced way. To achieve this, collaborative modules between teaching/research chairs/institutions, with sufficient time, are a necessity rather than an option. The experience has shown that a one-semester studio module is unlikely to achieve this and that at least a two-semester long module is required.

The final point in the learning line refers to the application of the integrated knowledge and skills in a real-life project. This final experience is vital to revisit all the knowledge gained, to understand the limits of the methods used in the design process for function, form, program and performance scenarios in comparison with real case/data, as well as to experience the language of interdisciplinary communication that is so necessary in working life. Although this point is at the end of the line, it does not necessarily mean that it is not appropriate for a novice undergraduate student to experience it. On the contrary, it would be a rich learning environment for a novice, back to the SDE21/22 experience, it is clear that this inter-level and interdisciplinary environment was full of rich learning opportunities for students from all levels.

## 5.7. Conclusion

The work in the scope of this chapter investigated the integrative effectiveness of the design studio for introducing BPS into design process in architectural education. The results show that the studio has a high potential for the targeted integration. The main components of the integrated design studio are identified as: design project, simultaneous interdisciplinary feedback, supplementary courses, concrete pedagogical methods, BPS and digital design tools, theoretical simplifications.

In addition, by bringing together all of the findings of the thesis, it has been possible to picture the role of the design studio within the whole architectural education, considering both graduate and undergraduate levels, in terms of the introduction of BPS. Therefore, the study concluded by presenting a framework for performance-based early design teaching, with studio education at its very center.

Since the prototypes were implemented and tested with a small group of students and interviewees, the results cannot be generalized. However, the prototyping experience and the feedback received from both students and interviewees are of high value for providing extensive investigation in drawing a framework for integrated design and performance teaching and assessing the potentials and risks on the path to the integration.

The objectives were to understand if a design studio is a useful method for integrated BPS teaching and to identify the basic features of a performance based early design studio through rapid prototyping and testing, which were achieved.

# Chapter 6

## CONCLUSION AND FINAL REMARKS

The research, which aimed to outline a framework for design-integrated BPS teaching in architectural education, consists of 4 main steps (I - IV), with the chapters of the thesis organized accordingly: Chapter 2 – (Step I) State of the art BPS in practice and architectural education, Chapter 3 – (Step II) Investigation of the BPS in higher education with surveys and investigation of design-integrated BPS teaching with interviews, Chapter 4 – (Step III) Exploration of early design BPS platform for teaching through platform prototyping, and Chapter 5 – (Step IV) Exploration of performance-based early design course for teaching through course prototyping, surveys and interviews.

### 6.1 Overview

The overview section summarizes the main steps of the research and presents the key findings.

#### Chapter 2 - (Step I) The state of the art BPS in practice and architectural education

The literature review showed that BPS is still not inherit in the practice of architecture, especially considering the use of BPS tools in the design phase of an architectural project. The challenges are seen stemming from two aspects, firstly, due to the scarce of BPS tools that can respond to the needs of architectural design process, especially in early design, secondly, the lack or low level of knowledge and skills of architects to apply BPS in their design workflows. It is a common opinion in the literature that for a higher adaptation of BPS in architectural practice it should be a native part of the design process, for which the following features of BPS tools are mentioned as the most critical: adequately simplified according to the design phase, interoperable and/or integrated with other tools of digital design and BPS, enabling multiple performance analyses, providing rich visual representation through the process and for the results, coupling with intelligent techniques, and accessible considering the performance price balance. Another critical point is shown as the gap between the knowledge and skills of graduates in BPS and the expectations of the AEC industry. The main prospect was the transformation of architectural education towards more interdisciplinary and integrated approaches, so that future practitioners of the architecture can gain the basic knowledge and skills of BPS during their education.

On the other hand, the investigation of how BPS are taught and used in architectural education has shown that the BPS education is mostly not provided at all, and when provided, it is often not integrated with design education. In addition to the challenges related to the tools mentioned above, the lack of effective implementation of pedagogical methods such as interdisciplinary teaching, design-build, experiential learning, evidence-based, comparing simulated data with measured data and project-based teaching methods for teaching BPS in architectural education has been identified as the main challenge. The architectural design studio emerged at the center with its potential to bring together all these methods and the use of BPS in the context of design. However, as the literature review as well as the investigation of the examples of design studios around the world showed that the integration of BPS into the design studio is rare, not easy, and thus requires more attention.

Overall, the state of the art points to the fact that a rather systematic approach is needed for the integration of performance assessments, especially BPS, in architectural design education.

#### Chapter 3 - (Step II) Investigation of BPS in higher education through surveys and interviews

The **"BPS in Teaching"** survey showed that the BPS in higher education in Germany has been mainly taught in an interdisciplinary environment in terms of both students' and lecturers' backgrounds, yet mainly at graduate level, through elective courses, separate from design education, as case-study driven rather than design-driven, in building scale and related to its sub-element with less consideration of site context, and by using BPS tools that are mostly not integrated or compatible with digital design environment. Future prospects for more design-integrated BPS education were identified as early introduction of BPS to students, early integration of BPS during design studies, and the use of BPS tools that are easy to use, easy to learn, integrated with CAD-based design tools, and coupled with intelligent design techniques that can provide guidance for early design explorations by comparing design alternatives.

The “BPS in SDE21/22” survey and review aimed to understand the integrative effectiveness of the pedagogical methods applied in the SDE 21/22 competition in relation to design and performance. The review showed that the "design, build, operate" is a powerful method to integrate BPS into the whole process of an architectural project. The early introduction of BPS into design projects, using a rich set of BPS tools but with a sufficient level of detail for the design phase in question, and the application of BPS through multi-domain assessments (i.e. climate, energy, comfort, passive and active solar, LCA, etc.) were observed to result in high performance projects that meet expectations not only in terms of energy, comfort and low environmental impact, but also in terms of architectural aesthetics. Further, it is revealed that flexible curricula, the use of all possible teaching platforms from face-to-face teaching to online teaching, and the adoption of pedagogical methods such as "learning by doing", "challenge-based learning" and "experiential learning" were important components of integrated BPS teaching. The survey results indicated that the CAD-based digital design environment has a high potential for the further development of digital platforms that incorporate design and BPS tools, and thus integrating performance analysis into the design process. Again, “ease of use” was identified as the most important feature of a BPS tool to be used in early design, which was followed by the “comparison of design alternatives”, “integration with a design tool”, “availability of intelligent design/simulation methods” and “suitability for both early and advanced design stages”.

The findings of the "BPS in SDE21/22" and "BPS in Teaching" surveys overlap in the sense that they both emphasize the importance of teaching BPS in design education - when training the future AEC actors, in an integrated manner, in a multidisciplinary way, considering both theoretical and tool-related simplifications, and therefore highlight the importance of integrated approaches for the creation of a higher performing built environment.

To further investigate the challenges and possible solutions for the design-integrated use of BPS in architectural education, the interviews with educators with a high level of experience in teaching building performance topics to architecture students using BPS tools were conducted.

Low level or lack of awareness for environmental issues, reluctance of students/educators to respond to BPS results, the level of competence of educators in building science, challenges in interdisciplinary teaching, different levels of students' building physics knowledge and BPS skills, students' struggle to understand BPS results, balancing design and performance content were identified as the main difficulties at student and instructor level in integrating BPS into the design process. At the tool level, the capabilities of tools that can help to overcome the uncertainties of early stage design with templates, to exchange data with other design and BPS tools and to be easy to use and learn were referred.

For better integration, compulsory BPS teaching at undergraduate level; flexible curricula that would allow for intra- and extra-university collaborations and thus enriching teaching in terms of interdisciplinarity and addressing issues related to teaching time constraints by distributing the teaching content and load among the collaborating courses; well-balanced course content in terms of design and performance; use of BPS tools supporting early design; and supervision that is intensive to assist students especially in interpreting BPS results and applying them to the design process, and that is interdisciplinary to balance design and performance discussions were mentioned as key points.

Chapter 4 - (Step III) Exploration of early design BPS platforms for teaching through platform prototyping

Following the results of the previous steps, i.e. literature review, survey and interviews, which revealed the importance of the availability of BPS in design environments, to explore the extent to which the adoption of simplified BPS in a design tool supports the integration of BPS in design teaching, the platforms coupling design and BPS tools are prototyped via visual scripting.

On the basis of the results of the previous steps, which highlighted the potential of the CAD-based digital environment for integration, as well as the capabilities of GH's VPL as a plug-in to Rhino, allowing the combination of various design, BPS and intelligent engineering tools, Rhino is chosen as the basis for the platform prototypes. Special attention was given to integration with a 3D CAD design tool, an architect friendly visually rich GUI, inclusion of basic building performance domains, and multi-scale analyses from zone to site, visual post-processing capabilities of the platforms, and most importantly, ease of use.

The first prototype, "EnergyPlus UI for Rhino", is a single-zone energy simulation platform that facilitates climate, energy and thermal comfort analyses, integrated into a 3D architectural design model, flexible at zone and site scales, and maintains the link between the overall picture of design and performance. The second prototype, “Radiance UI for Rhino”, provides daylighting, radiation and shadow analyses, with the same integration and visualization principles as “EnergyPlus UI for Rhino”. The prototypes were made available for students to use and test in an elective course in the architecture master's program to observe the students' experience.

The students' interaction with the prototypes was positive given to the predefined workflows, user interface guidance, and integration with a design tool they were already using. These prototypes were carefully designed to reduce the workload of defining technical and mechanical details during the performance simulations required in the early design phase, allowing the students to focus more on the relationship between the form and performance of a design. The students were also attracted by the ease with which architectural models already in the 3D modeling tool could be defined as simulation models, and the ease with which the geometric form of these models could be modified through the prototypes' interfaces.

On the other hand, the simulation run time was unfavorable due to the employment of a high number of tools in tandem. The required abstraction of an architectural model to create a simulation model to run energy simulation with “EnergyPlus UI for Rhino” was the main challenge for the students, so “Radiance UI for Rhino” was more attractive to the students because they could easily use their architectural models as a radiation and/or daylighting simulation model with few adjustments. Since the prototypes were designed using Radiance and EnergyPlus, which are validated simulation engines, there were no issues regarding the validity of the simulation results generated by the platform. Apart from that, implausible simulation results occurred due to user errors.

Overall, the platforms made BPS easier and more attractive to the students, who experienced it, with its integrated structure into the design tool, architect-friendly GUI, real-time interaction between design and BPS workflow, and raised the learning curve of the students at the intersection of design and BPS.

Chapter 5 - (Step IV) Exploration of performance-based early design course for teaching through course prototyping, surveys and interviews

The introduction of simplified and multi-domain BPS tools in a digital 3D design environment was an important step towards incorporating BPS into the design process, but as identified already in the first steps of the study, this requires a combination of a wide range of technical and pedagogical components, for which the architectural design studio can provide a ground. In response, studio prototypes were designed and tested in an elective course in architecture master's program, through observations during the use of these prototypes in the teaching, with the student surveys and educator interviews. The overall findings indicated that the integrative effectiveness of the design studio is significant.

The key points about the use of BPS in the early design process in the context of a design studio are as follows:

(1) When investigating the form, dimensions, orientation, and relationship of a design to its surroundings in early design phase, promoting the use of form and material related features of a design as input to BPS can support integration and enable BPS to be used not only as an evaluation method but also as an organic part of the design process, contributing to decision making and supporting creativity;

(2) The use of templates can help to focus on geometric inputs in early BPS applications, noting that students need to consider these inputs in later stages. It can support the inputs required for the optical and thermo-physical properties of the building, as well as occupancy, ventilation and air conditioning models that are not yet fully defined at early stage. This facilitates the incorporation of BPS into early design workflows;

(3) The use of simplified performance indicators and techniques for incorporating BPS into early design phase can be useful. Gradual transitions from simplified performance indicators to more advanced indicators are likely to have a positive impact on students' learning curve of BPS;

(4) The use of BPS tools that are suitable for early design use, have an architect-friendly interface, and allow for the integrated management of simulation inputs and results with the design model is of great importance for the targeted integration;

(5) Moreover, BPS tools that allow for automated investigations integrated with parametrization and optimization tools, increasing the speed and efficiency of the process, might be preferable even if they do not have a very well-designed interface, depending on the level of knowledge and the skills of the students about these parametrization and optimization tools and techniques.

At the end of the chapter, the results of all the research conducted within the scope of the thesis were evaluated together and concluded by outlining a framework for performance-based early design teaching in architectural education. The framework emphasizes the establishment of basic theoretical knowledge for design, building physics and environmental design, and computational skills in design, documentation and BPS in curricula prior to a performance-based design studio; design project-based learning; simultaneous interdisciplinary feedback; supplemental courses to improve and reinforce basic knowledge and skills as needed; intra- and extra-curricular collaborations; well-designed pedagogical methods; balance between theory and active experimentation; theoretical simplifications; and the use of BPS tools integrated and/or interconnected with digital design tools.

## 6.2 Limitations

In this section, the limitations of the methods used in this thesis are explained and some recommendations are made for the consideration and use of the data obtained by the methods and overall results of the thesis work.

Literature review: As the literature review is a snapshot in time, some of the assumptions made in this study, based on the existing literature, may lose their validity as new research becomes available. Therefore, the literature review should be considered as dated and should be carefully checked for updates in future research.

The review of design studio experiences in the literature was conducted based on what the researchers who shared these experiences reported in their research papers, so the results of this review should be evaluated with the understanding that there may be missing or incomplete information that was not shared by the original authors of the experiences.

Surveys: The surveys in the thesis were conducted online. Since the participants were alone when answering the questions, specific explanations about the general purpose and structure of the survey, and in some questions even about the content of the question, were included, and contact information was provided for possible questions from the participants, in order to avoid the risk of misunderstanding or misinterpretation of the questions by the participants and misleading the data. Cross-questions were used in the surveys to verify the accuracy of the main responses and to minimize the margin of error. Nevertheless, due to the nature of the survey, the limitation of one hundred percent accuracy of the survey data must be considered.

The BPS in Teaching survey did not have a large population (18 participants), but considering the population of experts teaching building physics and using BPS tools in the faculties of architecture and engineering at higher education institutions in Germany, the sample size was significant, about 2/3 of the members active in the relevant field. It was achieved to reach the most relevant sample group of academics active in teaching BPS. However, the sample sizes of the subgroups (i.e. the number of courses and/or BPS tools) are still not larger, which limits the generalization of the survey results.

The BPS in SDE21/22 survey was conducted with the participation of the competition teams. Each team was asked to answer the questions as a group of students who were mainly responsible for the BPS work in the competition. However, the person who conducted the survey, the author of the thesis, did not have full control over the teams to convince all teams to answer the survey questions as a group. Through personal contacts, the author found that more than half of the teams answered the questionnaire as a group, but on the other hand, some teams were known to have only one person from the team contributing to the questionnaire. This makes it difficult to draw general conclusions about the teams when evaluating the survey results.

Interviews: The results of the interviews with educators cannot be extrapolated to a larger scale due to the small group of respondents and the small number of courses. On the other hand, the experiences of these professionals were valuable in providing a deeper look at current and possible future models of BPS teaching.

Prototypes: As described by [226], *“a prototype is a working model built to develop and test design ideas.”.* Therefore, the prototypes of the BPS platforms and the design studio courses should not be considered as a final, but as a working model to be further developed. Although high-fidelity prototyping, which refers to prototypes that enable user experience by bringing the user as close as possible to a real interaction with a built mock-up, the test and evaluation of the prototypes was limited to the thesis author's observations and feedback from students who interacted with the prototypes.

In addition, materials, which refers to all hardware, software, and methods used to create the prototypes, are based on the choices of the thesis author, although these choices are based on the research evidence, the results obtained with the prototypes should be approached with caution, always keeping in mind the materials used.

Regarding platform prototyping, for future development of a digital platform that couples BPS and design tools, it is recommended to script a solution in Grasshopper to automatically detect non-convex surfaces and split them into convex sub-surfaces. It is also possible to provide notification of possible modeling errors, e.g. marking unclosed surfaces on 3D model with false color images. To overcome the unfavorable runtime, the prototypes can be programmed as original Rhino plugins instead of using a group of plugins via visual scripting in Grasshopper. However, the goal of this thesis was to see the advantages and disadvantages of rapid prototyping, which is achieved.

Regarding the studio prototyping, it should be mentioned that the studio prototypes were realized in a short period of time, without much opportunity for collaboration between teaching chairs at the university, and with limited feedback, especially on the design. In order to make the studio prototypes more effective, it is advisable to implement them over a relatively longer period of time in a more simultaneous and interdisciplinary feedback loop, paying attention to the balance between design and performance inquiries.

In addition, the possible impact on the overall results of the difficulties that students might have experienced due to the online teaching and learning during the test of the platform prototypes because of the COVID-19 pandemic and the native German speakers who participated in the prototype courses in English should be considered in the evaluation of the works.

## 6.3. Contribution

The literature review, which presents the state of the art of BPS use in the architectural field, provides an important perspective for future research by revealing gaps in the research field for all interested parties: BPS tools in optimization, environmental urban modeling, commissioning, digital twins, machine learning, etc. In particular, in the context of architectural education, the topics of architectural education curricula, teaching and learning collaborations, and dissemination of teaching and learning materials are the topics to be discovered.

The literature review on the use of BPS tools in architectural education reveals a large body of research, but few studies have systematically evaluated the topic. On the other hand, the systematic studies either addressed BPS teaching in a course that was not part of the design studio, or did not address BPS in studies that systematically examined the design studio. In this context, this study is significant for addressing BPS in the context of the design studio.

In addition, the study differs from other studies in that it deals with the design studio as a whole and examines the design process as a part of the entire educational process. The framework for performance based early design teaching in architectural education, which is presented as a concluding work of the research can inform and guide the educators in architectural education for similar and future initiatives for integrated design education.

In particular, the shared experiences of the platform prototypes can be a resource and stimulus for software developers or parties interested in developing BPS tools, especially targeting the early design phase and educational use; this is an important gap in the field and crucial for the wider adoption of BPS tools in both architectural practice and education.

Furthermore, the prototype design studios, where detailed experiences at the intersection of design and BPS education are shared, provide a resource for educators in related fields in their future work for the integration of BPS into design education, as the methods shared in these courses are presented with detailed explanations of their potentials and risks. The research is also significant for all design-led pedagogical approaches. It provides transferable recommendations to design educators who can promote the systematic and successful application of environmental and building performance considerations in contemporary architectural education.

Moreover, the presented research, with concrete recommendations and future perspectives, can be used as a reference point to understand the importance of the integrated adoption of BPS in the educational context and apply it more efficiently, not only for educators, but also for all parties responsible for supporting the promotion of education and for all decision makers shaping the future of architectural education.

Overall, the ultimate goal of the research is to demonstrate the importance of an interdisciplinary and multilayered architectural education in order to contribute to empowering today's students, as future actors, to better face the multidimensional and highly interactive challenges in the field of AEC.

## 6.4. Outlook

A survey among architecture students with a larger international sample size to learn more about students' experiences and expectations of BPS could be a valuable contribution to the field to further develop the pedagogical framework for integrating BPS into architecture education.

One of the key outcomes of the platform prototyping was the need for methods for simplified energy and comfort analyses in platforms that bring together design and performance models and enable integrated design investigations. The prototypes presented in this research used EnergyPlus as the simulation engine. A significant amount of time was invested in the preparation of custom templates to reduce student interaction with inputs such as mechanical system selection and the definition of loads and limits for a conditioned scenario, in order to open a space for more architectural geometry and material-related inputs that can help understand the relationship between architectural design and performance. In addition, the technical systems and conditioning models provided in EnergyPlus mostly reflect conditions that are compliant and/or appropriate in U.S. standards. Therefore, in order to avoid going into the details of an HVAC system and to provide options in European standards, much simpler methods such as "resistance and capacitance" models can be used to give students an insight into the concept of performance and to understand the impact of design and performance decisions on each other through quick analysis of alternatives and comparisons during the design process.

During the studio prototyping, it was a time- and resource-intensive process to research exemplary projects/studios, decide on methods and tools, and find examples of how BPS can be integrated into design education. From this point of view, it is clear that a platform that would bring together examples of BPS use cases in design education and provide example works and materials for relevant courses would be a valuable resource to promote targeted integration. For example, an online platform that is international and open to all students and educators who wish to participate. Furthermore, international cooperation between universities to create a free online teaching and learning platform for BPS, accessible to all students interested in the subject, would be a great opportunity to improve BPS knowledge and skills worldwide. To the author's knowledge, a similar initiative has been launched by IBPSA, but it is still in progress.

# References

1 European Council. Climate-Neutral EU by 2050. https://www.consilium.europa.eu/en/policies/climate-change/#:~:text=Under%20the%20European%20climate%20law,EU%20climate%20neutral%20by%202050 [latest visit 12.11.2023]

2 Citherlet, S. (2001) Towards the Holistic Assessment of Building Performance Based on an Integrated Simulation Approach. Swiss Federal Institute of Technology (EPFL), Lausanne.

3 Hensen, J. (2023) Building Performance S(t)imulation, Valedictory Lecture.

4 De Wilde, P. (2023) Building Performance Simulation in the Brave New World of Artificial Intelligence and Digital Twins: A Systematic Review. *Energy and Buildings*, 292, 113171. https://doi.org/https://doi.org/10.1016/j.enbuild.2023.113171.

5 Lechner, N. and Andrasik, P. (2021) Heating, Cooling, Lighting Sustainable Design Strategies Towards Net Zero Architecture. 5th ed., John Wiley & Sons.

6 Konis, K. and Selkowitz, S. (2017) A Performance-Based Design and Delivery Process. In: Konis, K. and Selkowitz, S., Eds., Effective Daylighting with High-Performance Facades: Emerging Design Practices, Springer International Publishing, Cham, 157–198. https://doi.org/10.1007/978-3-319-39463-3_4.

7 Cody, B. (2005) Form Follows Energy. GAM.02 – Design Science in Architecture. In: Schomburg, H., Ed., Springer Publishing, Vienna / New York. https://www.mvd.org/en/prj/gam-02/.

8 Li, S., Liu, L. and Peng, C. (2020) A Review of Performance-Oriented Architectural Design and Optimization in the Context of Sustainability: Dividends and Challenges. *Sustainability*, 12. https://doi.org/10.3390/su12041427.

9 Lin, S.-H.E. and Gerber, D.J. (2014) Designing-in Performance: A Framework for Evolutionary Energy Performance Feedback in Early Stage Design. *Automation in Construction*, 38, 59–73. https://doi.org/https://doi.org/10.1016/j.autcon.2013.10.007.

10 Kanters, J. and Horvat, M. (2012) The Design Process Known as IDP: A Discussion. *Energy Procedia*, 30, 1153–1162. https://doi.org/https://doi.org/10.1016/j.egypro.2012.11.128.

11 Lechner, N. (2015) Heating, Cooling, Lighting: Sustainable Design Methods for Architects. 4th ed., John Wiley & Sons, New Jersey.

12 Tereci, A., Kesten Erhart, D., Tahira, S., Ozkan, E. and Eicker, U. (2010) EE2E043 The Impact of the Urban Form on Building Energy Demand.

13 Naboni, E. (2013) Environmental Simulation Tools in Architectural Practice. The Impact on Processes, Methods and Design. https://doi.org/10.13140/2.1.3021.3440.

14 Ulukavak Harputlugil, G. and Bedir, M. (2008) Exploring Design Support Possibilities of Building Performance Simulation Tools in Building Design Process.

15 Soebarto, V., Hopfe, C., Crawley, D. and Rawal, R. (2015) Capturing the Views of Architects About Building Performance Simulation to Be Used During Design Processes. Building Simulation 2015: 14th Conference of IBPSA, 1480–1487. https://doi.org/10.26868/25222708.2015.2790.

16 Fernandez-Antolin, M.-M., del-Río, J.-M., del Ama Gonzalo, F. and Gonzalez-Lezcano, R.-A. (2020) The Relationship between the Use of Building Performance Simulation Tools by Recent Graduate Architects and the Deficiencies in Architectural Education. *Energies*, 13. https://doi.org/10.3390/en13051134.

17 Ulukavak Harputlugil, G., Hopfe, C., Struck, C. and Hensen, J. (2006) Relation between Design Requirements and Building Performance Simulation. Proceedings of the 1st International CIB Endorsed METU Postgraduate Conference: Built Environment and Information Technologies, March, 16–18.

18 Hopfe, C., Struck, C., Ulukavak Harputlugil, G., Hensen, J. and Wilde, P. (2005) Exploration of the Use of Building Performance Simulation for Conceptual Design. *IBPSA-NVL Conference*, 20, 1–16.

19 Attia, S., Hensen, J.L.M., Beltrán, L. and De Herde, A. (2012) Selection Criteria for Building Performance Simulation Tools: Contrasting Architects' and Engineers' Needs. *Journal of Building Performance Simulation*, Taylor & Francis, 5, 155–169. https://doi.org/10.1080/19401493.2010.549573.

20 Kalay, Y. and Jeong, Y. (2003) A Collaborative Design Simulation Game. *International Journal of Architectural Computing*, 1, 423–434. https://doi.org/10.1260/147807703773633446.

21 Augenbroe, G. (1992) Integrated Building Performance Evaluation in The Early Design Stages. *Building and Environment*, Pergamon, 27, 149–161. https://doi.org/10.1016/0360-1323(92)90019-L.

22 Mahmoud, R., Kamara, J.M. and Burford, N. (2020) Opportunities and Limitations of Building Energy Performance Simulation Tools in the Early Stages of Building Design in the UK. *Sustainability*, 12, 9702. https://doi.org/10.3390/su12229702.

23 Hensen, J. (2004) Towards More Effective Use of Building Performance Simulation in Design. *Van Leeuwen, J.P. and H.J.P. Timmermans (eds.) Developments in Design & Decision Support Systems in Architecture and Urban Planning, Eindhoven: Eindhoven University of Technology, ISBN 90-6814-155-4, p. 291-306*.

24 Alsaadani, S. and Bleil de Souza, C. (2019) Teaching BPS to Architects: A Closer Look at the Building Performance Simulation 'Consumer' and 'Performer' Training Paradigms. *IOP Conference Series: Earth and Environmental Science*, 397, 012004. https://doi.org/10.1088/1755-1315/397/1/012004.

25 Kalpkirmaz Rizaoglu, I. (2020) Internal Report on the Results of the "Building Performance Simulation in Teaching" Survey. Wuppertal.

26 Kalpkirmaz Rizaoglu, I. and Voss, K. (2020) Building Performance Simulation to Stimulate Architectural Early Design: Integrating Design and Simulation. In: Rodríguez-Álvarez, J. and Gonçalves, J.C., Eds., 35th PLEA Conference on Passive and Low Energy Architecture, A Coruña, 1525–1530. https://doi.org/https://doi.org/10.17979/spudc.9788497497947.

27 Kalpkirmaz Rizaoglu, I. and Voss, K. (2022) Building Performance Simulation in Design Education: Design-Integrated versus Additive. *Proceedings of BauSim 2022: 9th Conference of IBPSA-Germany and Austria*. https://doi.org/10.26868/29761662.2022.43.

28 Mahdavi, A., Martens, B., Pont, U., Schuss, M., Teufl, H. and Berger, C. (2022) Excellence in Building Science Education: Experiences with a Central European Experiment. *Central Europe towards Sustainable Building*, Czech Technical University in Prague, 38, 316–322. https://doi.org/10.14311/APP.2022.38.0316.

29 Beausoleil-Morrison, I. and Hopfe, C. (2015) Teaching Building Performance Simulation Through A Continuous Learning Cycle. Building Simulation 2015: 14th Conference of IBPSA, 2757–2764. https://doi.org/10.26868/25222708.2015.2834.

30 Hopfe, C.J., Soebarto, V., Crawley, D. and Rawal, R. (2017) Understanding the Differences of Integrating Building Performance Simulation in the Architectural Education System. Building Simulation Conference Proceedings, International Building Performance Simulation Association, 1095–1102. https://doi.org/10.26868/25222708.2017.319.

31 Hopfe, C.J., McLeod, R.S., Gustin, M., Brembilla, E. and McElroy, L. (2022) Teaching Data Analysis for Building Performance Simulation – Series: Building Simulation and Calculation Tools in Teaching. *Bauphysik*, 44, 285–290. https://doi.org/https://doi.org/10.1002/bapi.202200027.

32 Gentile, N., Kanters, J. and Davidsson, H. (2020) A Method to Introduce Building Performance Simulation to Beginners. *Energies*, 13, 1941. https://doi.org/10.3390/en13081941.

33 Voss, K. and Kalpkirmaz Rizaoglu, I. (2022) Use of Computer Programs in University Teaching – Series: Building Simulation and Calculation Tools in Teaching (Org. in German: Einsatz von Computerprogrammen in Der Hochschullehre – Serie: Gebäudesimulation Und Berechnungstool in Der Lehre). 2022 Bauphysik Kalender. https://doi.org/10.1002/bapi.202200021.

34 Francis, M. and El Asmar, J.-P. (2020) A Novel Method of Teaching Building Performance Simulation in Post-Graduate Sustainable Architecture. 35th PLEA, 1595–1600.

35 Clarke, J.A. and Hensen, J.L.M. (2015) Integrated Building Performance Simulation: Progress, Prospects and Requirements. *Building and Environment*, 91, 294–306. https://doi.org/https://doi.org/10.1016/j.buildenv.2015.04.002.

36 Hensen, J. (2023) Building Performance S(t)Imulation I VALEDICTORY LECTURE.

37 Beausoleil-Morrison, I. and Hopfe, C. (2016) Developing and Testing A New Course for Teaching the Fundamentals of Building Performance Simulation. ESIM.

38 ArchDaily - Reporting on the Result of Design Intelligence Survey in 2012. https://www.archdaily.com/297294/forget-the-rankings-the-best-us-architecture-schools-for-2013-are [latest visit 24.07.2023].

39 Scambia, L. and Hong, D. (2017) With Regards to Energy Modelling: How Does Students' Knowledge Compare with Industry Expectations? https://doi.org/10.26868/25222708.2017.121.

40 Pendl, G. (2022) The Architectural Profession in Europe 2020 - A Sector Study. https://www.ace-cae.eu/activities/publications/ace-2020-sector-study/ [latest visit 22.08.2023].

41 Simon, H. Alexander. (1996) The Sciences of the Artificial. Third edition., MIT Press.

42 Lawson, B. (2005) How Designers Think – The Design Process Demystified. University Press, Cambridge, Fourth., Architectural Press, Oxford.

43 Royal Institute of Architects. (2020) Stages of a Building Project - 'RIBA Plan of Work 2020 Overview.' https://www.architecture.com/-/media/GatherContent/Test-resources-page/Additional-Documents/2020RIBAPlanofWorkoverviewpdf.pdf [latest visit 10.11.2023].

44 Stages of a Building Project According to German Honorarium Regulations for Architects and Engineers (HOAI). https://archxtecture.com/en/hoai-explained [latest visit 12.11.2023].

45 Dictionary Definition of "Performance." https://dictionary.cambridge.org/dictionary/english/performance [latest visit 17.10.2023].

46 Vitruvius, Rowland, I.D. and Howe, T.N. (1999) Vitruvius: "Ten Books on Architecture." Cambridge University Press, Cambridge. https://doi.org/DOI: 10.1017/CBO9780511840951.

47 Gibson, J. (1982) Working with the Performance Approach in Building. The performance Concept in Building (CIB) – Working Commission 60 (W60) Report,Netherlands. https://books.google.de/books?id=zgiTzgEACAAJ.

48 De Wilde, P. (2018) Emergent Theory of Building Performance Analysis. 447–466. https://doi.org/10.1002/9781119341901.ch11.

49 Lanteigne, V., Rider, T.R. and Stratton, P.A. (2023) Inclusive Building Performance: A New Design Paradigm. In: Mostafa, M., Baumeister, R., Thomsen, M.R. and Tamke, M., Eds., Design for Inclusivity, Springer International Publishing, Cham, 783–791.

50 Akin, O. (1987) Psychology of Architectural Design. Pion, London.

51 Wynn, D. and Clarkson, J. (2005) Models of Designing. In: Clarkson, J. and Eckert, C., Eds., Design Process Improvement: A Review of Current Practice, Springer London, London, 34–59. https://doi.org/10.1007/978-1-84628-061-0_2.

52 Foliente, G., Huovila, P., Spekkink, D., Ang, G. and Bakens, W. (2005) Performance Based Building R&D Roadmap. https://doi.org/10.13140/2.1.3148.8643.

53 Oxman, R. (2008) Performance-Based Design: Current Practices and Research Issues. *International Journal of Architectural Computing vol. 6 - no. 1, pp. 1-17*, 6. https://doi.org/10.1260/147807708784640090.

54 Shi, X. (2010) Performance-Based and Performance-Driven Architectural Design and Optimization. *Frontiers of Architecture and Civil Engineering in China*, 4, 512–518. https://doi.org/10.1007/s11709-010-0090-6.

55 Ampanavos, S. and Malkawi, A. (2021) Early-Phase Performance-Driven Design Using Generative Models. *Communications in Computer and Information Science*, Springer Science and Business Media Deutschland GmbH, 1465 CCIS, 87–106. https://doi.org/10.1007/978-981-19-1280-1_6.

56 Bucher, M.J.J., Kraus, M.A., Rust, R. and Tang, S. (2023) Performance-Based Generative Design for Parametric Modeling of Engineering Structures Using Deep Conditional Generative Models. *Automation in Construction*, Elsevier, 156, 105128. https://doi.org/10.1016/J.AUTCON.2023.105128.

57 Becker, K. and Parker, J.R. (2009) A Simulation Primer. Digital Simulations for Improving Education, IGI Global, 1–24. https://doi.org/10.4018/978-1-60566-322-7.ch001.

58 Schmitz, H.-J. (2020) Teaching Concepts of Building Performance Simulation for Architecture Students (German: LEHRKONZEPTE DER BUILDING PERFORMANCE SIMULATION FÜR ARCHITEKTURSTUDIERENDE). IBPSA BAUSIM 2020, 492–498. https://doi.org/10.3217/978-3-85125-786-1-58.

59 De Wilde, P. (2018) Building Performance Analysis. *Building Performance Analysis*, Wiley. https://doi.org/10.1002/9781119341901.

60 De Wilde, P. (2004) Computational Support for the Selection of Energy Saving Building Components. Delft University of Technology, Delft.

61 Performance Indicator — DOE Directives, Guidance, and Delegations. https://www.directives.doe.gov/terms_definitions/performance-indicator. [latest visit 22.09.2023]

62 Hensen, J. and Lamberts, R. (2011) Building Performance Simulation for Design and Operation. Hensen, J.R., Ed., Spon Press, London.

63 Waern, K.-G. (1988) Chapter 31 - Cognitive Aspects of Computer Aided Design. In: HELANDER, M., Ed., Handbook of Human-Computer Interaction, North-Holland, Amsterdam, 701–708. https://doi.org/https://doi.org/10.1016/B978-0-444-70536-5.50036-1.

64 D. Camba, J., Hartman, N. and Bertoline, G. (2023) Computer-Aided Design, Computer-Aided Engineering, and Visualization. 641–659. https://doi.org/10.1007/978-3-030-96729-1_28.

65 Kubba, S. (2012) Chapter 5 - Building Information Modeling. In: Kubba, S., Ed., Handbook of Green Building Design and Construction, Butterworth-Heinemann, Boston, 201–226. https://doi.org/https://doi.org/10.1016/B978-0-12-385128-4.00005-6.

66 Brown, G. (1990) The BRIS Simulation Program for Thermal Design of Buildings and Their Services. *Energy and Buildings*, 14, 385–400. https://doi.org/https://doi.org/10.1016/0378-7788(90)90100-W.

67 Kusuda, T. (1999) Early History and Future Prospects of Building System Simulation. *Proceedings of Building Simulation '99*, 1.

68 Ahn, J. and Haberl, J. (2023) Origins of Whole-Building Energy Simulations for High-Performance Commercial Buildings: Contributions of NATEOUS, SHEP, TACS, CP-26, and RESPTK Programs. *Science and Technology for the Built Environment*, 29, 1–16. https://doi.org/10.1080/23744731.2023.2181618.

69 Aleksandrowicz, O. and Mahdavi, A. (2018) The Application of Building Performance Simulation in the Writing of Architectural History: Analysing Climatic Design in 1960s Israel. *Frontiers of Architectural Research*, 7, 367–382. https://doi.org/https://doi.org/10.1016/j.foar.2018.06.003.

70 Negendahl, K. (2015) Building Performance Simulation in the Early Design Stage: An Introduction to Integrated Dynamic Models. *Automation in Construction*, 54, 39–53. https://doi.org/https://doi.org/10.1016/j.autcon.2015.03.002.

71 Pan, Y., Zhu, M., Lv, Y., Yang, Y., Liang, Y., Yin, R., Yang, Y., Jia, X., Wang, X., Zeng, F., Huang, S., Hou, D., Xu, L., Yin, R. and Yuan, X. (2023) Building Energy Simulation and Its Application for Building Performance Optimization: A Review of Methods, Tools, and Case Studies. *Advances in Applied Energy*, Elsevier, 10, 100135. https://doi.org/10.1016/J.ADAPEN.2023.100135.

72 Di Biccari, C., Calcerano, F., D'Uffizi, F., Esposito, A., Campari, M. and Gigliarelli, E. (2022) Building Information Modeling and Building Performance Simulation Interoperability: State-of-the-Art and Trends in Current Literature. *Advanced Engineering Informatics*, 54, 101753. https://doi.org/https://doi.org/10.1016/j.aei.2022.101753.

73 Clarke, J.A. (Joe A.). (2001) Energy Simulation in Building Design. Butterworth-Heinemann, 362.

74 Building Energy Software Tool (BEST) by US DOE. https://www.webharvest.gov/peth04/20041015000220/http://www.eere.energy.gov/buildings/tools_directory/ [latest visit 22.09.2023].

75 Dictionary Definition of "Architecture." https://www.oed.com/search/dictionary/?scope=Entries&q=architecture [latest visit 12.08.2023].

76 Rittel, H.W.J. and Webber, M.M. (1973) Dilemmas in A General Theory of Planning. *Policy Sciences*, 4, 155–169. https://doi.org/10.1007/BF01405730.

77 Voss, K., Hendel, S. and Stark, M. (2021) Solar Decathlon Europe – A Review on the Energy Engineering of Experimental Solar Powered Houses. *Energy and Buildings*, 251, 111336. https://doi.org/https://doi.org/10.1016/j.enbuild.2021.111336.

78 Voss, K., Kalpkirmaz Rizaoglu, I., Balcerzak, A. and Hansen, H. (2023) Solar Energy Engineering and Solar System Integration – The Solar Decathlon Europe 21/22 Student Competition Experiences. *Energy and Buildings*, Elsevier, 285, 112891. https://doi.org/10.1016/J.ENBUILD.2023.112891.

79 Kalpkirmaz Rizaoglu, I. and Voss, K. (2024) Building Performance with An Integrated Simulation Approach: Experiences in Solar Decathlon Europe 21/22 and Future Perspectives. *Building and Environment*. https://doi.org/10.1016/j.buildenv.2024.111261.

80 Reinhart, C.F., Dogan, T., Ibarra, D. and Samuelson, H.W. (2012) Learning by Playing – Teaching Energy Simulation as a Game. *Building Performance Simulation*, Taylor & Francis, 5, 359–368. https://doi.org/10.1080/19401493.2011.619668.

81 Schlueter, A. and Thesseling, F. (2009) Building Information Model Based Energy/Exergy Performance Assessment in Early Design Stages. *Automation in Construction*, 18, 153–163. https://doi.org/10.1016/j.autcon.2008.07.003.

82 Attia, S. and Herde, A. (2011) Early Design Simulation Tools for Net Zero Energy Buildings: A Comparison of Ten Tools. *Proceedings of Building Simulation 2011: 12th Conference of International Building Performance Simulation Association*.

83 Strunge, J. (2017) Building Performance Simulation in Architectural Design. Advanced Building Skins 2017.

84 Mahmoud, R., Kamara, J. and Burford, N. (2019) An Analytical Review of Tools and Methods for Energy Performance Simulation in Building Design. 36th CIB W78 2019, Newcastle University, 1008–1021.

85 Samuelson, H., Lantz, A. and Reinhart, C. (2012) Non-Technical Barriers to Energy Model Sharing and Reuse. *Building and Environment*, 54, 71–76. https://doi.org/10.1016/j.buildenv.2012.02.001.

86 IBPSA-USA Early Design Analysis Survey. https://www.ibpsa.us/committee-spotlight-ibpsa-usa-research-committee/ [latest visit 25.11.2023].

87 Capo, P. and Wackerle, M. (2019) Architect's Guide to Building Performance. The American Institute of Architects, New York. https://www.aia.org/resources/6157114-architects-guide-to-building-performance [latest visit 25.11.2023].

88 Østergård, T., Jensen, R. and Maagaard, S. (2016) Building Simulations Supporting Decision Making in Early Design – A Review. *Renewable and Sustainable Energy Reviews*, 61, 187–201. https://doi.org/10.1016/j.rser.2016.03.045.

89 Oxman, R. (2008) Performance-Based Design: Current Practices and Research Issues. *International Journal of Architectural Computing vol. 6 - no. 1, pp. 1-17*, 6. https://doi.org/10.1260/147807708784640090.

90 Konis, K., Gamas, A. and Kensek, K. (2016) Passive Performance and Building Form: An Optimization Framework for Early-Stage Design Support. *Solar Energy*, 125, 161–179. https://doi.org/10.1016/j.solener.2015.12.020.

91 Cerezo, C., Dogan, T. and Reinhart, C. (2014) Towards Standarized Building Properties Template Files for Early Design Energy Model Generation.

92 See, R., Haves, P., Sreekanthan, P., Basarkar, M., O Donnell, J. and Settlemyre, K. (2011) Development of a User Interface for the EnergyPlus Whole Building Energy Simulation Program. Proceedings of Building Simulation 2011: 12th Conference of International Building Performance Simulation Association.

93 Maile, T., Fischer, M. and Bazjanac, V. (2007) Building Energy Performance Simulation Tools - a Life-Cycle and Interoperable Perspective. *Facil. Eng. (CIFE) Working Pap.*, 107.

94 Kamel, E. and Memari, A. (2018) Review of BIM's Application in Energy Simulation: Tools, Issues, and Solutions. *Automation in Construction*, 97, Pages 164-180. https://doi.org/10.1016/j.autcon.2018.11.008.

95 Senel Solmaz, A. (2019) A Critical Review on Building Performance Simulation Tools. 12, 7–21.

96 Dimara, A., Krinidis, S., Ioannidis, D. and Tzovaras, D. (2023) Building Performance Simulation. 53–67. https://doi.org/10.1007/978-3-031-32309-6_4.

97 Grasshopper. https://www.grasshopper3d.com/ [latest visit 25.11.2023].

98 Autodesk. Dynamo Studio. https://www.autodesk.com/products/dynamo-studio/overview [latest visit 26.11.2023].

99 Marsh, A. (2000) Playing Around with Science. Proceedings of the 34th Conference of the Australia and New Zealand Architectural Science Association, Adelaide, 147–152.

100 Marsh, A. (1996) Integrating Performance Modeling into the Initial Stages of Design. ANZAScA Conference Proceedings, Hong Kong.

101 Abdullah, A.H., Abu Bakar, S. and Rahman, I. (2013) Simulation of Office's Operative Temperature Using ECOTECT Model. *Simulation of Office's Operative Temperature Using ECOTECT Model*, 1, 33–37.

102 Yang, L., He, B.-J. and Ye, M. (2014) Application Research of ECOTECT in Residential Estate Planning. *Energy and Buildings*, 72, 195–202. https://doi.org/https://doi.org/10.1016/j.enbuild.2013.12.040.

103 Delbin, S., Silva, V., Kowaltowski, D. and Labaki, L. (2006) Implementing Building Energy Simulation into the Design Process: A Teaching Experience in Brazil. *PLEA 2006 - 23rd International Conference on Passive and Low Energy Architecture, Conference Proceedings*, 6–8.

104 Autodesk. Ecotect Analysis Discontinuation. https://www.autodesk.com/support/technical/article/caas/sfdcarticles/sfdcarticles/Ecotect-Analysis-Discontinuation-FAQ.html [latest visit 26.11.2023].

105 Marsh, A. ECOTECT as a Teaching Tool. https://andrewmarsh.com/articles/2005/ecotectasteacher/ [latest visit 28.11.2023]

106 Rhinoceros 3D. https://www.rhino3d.com/ [latest visit 25.12.2023].

107 Solemma. Diva-for Rhino. https://www.solemma.com/diva [latest visit 25.12.2023].

108 Ladybug. https://www.ladybug.tools/ladybug.html [latest visit 10.09.2023].

109 Honeybee. https://www.ladybug.tools/honeybee.html [latest visit 12.12.2023].

110 RADIANCE. https://www.radiance-online.org/ [latest visit 13.12.2023].

111 USA DOE. EnergyPlus. https://energyplus.net/ [latest visit 14.12.2023].

112 Brown, N.C. and MUELLERa, C.T. (2017) Automated Performance-Based Design Space Simplification for Parametric Structural Design. https://api.semanticscholar.org/CorpusID:53005032.

113 Autodesk. Revit. https://www.autodesk.com/products/revit/overview?us_oa=dotcom-us&us_si=f70969ef-3cc8-47ab-8b6f-f1d359e6abd6&us_st=revit&us_pt=RVT&term=1-YEAR&tab=subscription&plc=RVT [latest visit 10.09.2023].

114 Solemma. https://www.solemma.com/ [latest visit 11.09.2023].

115 Solemma. ClimateStudio. https://www.solemma.com/climatestudio [latest visit 12.09.2023].

116 Cody, B. (2005) Form Follows Energy. Design Science in Architecture, Springer Vienna, Vienna, 28–41. https://doi.org/10.1007/3-211-37790-5_2.

117 Kalay, Y.E. (1999) Performance-Based Design. *Automation in Construction*, 8, 395–409. https://doi.org/https://doi.org/10.1016/S0926-5805(98)00086-7.

118 Neitzke, P., Steckeweh, C. and Wustlich, R. (1998) Niedrigenergiehaus, Berlin-Marzahn (1997). In: Neitzke, P., Steckeweh, C. and Wustlich, R., Eds., CENTRUM: Jahrbuch Architektur Und Stadt 1998 – 1999, Vieweg+Teubner Verlag, Wiesbaden, 196–198. https://doi.org/10.1007/978-3-322-83185-9_45.

119 Rahm, P. (2018) Thermodynamic Practice- Front Matter. In: De Rycke, K., Gengnagel, C., Baverel, O., Burry, J., Mueller, C., Nguyen, M.M., Rahm, P. and Thomsen, M.R., Eds., Humanizing Digital Reality: Design Modelling Symposium Paris 2017, Springer Singapore, Singapore, 73–85. https://doi.org/10.1007/978-981-10-6611-5_8.

120 Stalder, L. (2010) Interview with Philippe Rahm - Form and Function Follow Climate. DEPARTEMENT ARCHITEKTUR ETH ZÜRICH, 89–93.

121 Konis, K. and Selkowitz, S. (2017) Case Studies. In: Konis, K. and Selkowitz, S., Eds., Effective Daylighting with High-Performance Facades: Emerging Design Practices, Springer International Publishing, Cham, 199–249. https://doi.org/10.1007/978-3-319-39463-3_5.

122 AIA 2022 COTE® Top Ten. https://www.aia.org/showcases/6483992-edwin-m-lee-apartments [latest visit 10.09.2023].

123 Kubitza, M. Manuel Kubitza Art-Directory & Photography. https://www.manuelkubitza.de/projekte_fotograf/rocket-tower/ [latest visit 13.11.2023].

124 Sustainability Solution Groups. https://www.ssg.coop/vancouver-convention-centre-honoured-by-aia/ [latest visit 13.11.2023].

125 Archi-Monarch. https://archi-monarch.com/zaha-hadid/ [latest visit 13.11.2023].

126 International Living Future Institute. https://living-future.org/case-studies/bullitt-center-2/ [latest visit 13.11.2023].

127 World-Architects. https://www.world-architects.com/en/behnisch-architekten-stuttgart/project/john-and-frances-angelos-law-center-university-of-baltimore [latest visit 13.11.2023].

128 Fernandez-Antolin, M.-M., del Río, J.M. and Gonzalez-Lezcano, R.-A. (2021) The Use of Gamification in Higher Technical Education: Perception of University Students on Innovative Teaching Materials. *International Journal of Technology and Design Education*, 31, 1019–1038. https://doi.org/10.1007/s10798-020-09583-0.

129 Solar Decathlon Europe21/22. https://sdeurope.uni-wuppertal.de/en/ [latest visit 07.06.2023].

130 Soebarto, V.I. (2005) Teaching an Energy Simulation Program in An Architecture School: Lessons Learned. In: Beausoleil Morrison, I. and Bernier, M., Eds., 9th International IBPSA Conference, Montreal, 1147–1154. https://hdl.handle.net/2440/29068.

131 de Gaulmyn, C. and Dupre, K. (2019) Teaching Sustainable Design in Architecture Education: Critical Review of Easy Approach for Sustainable and Environmental Design (EASED). *Frontiers of Architectural Research*, Elsevier, 8, 238–260. https://doi.org/10.1016/J.FOAR.2019.03.001.

132 Augenbroe, G. (2019) The Role of Simulation in Performance Based Building. In: Hensen, J. and Lamberts, R., Eds., Building Performance Simulation for Design and Operation, London, 31.

133 Alexandrou, E., Bougiatioti, F. and Katsaros, M. (2020) Assessment of the Sustainable Redesign of Existing Buildings in Greece in the Context of an Undergraduate Course: Application of Passive Solar Systems in Existing, Typical Residences. *IOP Conference Series: Earth and Environmental Science*, IOP Publishing, 410, 12089. https://doi.org/10.1088/1755-1315/410/1/012089.

134 Grant, E. (2017) Integrating Building Performance with Design: An Architecture Student's Guidebook. https://doi.org/10.4324/9781315680071.

135 Beausoleil-Morrison, I. (2018) Learning The Fundamentals of Building Performance Simulation Through An Experiential Teaching Approach. *Journal of Building Performance Simulation*, Taylor & Francis, 12, 308–325. https://doi.org/10.1080/19401493.2018.1479773.

136 Säwén, T., Magnusson, E., Hollberg, A. and Kalagasidis, A.S. (2022) A Characterisation Framework for Parametric Building Performance Simulation Tools. Hviid, C.A., Khanie, M.S. and Petersen, S., Eds., *E3S Web of Conferences*, EDP Sciences, 362, 03004. https://doi.org/10.1051/e3sconf/202236203004.

137 Waibel, C., Thomas, D., Elesawy, A., Hischier, I., Walker, L. and Schlueter, A. (2021) Integrating Energy Systems into Building Design with Hive: Features, User Survey and Comparison with Ladybug and Honeybee Tools. https://doi.org/10.26868/25222708.2021.30526.

138 Hernandez Neto, A. (2018) Teaching Building Performance Simulation: Considerations on Methodologies and Course Levels. *International Journal of Mechanical Engineering Education*, SAGE Publications Ltd STM, 47, 293–314. https://doi.org/10.1177/0306419018775596.

139 Hand, J., Hensen, J.L.M. and Weir, J. (1998) RECENT EXPERIENCES AND DEVELOPMENTS IN THE TRAINING OF SIMULATIONISTS. https://api.semanticscholar.org/CorpusID:16307496.

140 Hamza, N. and Horne, M. (2007) Educating the Designer: An Operational Model for Visualizing Low-Energy Architecture. *Building and Environment*, 42, 3841–3847. https://doi.org/https://doi.org/10.1016/j.buildenv.2006.11.003.

141 Charles, P. and Thomas, C. (2009) Four Approaches to Teaching with Building Performance Simulation Tools in Undergraduate Architecture and Engineering Education. *Journal of Building Performance Simulation*, 2, 95–114. https://doi.org/10.1080/19401490802592798.

142 Strobbe, T., Verstraeten, R., Delghust, M., Laverge, J., Meyer, R. and Janssens, A. (2015) Using A Building Information Modelling Approach for Teaching About Residential Energy Use and Official Energy Performance. Proceedings of IBPSA 14th Conference BS2015, 2699–2704. https://doi.org/10.26868/25222708.2015.2442.

143 Kalpkirmaz Rizaoglu, I. and Voss, K. (2023) Summer Thermal Comfort in Architectural Early Design Workflows. CESBP 2022, AIP Conf. Proc. 2918, 020029 (2023). https://doi.org/https://doi.org/10.1063/5.0171066.

144 Jian, Y. (2010) Application of Simulation Software in the Teaching of Building Energy Efficiency. Proceedings of International Conference on Optics, Photonics and Energy Engineering, 438–441.

145 Gatermann, H. (2020) Image & Colour. Atlas of Digital Architecture: Terminology, Concepts, Methods, Tools, Examples, Phenomena, Birkhäuser, Berlin, Boston, 229–254. https://doi.org/https://doi.org/10.1515/9783035620115-010.

146 Ladybug Tools. https://www.ladybug.tools/ [latest visit 25.11.2023].

147 Rasoulzadeh, S., Senk, V., Kovacic, I., Reisinger, J., Füssl, J. and Hensel, M. (2022) Linking Early Design Stages with Physical Simulations Using Machine Learning. Intelligent Computing in Engineering, 216–226. https://doi.org/10.7146/aul.455.c212.

148 ICEbear. http://www.idbuild.dk/icebear [latest visit 10.11.2023].

149 Mitchell, W.J. (1990) The Logic of Architecture: Design, Computation, and Cognition. 1st ed., MIT Press, Cambridge, MA, USA.

150 Jo, S.J. and Grant, E. (2022) LEARNING BUILDING PERFORMANCE SIMULATION AS NOVICE USERS IN ARCHITECTURAL DESIGN. *Journal of Green Building*, Allen Press, 17, 3–22. https://doi.org/10.3992/JGB.17.2.3.

151 Salama, A.M. (2021) The Conventional Approach to Studio Teaching Practice 1. Transformative Pedagogy in Architecture and Urbanism, Routledge (Taylor & Francis), 81–119. https://doi.org/10.4324/9781003140047-4.

152 Adeoye, L., Baumgartner, E., Diefenthaler, A. and Suzuki, S. (2021) Designing Design Education. White Book on the Future of Design Education. Böninger, C., Frenkler, F. and Schmidhuber, S., Eds.

153 Gunoz, O. and Uluoğlu, B. (2023) Variants of Design Studio: A Phenomenographi Research on Students' Conceptions of Design Studio Environment. *Journal of Design Studio*, 5, 5–20. https://doi.org/10.46474/jds.1234644.

154 Mahdavi, A., Martens, B., Pont, U., Schuss, M., Teufl, H. and Berger, C. (2022) Excellence in Building Science Education: Experiences with a Central European Experiment. 38. https://doi.org/10.14311/APP.2022.38.0316.

155 Reinhart, C., Geisinger, J., Dogan, T. and Saratsis, E. (2015) Lessons Learnt from A Simulation-Based Appraoch to Teaching Building Science to Designers. https://doi.org/10.26868/25222708.2015.2468.

156 Hill, G. (2016) Drawn Together: Student Views of Group Work in the Design Studio. *Journal of Architectural and Planning Research*, 33, 293–308.

157 Strand, R.K., Liesen, R.J. and Witte, M.J. (2004) Resources for Teaching Building Energy Simulation. Proceedings of IBPSA - SimBuild 2004, 1–8.

158 Bernier, M.A., Kummert, M., Sansregret, S., Bourgeois, D. and Thevenard, D. (2016) TEACHING A BUILDING SIMULATION COURSE AT THE GRADUATE LEVEL. https://api.semanticscholar.org/CorpusID:168165795.

159 Rajagopalan, P., Wong, J.P.C. and Andamon, M.M. (2016) Building Performance Simulation in the Built Environment Education: Experience from Teaching Two Disciplines. School of Architecture and Built Environment, The University of Adelaide, Adelaide, Australia, Australia, 359–368.

160 Brown, J.B. and Russell, P. (2022) When Design-Build Met the Live Project – or – What Is a Live-Build Project Anyway? In: Smet, B.P.A. De, Ed., Experiential Learning in Architectural Education: Design-Build and Live Projects, Routledge, Abingdon, 9–24. https://doi.org/10.4324/9781003267683-2.

161 Voss, K., Sánchez, S., Russel, P., Arranz, B., Holloway, L., Hendel, S., Amaral, Richard, Stark, M., Balcerzak, A., Luijn, Anne. Ingeborg and Ar, . (2020) Solar Decathlon Europe - Analysis of the Results.

162 Badanes, S. (2008) The Transformative Power of Architectural Education. In: Bell, B. and Wakeford, K., Eds., Expanding Architecture Design as Activism, Metropolis.

163 Gaber, T. (2014) The Agency of Making and Architecture Education: Design-Build Curriculum in a New School of Architecture. *International Journal of Architectural Research: ArchNet-IJAR*, 8, 21–31. https://doi.org/10.26687/archnet-ijar.v8i3.507.

164 US Department of Energy. Solar Decathlon. https://www.solardecathlon.gov/ [latest visit 13.11.2023].

165 Chiuini, M., Grondzik, W., King, K., Mcginley, W. and Owens, J. (2013) Architect and Engineer Collaboration: The Solar Decathlon As a Pedagogical Opportunity. 216–225. https://doi.org/10.1061/9780784412909.021.

166 Marriage, G. (2017) Solar Decathlon. Interdisciplinary and Collaborative Research Competing on a World Stage. *The Journal of Public Space*, 2, 31. https://doi.org/10.5204/jps.v2i3.111.

167 Herrera-Limones, R., Rey-Pérez, J., Hernández-Valencia, M. and Roa-Fernández, J. (2020) Student Competitions as a Learning Method with a Sustainable Focus in Higher Education: The University of Seville “Aura Projects” in the “Solar Decathlon 2019.” *Sustainability*, 12. https://doi.org/10.3390/su12041634.

168 Konstantinos, K. (2022) Collaborative Practice-Based Learning Methods in Architectural Design and Building Technology Education in a Cross-Cultural, Cross-Geographical Environment. *Journal of Architectural Engineering*, American Society of Civil Engineers, 28, 05022001. https://doi.org/10.1061/(ASCE)AE.1943-5568.0000525.

169 Kolb, D. (1984) Experiential Learning: Experience as the Source of Learning and Development. *Journal of Business Ethics*, Prentice-Hall, 1.

170 Kolb, D. (2014) Experiential Learning: Experience as the Source of Learning and Development Second Edition. 2nd ed., Pearson Education.

171 Hand, J. and Crawley, D. (1997) Forget the Tool When Training New Simulation Users.

172 Karadağ, D. (2023) Gamification of Design Studio in the Context of a User-Centered Design Workshop. *Interaction Design and Architecture(s)*, 56, 115–129. https://doi.org/10.55612/s-5002-056-006.

173 Rodriguez-Ubinas, E., Rodriguez, S., Voss, K. and Todorovic, M.S. (2014) Energy Efficiency Evaluation of Zero Energy Houses. *Energy and Buildings*, 83, 23–35. https://doi.org/https://doi.org/10.1016/j.enbuild.2014.06.019.

174 Banfield, B., McDowell, C., Robinson, D. and Agalgaonkar, A. (2019) Evaluation of In-Depth Energy Modelling for the Design and Operation of a Net-Positive Energy Solar Decathlon House. *E3S Web of Conferences*, 111, 4024. https://doi.org/10.1051/e3sconf/201911104024.

175 López-Escamilla, Á., Herrera-Limones, R. and León-Rodríguez, Á.L. (2022) Evaluation of Environmental Comfort in a Social Housing Prototype with Bioclimatic Double-Skin in a Tropical Climate. *Building and Environment*, 218, 109119. https://doi.org/https://doi.org/10.1016/j.buildenv.2022.109119.

176 Ibarra, D. and Reinhart, C. (2013) Teaching Daylight Simulations – Improving Modeling Workflows For Simulation Novices. https://doi.org/10.26868/25222708.2013.2531.

177 Dhaouadi, K. and Leclercq, P. (2022) Shaping Sustainability in Architectural Education: The Integrated Design as a Tool. *Journal of Design Studio*, 4, 217–226. https://doi.org/10.46474/jds.1218258.

178 Nasar, Z. (2020) ParaSIM: A Hybrid Technology-Enhanced Framework to Learning Energy Modelling in Architectural Design Education. Doctor in Philosophy, University of Liverpool.

179 Yildirim, T. and Yavuz, A.O. (2012) Comparison of Traditional and Digital Visualization Technologies in Architectural Design Education. *Procedia - Social and Behavioral Sciences*, 51, 69–73. https://doi.org/https://doi.org/10.1016/j.sbspro.2012.08.120.

180 Vujovic, M., Stojanovic, D., Selami, T. and Hensel, M. (2023) Design and Science: Content Analysis of Published Peer-Reviewed Research over the Last Four Decades. *Frontiers of Architectural Research*, Elsevier, 12, 613–629. https://doi.org/10.1016/J.FOAR.2023.04.001.

181 Oh, Y., Ishizaki, S., Gross, M.D. and Yi-Luen Do, E. (2013) A Theoretical Framework of Design Critiquing in Architecture Studios. *Design Studies*, 34, 302–325. https://doi.org/https://doi.org/10.1016/j.destud.2012.08.004.

182 Grover, R., Emmitt, S. and Copping, A. (2020) Critical Learning for Sustainable Architecture: Opportunities for Design Studio Pedagogy. *Sustainable Cities and Society*, 53, 101876. https://doi.org/https://doi.org/10.1016/j.scs.2019.101876.

183 Goldschmidt, G., Hochman, H. and Dafni, I. (2010) The Design Studio “Crit”: Teacher–Student Communication. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 24. https://doi.org/10.1017/S089006041000020X.

184 Berger, C. and Mahdavi, A. (2019) Integrating Building Physics and Performance Simulation In Architectural Curricula: A Collaborative Effort. IBPSA 16th Int. Building Simulation Conference Rome, 1595–1600. https://doi.org/10.26868/25222708.2019.210117.

185 ResearchGate. https://www.researchgate.net/ [latest visit 07.09.2023].

186 ScienceDirect. https://www.sciencedirect.com/ [latest visit 07.09.2023].

187 Academia. https://www.academia.edu/ [latest visit 07.09.2023].

188 Ecotect. https://andrewmarsh.com/projects/past-software/ [latest visit 09.10.2023].

189 Charles, P. and Thomas, C. (2009) Building Performance Simulation in Undergraduate Multidisciplinary Education: Learning from an Architecture and Engineering Collaboration. *IBPSA 2009 - International Building Performance Simulation Association 2009*.

190 TRNSYS. https://www.trnsys.com/ [latest visit 11.09.2023].

191 CONTAM. https://www.nist.gov/publications/contamw-20-user-manual [latest visit 11.09.2023].

192 Dhaouadi, K. and Leclercq, P. (2022) Shaping Sustainability in Architectural Education: The Integrated Design as a Tool. *Design Studio*, 4, 217–226.

193 Gulec Ozer, D. and Turan, B. (2015) Ecological Architectural Design Education Practices Via Case Studies. *MEGARON / Yıldız Technical University, Faculty of Architecture E-Journal*, 10. https://doi.org/10.5505/megaron.2015.20592.

194 Biggs, J.B. and Collis, K.F. (1981) Evaluating the Quality of Learning The SOLO Taxonomy (Structure of the Observed Learning Outcome). Edward, A.J., Ed.

195 Mohamadin, M., Abouaiana, A. and Sakr, Y. (2018) Integrating Energy Performance Assessment Tools in Architectural Design Studio Education. International Conference for Sustainable Design of the Built Environment, 236–244. https://doi.org/10.5281/zenodo.4025346.

196 Autodesk FormIt. https://formit.autodesk.com/ [latest visit 28.10.2023].

197 Autodesk. Insight. https://www.autodesk.com/products/insight/overview [latest visit 28.10.2023].

198 Anindita, M.K.A., Ola, F.B., Suwarno, N. and Sekarlangit, N. (2022) Utilization of Building Design Performance Simulation in the Architectural Design Studio Process. *ARTEKS: Jurnal Teknik Arsitektur*, 7, 163–174. https://doi.org/10.30822/arteks.v7i2.1391.

199 Climate Consultant. https://www.sbse.org/resources/climate-consultant [latest visit 28.10.2023].

200 Sefaira. https://www.sketchup.com/products/sefaira [latest visit 28.10.2023].

201 Kalpkirmaz Rizaoglu, I. (2023) Building Performance Simulation Tools. In: Voss, K. and Simon, K., Eds., Solar Decathlon Europe 21/22 – Competition Source Book, Wuppertal, 150–153. https://doi.org/10.25926/svtg-e916.

202 Trochim, W. and Donnelly, J. (2006) The Research Methods Knowledge Base. 3rd ed., Atomic Dog.

203 Dillman, D.A., Smyth, J.D. and Christian, L.M. (2014) Internet, Phone, Mail, and Mixed Mode Surveys: The Tailored Design Method, 4th Ed. Internet, Phone, Mail, and Mixed Mode Surveys: The Tailored Design Method, 4th Ed., John Wiley & Sons Inc, Hoboken, NJ, US.

204 Boyce, C. and Neale, P. (2006) Monitoring and Evaluation-2 CONDUCTING IN-DEPTH INTERVIEWS: A Guide for Designing and Conducting In-Depth Interviews for Evaluation Input.

205 Kalpkirmaz Rizaoglu, I. BPS in Teaching Survey. http://isilkalpkirmaz.com/ [latest visit 12.12.2023].

206 University of Wuppertal - Faculty of Architecture and Civil Engineering. https://www.archbau.uni-wuppertal.de/en/ [latest visit 28.10.2023].

207 German Federal Ministry for Economic Affairs and Climate Action. https://www.bmwk.de/Navigation/EN/Home/home.html [latest visit 21.11.2023].

208 German Federal Ministry for Economic Affairs and Climate Action, (2021). Climate Change Act 2021. https://www.bundesregierung.de/breg-de/schwerpunkte/klimaschutz/climate-change-act-2021-1936846 [latest visit 21.11.2023].

209 Voss, K. and Simon, K., Eds. (2023) Solar Decathlon Europe 21/22 – Competition Source Book. Wuppertal. DOI: 10.25926/svtg-e916.

210 Claus, L., Herb, S., Frenzel, C. and Stave, J. (2022) A Faster Method for The Simulation-Based Parametric Optimization of Structural Shading. https://doi.org/10.26868/29761662.2022.13.

211 Voss, K., Hansen, H., Kaliga, M. and Kalpkirmaz Rizaoglu, I. (2023) Solar Decathlon Europe 2022 – Bauphysikalische Ergebnisse von Demonstrationsgebäuden. 2023 Bauphysik Kalender, Wiley, 531–550. https://doi.org/10.1002/9783433611289.ch15.

212 Carbonare, N., Bühler, M., Pfafferott, J. and Wagner, A. (2022) RoofKIT – Building Simulation in Sustainable Housing at the Solar Decathlon Europe 21/22.

213 Wagner, A., Hebel, D., Carbonare, N. and Gebauer, R. (2022) RoofKIT - Circular Construction and Solar Energy Use in Practice at the Solar Decathlon Europe 21/22. *IOP Conference Series: Earth and Environmental Science*, IOP Publishing, 1078, 12058. https://doi.org/10.1088/1755-1315/1078/1/012058.

214 IEA EBC Annex 74 ''Competition and Living Lab Platform". https://annex74.iea-ebc.org/ [latest visit 21.12.2023].

215 Building Energy Competition & Living Lab Knowledge Platform. https://building-competition.org/ [latest visit 21.12.2023].

216 Solar Decathlon 21/22 Competition Results. https://sdeurope.uni-wuppertal.de/en/competition/results/ [latest visit 21.12.2023].

217 Lichtmeß, M. (2020) SimRoom 4 – A Learning Tool for Dynamic Space and Energy Balances, SDE 21/22 Special Edition. https://ingefo.de/Werkzeuge/SimRoom/ [latest visit 21.12.2023].

218 Lichtmeß, M., SimRoom as a Learning and Teaching Tool. https://www.ingefo.de/Lehre/ [latest visit 21.12.2023].

219 Lichtmeß, M., SimRoom- Comparison with Different BPS Tools. https://ingefo.de/Werkzeuge/SimRoom/ [latest visit 22.12.2023].

220 Bauwens, G. and Roels, S. (2014) Co-Heating Test: A State-of-the-Art. *Energy and Buildings*, 82, 163–172. https://doi.org/https://doi.org/10.1016/j.enbuild.2014.04.039.

221 Building Energy Performance Assessment Based on In-Situ Measurements, International Energy Agency, Energy in Buildings and Community Systems Programme. https://www.iea-ebc.org/projects/project?AnnexID=71.

222 EQUA. IDA ICE. https://www.equa.se/en/ida-ice [latest visit 11.10.2023].

223 DesignBuilder. https://designbuilder.co.uk/ [latest visit 11.10.2023].

224 Lichtmeß, M., EnerCalC. https://www.ingefo.de/Werkzeuge/EnerCalC/ [latest visit 11.10.2023].

225 Lichtmeß, M., SimRoom. https://ingefo.de/Werkzeuge/SimRoom/ [latest visit 11.10.2023].

226 Walker, M., Takayama, L., Landay, J. and Leila. (2002) High-Fidelity or Low-Fidelity, Paper or Computer Choosing Attributes When Testing Web Prototypes. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 46. https://doi.org/10.1177/154193120204600513.

227 Erickson, T. (1995) Notes on Design Practice: Stories and Prototypes as Catalysts for Communication. Scenario-Based Design: Envisioning Work and Technology in System Development, John Wiley & Sons, Inc., USA, 37–58.

228 The Alliance for Sustainable Energy. OpenStudio. https://openstudio.net/ [latest visit 12.10.2023].

229 Daysim. https://www.radiance-online.org/community/mailing-lists/archives/radiance-daysim [latest visit 12.10.2023].

230 HumanUI. https://www.food4rhino.com/en/app/human-ui [latest visit 12.10.2023].

231 European Norm. DIN EN 16798-1:2022- Energy Performance of Buildings. https://doi.org/https://dx.doi.org/10.31030/3327351.

232 Bigladder. Ideal Loads Air System. https://bigladdersoftware.com/epx/docs/8-0/engineering-reference/page-092.html [latest visit 22.09.2023].

233 Relux Informatik AG. Relux. https://reluxnet.relux.com/en/ [latest visit 22.09.2023].

234 Daniel, C. (1973) One-at-a-Time Plans. *Journal of the American Statistical Association*, Taylor & Francis, 68, 353–360. https://doi.org/10.1080/01621459.1973.10482433.

235 Wortmann, T. Opossum. https://www.food4rhino.com/en/app/opossum-optimization-solver-surrogate-models [latest visit 23.09.2023].

236 Meteotest AG. Meteonorm. https://meteonorm.com/en/ [latest visit 10.10.2023].

237 Hovestadt, L., Hirschberg, U. and Fritz, O. (2020) Atlas of Digital Architecture: Terminology, Concepts, Methods, Tools, Examples, Phenomena. De Gruyter, Berlin. https://doi.org/10.1515/9783035620115.

238 Fu, F. (2018) Design and Analysis of Complex Structures. *Design and Analysis of Tall and Complex Structures*, Elsevier, 177–211. https://doi.org/10.1016/B978-0-08-101018-1.00006-X.

239 Wortmann, T., Costa, A., Nannicini, G. and Schroepfer, T. (2015) Advantages of Surrogate Models for Architectural Design Optimization. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 29, 471–481. https://doi.org/10.1017/S0890060415000451.

240 Walther, K., Kalpkirmaz Rizaoglu, I., Kirant Mitic, H. and Derbas, G. (2021) Building 2226 on the Test Bench: Simulation Study on the Relocated 2226 Building by Baumschlager Eberle.

241 Baumschlager Eberle. Building 2226. https://www.baumschlager-eberle.com/werk/projekte/projekt/2226/ [latest visit 13.09.2023].

242 Nakic´enovic´, N., Davidson, O., Davis, G., Grubler, A., Kram, T., La Rovere, E., Metz, B., Morita, T., Pepper, W., Pitcher, H., Sankovski, A., Shukla, P., Swart, R., Watson, R. and Dadi, Z. (2000) Summary for Policymakers - Emissions Scenarios: A Special Report of IPCC Working Group III.

# List of Figures

## Chapter 1 figures



## Chapter 2 figures



## Chapter 3 figures

### Chapter 4 figures

Chapter 5 figures

# List of Tables

# List of Publications

## Peer reviewed publications


Kalpkirmaz Rizaoglu, I. and Voss, K. (2024). Building Performance Analyses in Higher Education: The Solar Decathlon 21/22 Experience, PLEA Conf. in Wroclaw, Poland.

Kalpkirmaz Rizaoglu, I. and Voss, K. (2024). Building Performance with an Integrated Simulation Approach: Experiences in Solar Decathlon Europe 21/22 and Future Perspectives, Building and Environment, 253. https://doi.org/10.1016/j.buildenv.2024.111261.

Voss, K., Hansen, H., Kaliga, M., Kalpkirmaz Rizaoglu, I. (2023). *"Solar Decathlon Europe 2022 - Building physics results of demonstration buildings"* (org. in German: *„Solar Decathlon Europe 2022 - Bauphysikalische Ergebnisse von Demonstrationsgebäuden"*), in Fouad, N. A. (ed) *Bauphysik Kalender: Nachhaltigkeit*, Ernst & Sohn GmbH & Co. KG., pp 531-550. https://doi.org/10.1002/9783433611289.ch15

Voss, K., Kalpkirmaz Rizaoglu, I., Balcerzak, A., Hansen, H. (2023). Solar Energy Engineering and Solar System Integration – The Solar Decathlon Europe 21/22 Student Competition Experiences, Energy and Buildings, 285, (112891). https://doi.org/10.1016/j.enbuild.2023.112891

Kalpkirmaz Rizaoglu, I. and Voss, K. (2022). Building Performance Simulation in Design Education: Design-Integrated Versus Additive Use. BauSIM Conf. in Weimar, Germany. https://doi.org/10.26868/29761662.2022.43

Kalpkirmaz Rizaoglu, I. and Voss, K. (2022). Summer Thermal Comfort in Architectural Early Design Workflows. Proceedings of CESBP 2022. 5th Central European Symposium on Building Physics in Bratislava, Slovakia. https://doi.org/10.1063/5.0171066

Voss, K. and Kalpkirmaz Rizaoglu, I. (2022). *"Use of Computer Programs in University Teaching – Series: Building simulation and calculation tools in teaching"* (org. in German: *„Einsatz von Computerprogrammen in der Hochschullehre – Serie: Gebäudesimulation und Berechnungstool in der Lehre"*). Bauphysik 44, H. 4, pp 228-229. https://onlinelibrary.wiley.com/doi/10.1002/bapi.202200021

Kalpkirmaz Rizaoglu, I. and Voss, K. (2020). Building Performance Simulation to Stimulate Architectural Early Design, Proc. Of PLEA Conf. in A Coruña, Spain, pp. 1525. https://doi.org/10.17979/spudc.9788497497947

Hess, S., Kreulitsch, D., Schmid, M., Kalpkirmaz Rizaoglu, I., Honold, A., Stobbe, M., Nytsch-Geussen, C., Lützkendorf, T. (2020). Key action fields for nearly carbon-neutral districts: stakeholder-specific strategies and practice. World Sustainable Built Environment Conference, BEYOND Conf. in Göteborg, Sweden. 10.1088/1755-1315/588/2/022039


## Reports


Walther, K., Kalpkirmaz Rizaoglu, I., Kirant-Mitic, H.T., Derbas, G. (2021). Building 2226 on the Test Bench - Simulation Study on the Relocated 2226 Building by Baumschlager Eberle. IBPSA Building Simulation 2021 Conf. in Brugge, Belgium (Awarded with 1st prize in the modeling competition of IBPSA BS2021).

Kalpkirmaz Rizaoglu, I., Voss, K. (2021). Internal Report for Center for Graduate Studies (CGS): "Performance Based Design – Teaching Activities in Winter Semester 2020-2021" (org. in German: „Performance Based Design – Lehrtätigkeit im Wintersemester 2020-2021"), Bergische Universität Wuppertal, Germany.

Hess, S., Honold, A., Stobbe, M., Kreulitsch, D., Kalpkirmaz Rizaoglu, I., Schmid, M., Lützkendorf, T., Gerber, A., Nytsch-Geusen, C., Voss, K., Dinkel, A. and Herkel, S. (2021) Forschungskolleg EnEff.Gebäude.2050 Final Report - Innovative Projects for the Nearly Climate-Neutral Building Stock 2050. FKZ: 03EGB0006 B - Forschungszentrum Jülich GmbH (PTJ) Freiburg, Germany.

Kalpkirmaz Rizaoglu, I., Voss, K. (2020) Internal Report on the Results of the “Building Performance Simulation in Teaching” Survey for the Participants in the Scope of the Conference of Professors for Building Physics and Technical Building Equipment. University of Wuppertal, Germany.

Books Sections

Kalpkirmaz Rizaoglu, I. (2023). “*Building Performance Simulation Tools”*, in Voss, K., Simon, K. (ed.) *Solar Decathlon Europe 21/22 – Competition Source Book*. Wuppertal. BUW, pp. 150-153. 10.25926/svtg-e916

Kalpkirmaz Rizaoglu, I., Voss, K. (2023). “*Co-heating Test”*, in Voss, K., Simon, K. (ed.) *Solar Decathlon Europe 21/22 – Competition Source Book*. Wuppertal. BUW, pp. 124-125. 10.25926/svtg-e916

Hillebrandt, A., Hans, N. S., Voss, K. and Kalpkirmaz Rizaoglu, I. (2022). *“Urban Construction: Reflections on the past and future of urban construction with wood using the example of Wuppertal's Nordstadt”* (org. in German: *„Urbanes Bauen: Rückbesinnung und Zukunft im urbanen Bauen mit Holz am Beispiel der Wuppertaler Nordstad“*). Wuppertal. https://doi.org/10.25926/nvns-ek77

Kalpkirmaz- Rizaoglu, I., Voss, K. (Eds). (2021). *“Performance Based Design – Investigations Regarding Energy, Daylight and Thermal Comfort”* (org. in German: *„Untersuchungen Hinsichtlich Energie, Tageslicht und Thermischem Komfort“*). Bergische Universität Wuppertal- Kurtz Reinartz, Wuppertal.

Columns in Architectural Magazines

Kalpkirmaz Rizaoglu, I. and Bozkurt, H. (2023) A Smile: Cafe ADA - The story of the transformation of a factory building into the city's living room. XXI Architecture and Design Online Platform. [Available: https://xximagazine.com/c/a-smile-cafe-ada]

Kalpkirmaz Rizaoglu (2022). A Sustainable City Is Possible! Only If We Work Together - Solar Decathlon Europe 21/22. XXI Architecture and Design Online Platform. [Available: https://xximagazine.com/c/solar-decathlon-europe-21-22]

# Appendix

## Appendix A

### AI: “BPS in Teaching” Survey – Questionnaire summary

| Category 1: | Personal Information |
|---|---|
| 1 | Academic title (text entry) |
| 2 | Name and surname (text entry) |
| 3 | Type of the institution (University, Applied University, Other) (single choice), if Other: Other institution type (text entry) |
| 4 | Name of the institution (text entry) |
| 5 | Department (text entry) |
| 6 | Is respondent the head of the department? (Yes, No) (single choice) |
| 7 | Field: educational background of the respondent (Architect, Civil Engineer, Mechanical Engineer, Physicist, Other) (multiple choice), if Other: Other fields (text entry) |
| 8 | E- mail address (text entry) |
| 9 | Teaching experience in years (Less than 5, 5-10, 11-15,16-20, More than 20) (single choice) |
| Category 2: | Course: Questions about the courses in which BPS tool(s) are used (Questions of the category 2 are repeated for each course.) |
| 1,2 | General information: the name of the course (text entry), the level of the course (Graduate, Undergraduate) (single choice), if Undergraduate: The semester of the course (single choice) |
| 3 | Field(s) of the target students of the course (Architecture, Civil Engineering, Other) (multiple choice), if Other: Other fields (text entry) |
| 4 | Course credit (number slider) |
| 5 | Is the course compulsory or elective? (single choice) |
| 6 | Any prerequisite for the course (Yes, No) (single choice), if Yes: Types, names and the typical contents of the prerequisite courses (text entry) |
| 7 | Number of the students of the course (Less than 10, 11-20, 21-30, 31-40, More than 40) (single choice) |
| 8 | Teaching methods (Face to Face, Online Teaching, Online Tutorials, Other) (multiple choice), if Other: Other teaching methods (text entry) |
| 9 | Percentage of time spent on theory, software training, application & parameter studies, analysis & post-processing (multiple number sliders) |
| 10 | Percentage of how much the course is design driven and case study driven (multiple number sliders) |
| 11 | Percentage of the BPS within course (number slider) |
| 12 | Course Format (Part of Design Studio, A Separate Course, but supports Design studio, An Independent Course, Other) (single choice), if Other: Other formats (text entry) |
| 13 | Study Format (Group Study, Individual Study, Both) (single choice) |
| 14 | Exam Format (Oral Presentation with Slideshow, Oral Poster Presentation, Oral Examination, Written Elaboration, Other) (multiple choice), if Other: Other formats (text entry) |
| 15 | Types of the projects mostly handled (Residential, Hotel, Office, Educational, Healthcare, Other) (single choice), if Other: Other types (text entry) |
| 16 | Project scales (Urban scale, District Scale, Building Block, Building, Building Envelop, Single zone, System, Element, Material, Other) (multiple choice), if Other: Other scales (text entry) |
| 17 | Design and documentation tools (Hand Drawing, Rules of Thumb, Physical Models, CAD, BIM, Other) (multiple choice), if Other: Other tools (text entry) |
| 18 | BPS Tools that is used in related course (3D Max, AECOsim, CATT-Acoustic, EnerCalC, DaySIM, DesignBuilder, DIALux evo, Diva, Ecotect, EnergyPlus, IES VE, Insight 360/Revit, Ladybug & Honeybee, OpenStudio, Radiance, Relux/Dialux, Sefaira, SimRoom, TRNSYS, VisualDOE, Wufi, Delphin, Other 1, Other 2, Other 3) (multiple choice), if Other 1, 2 and/or 3: Other tool(s) (text entry) |
| Category 3: | BPS Tool: Questions about the BPs Tool(s) used in the related course |
| 1 | The purpose of BPS Tool Usage (Energy and Indoor Comfort, Hygrothermal, Acoustic, Lighting, Life Cycle Assessment, Fire Protection, Urban Microclimate, Other) (multiple choice), if Other: Other purposes (text entry) |
| 2 | If the students are required to know BPS Tool beforehand. (Yes, No) (single choice) |
| 3 | Version of the tool (text entry) |
| 4 | Design stage options of the BSP Tool (Only for Early Design, Only for Advanced, Both) (single choice) |
| 5 | Representation format of the BPS Tool (Visual, Numerical, Both) (single choice) |

| | |
|---|---|
| 6 | BPS Tool Features (Context or climate based early design Advice, Comparing design alternatives, Generating design alternatives by using parameters,<br>Support for new building technologies, Real-time simulation preview, Outputs available within 3D modeling environment, Ready to go report templates) (multiple choice) |
| 7 | Error Occurrence Rate (number slider) |
| 8 | User-friendliness Rate of the GUI (number slider) |
| 9 | Satisfaction rate (number slider) |
| 10 | Main reasons to use that software for teaching (text entry) |
| 11 | Link(s) for students' works (text entry) |
| | **Suggestions and Comments (text entry)** |

## AII: "BPS in Teaching" Survey – List of BPS tools

| | Tool Name | Link for Tool | License | Developer |
|---|---|---|---|---|
| 1 | Design Builder | https://designbuilder.co.uk// | not free | DBS is a Private Limited Company, UK |
| 2 | Ladybug & Honeybee | https://www.ladybug.tools/<br><br>https://www.food4rhino.com/app/ladybug-tools | free | Mostapha Sadeghipour Roudsari,<br>Chris Mackey, MIT, USA |
| 3 | Relux/DiaLux | https://relux.com/en/<br><br>https://www.dialux.com/en-GB/ | free | RELUX Informatik AG, Switzerland<br><br>German Institute for Applied Lighting Technology (DIAL) |
| 4 | DaySIM | http://web.mit.edu/SustainableDesignLab/software.html<br><br>https://daysim.ning.com/main/index/locked | free | MIT Sustainable Design Lab, USA |
| 5 | OpenStudio | https://www.openstudio.net/ | free | Collaboration by<br>NREL, ANL, LBNL,<br>ORNL, and PNNL, USA |
| 6 | Radiance | https://www.radiance-online.org/<br><br>https://windows.lbl.gov/software/radiance | free | Greg Ward started developing Radiance in 1985 while at Lawrence Berkeley National Laboratory (LBNL), USA |
| 7 | TRNSYS | http://www.trnsys.com/index.html<br><br>http://sel.me.wisc.edu/trnsys. | not free | Transient System Simulation Program, Solar Energy Laboratory, University of Wisconsin, Madison, USA |
| 8 | EnerCalC | https://projektinfos.energiewendebauen.de/en/project/enercalc-simplified-energy-balancing-to-din-v-18599/ | free | Dr.-Ing.Markus Lichtmeß, Luxemburg |
| 9 | IDA ICE | https://www.equa.se/en/ida-ice | not free | EQUA Simulation AB, Sweden |
| 10 | THERM (7.4) | https://windows.lbl.gov/software/therm | free | Lawrence Berkeley National Laboratory (LBNL), USA |
| 11 | TRAIL | https://www.uni-weimar.de/de/bauingenieurwesen/professuren/bauphysik/aktuelles/titel/neue-trail-version-online/<br><br>https://www.trail-energie.de/ | free | Bauhaus University Weimar, Professorship in Building Physics<br>Prof. Dr.-Ing. Conrad Völker - Civil Engineering & Architecture and Urbanism,Germany |
| 12 | THERAKLES | http://bauklimatik-dresden.de/therakles/index.php | free | Institute for Building Physics, TU Dresden<br>Dr. Andreas Nicola, |

| | | | | |
|---|---|---|---|---|
| | | | | Dr.-Ing. Peggy Freudenberg, Dipl.-Ing. Heiko Fechner, Germany |
| 13 | Dymola Modelica | https://www.3ds.com/products-services/catia/products/dymola/?woc=%7B%22category%22%3A%5B%22category%2Fdymola%22%5D%7D&wockw=card_content_cta_1_url%3A%22https%3A%2F%2Fblogs.3ds.com%2Fcatia%2F%22<br><br>https://www.3ds.com/products-services/catia/products/dymola/industry-solutions/ | not free | Dassault Systèmes, France |
| 14 | STAR-CCM+ | https://www.plm.automation.siemens.com/global/en/products/simcenter/STAR-CCM.html | not free | SIEMENS, Germany |
| 15 | DIVA | https://www.solemma.com/<br><br>https://www.solemma.com/Diva.html | not free | SOLEMMA Team, USA |
| 16 | ZUB Argos Pro | https://www.zub-systems.de/en/produkte/argos/pro | not free | ZUB Systems GmbH, Germany |
| 17 | eLCA | https://www.bauteileditor.de/ | | Bundesinstitut für Bau-, Stadt- und Raumforschung (BBSR), Germany |
| 18 | EnOB Lernnetz | http://solarpotential-fbta.ieb.kit.edu/ | free | KIT - Karlsruhe Institute for Technology, BUW - University Wuppertal, Germany |
| 19 | DECA | NA | NA | NA |
| 20 | CATT-Acoustic | http://www.catt.se/ | not free | Bengt-Inge Dalenbäck Gothenburg, Sweden |
| 21 | Wufi | https://wufi.de/en/ | not free | Fraunhofer Institute for Building Physics, Department Hygrothermics |
| 22 | ENVI-met | https://www.envi-met.com/ | not free | ENVI_MET GmbH, Germany |
| 23 | TAS | https://www.edsl.net/tas-engineering/ | not free | Environmental Design Solutions Limited, UK |
| 24 | ZUB Helena | https://www.zub-systems.de/en/produkte/helena | not free | ZUB Systems GmbH, Germany |
| 25 | ZUB Argos | https://www.zub-systems.de/en/produkte/argos | not free | ZUB Systems GmbH, Germany |
| 26 | EnergyPlus | https://energyplus.net/ | free | EnergyPlus is funded by the U.S. Department of Energy's (DOE) Building Technologies Office (BTO), and managed by the National Renewable Energy Laboratory (NREL). EnergyPlus is developed in collaboration with NREL, various DOE National Laboratories, academic institutions, and private firms.USA |
| 27 | VI-Suite | http://arts.brighton.ac.uk/projects/vi-suite<br><br>http://blogs.brighton.ac.uk/visuite/ | free | University of Brighton, UK |

| | | | | |
|---|---|---|---|---|
| 28 | TRNLizard | https://trnsys.de/docs/trnlizard/trnlizard_uebersicht_en.htm<br><br>https://www.food4rhino.com/app/trnlizard | free | Transsolar Energietechnik GmbH, Germany |
| 29 | Energieberater | NA | NA | NA |
| 30 | PHPP | https://passivehouse.com/04_phpp/04_phpp.htm | not free | Passive House Institute; Germany |

## AIII: Interview – Questionnaire

Performance Based Design Studio Interview

**Interviewer:** Isil Kalpkirmaz Rizaoglu

**Interviewee:** (Title, Name, Surname)

**Date:** (day, month, year), (time), (time zone)

INTERVIEW PARTS

**PART 1: INTERVIEWEE'S BACKGROUND –** 10 minutes

**Q1**: How many years of experience do you have with teaching architecture students?

**Q2**: How many years of experience do you have with teaching the topics of building performance to architects using BPS tools.

**Q3**: Do you teach graduate and/ or undergraduate students?

- ☐ graduate
- ☐ undergraduate
- ☐ both

**Q4**: Do you teach only architecture students or both architecture and engineering students?

- ☐ only architecture students
- ☐ both

**Q5**: How would you describe your experience with BPS tools?

**PART 2- PRESENTATION OF THE FRAMEWORK** – 20mins

(via Power Point Presentation)

**PART 3 - FEEDBACK ON THE PRESENTED FRAMEWORK** – 15 mins

**Q1:** What are the strengths / weakness of the framework.

| Strengths | Weaknesses |
|---|---|
| ▪ | ▪ |

**Q2:** General comments about the framework?

## PART 4 – LEARNING FROM INTERVIEWEE'S EXPERIENCES – 15 mins

Q1: Can you provide **details about an example course that is taught by you**, preferably a design studio, regarding the following topics?

1. **Course name:**

| |
|---|
| |

2. **Course format**

☐ Design Studio

☐ Separate course but supports Design Studio

☐ Separate course without design focus

3. **Level of the course**

☐ undergraduate

☐ graduate

4. **Compulsory or elective?**

☐ compulsory

☐ elective

5. **Face-to-face or online?**

☐ online

☐ face-to-face

☐ combined

6. **Average number of the students per semester**

☐ Less than 10

☐ 10-20

☐ 20-40

☐ other

7. **Design content, scope and performance topics, and in particular ratio between the analytical and creative part of the course...**

| |
|---|
| |

8. **Design scales included**

☐ urban scale

☐ district scale

☐ building block

☐ building

☐ building envelope

☐ building zone

☐ building elements

☐ building materials

☐ other

9. **Course activities**

☐ literature research

☐ excursion

☐ case- studies

☐ lab- studies / experiments

☐ lectures

☐ workshops (please define the content of the workshops)

☐ supervisions / consultation

☐ exhibitions

☐ other:

10. **Assignments / Exams**

☐ Comprehension questions

☐ Assignments

☐ Oral exams, i.e. colloquiums, forums etc.

☐ Written exams, i.e. classroom exams, reports, booklets etc.

11. **Design tools**

☐ Hand drawings / sketches

☐ Design guidelines

☐ Rules of Thumb

☐ 2D and/or 3D physical architectural models

☐ CAD Tools:

☐ BIM Tools

☐ Other

12. **Please select** the relation between the performance and the design actions that is applied in the course:

| DESIGN | PERFORMANCE |
|---|---|
| ☐ Settlement / Building footprint<br>☐ Mass studies / Form finding<br>☐ Orientation<br>☐ Envelope<br>☐ Spatial organization / Layout<br>☐ Building elements, i.e., shading, openings etc.<br>☐ Materials<br>☐ Other: | **Climate Analyses**,<br>i.e. different climates and/or future climate, and/or urban heat island effect etc. |

| | |
|---|---|
| ☐ Settlement / Building footprint<br>☐ Mass studies / Form finding<br>☐ Orientation<br>☐ Envelope<br>☐ Spatial organization / Layout<br>☐ Building elements, i.e., shading, openings etc.<br>☐ Materials<br>☐ Other: | **Daylighting**<br>+ artificial lighting |
| ☐ Settlement / Building footprint<br>☐ Mass studies / Form finding<br>☐ Orientation<br>☐ Envelope<br>☐ Spatial organization / Layout<br>☐ Building elements, i.e., shading, openings etc.<br>☐ Materials<br>☐ Other: | **Energy Balance** |
| ☐ Settlement / Building footprint<br>☐ Mass studies / Form finding<br>☐ Orientation<br>☐ Envelope<br>☐ Spatial organization / Layout<br>☐ Building elements, i.e., shading, openings etc.<br>☐ Materials<br>☐ Other: | **Indoor Climate**<br>Ventilation, air quality |
| ☐ Settlement / Building footprint<br>☐ Mass studies / Form finding<br>☐ Orientation<br>☐ Envelope<br>☐ Spatial organization / Layout<br>☐ Building elements, i.e., shading, openings etc.<br>☐ Materials<br>☐ Other: | **Active Solar Energy Use**<br>i.e., Photovoltaic Systems<br>i.e., solar radiation and shading analyses |

Q2: **Main difficulties and drawbacks** in integrating building performance – particularly BPS into design process in architectural education in general.

| |
|---|
| ... |

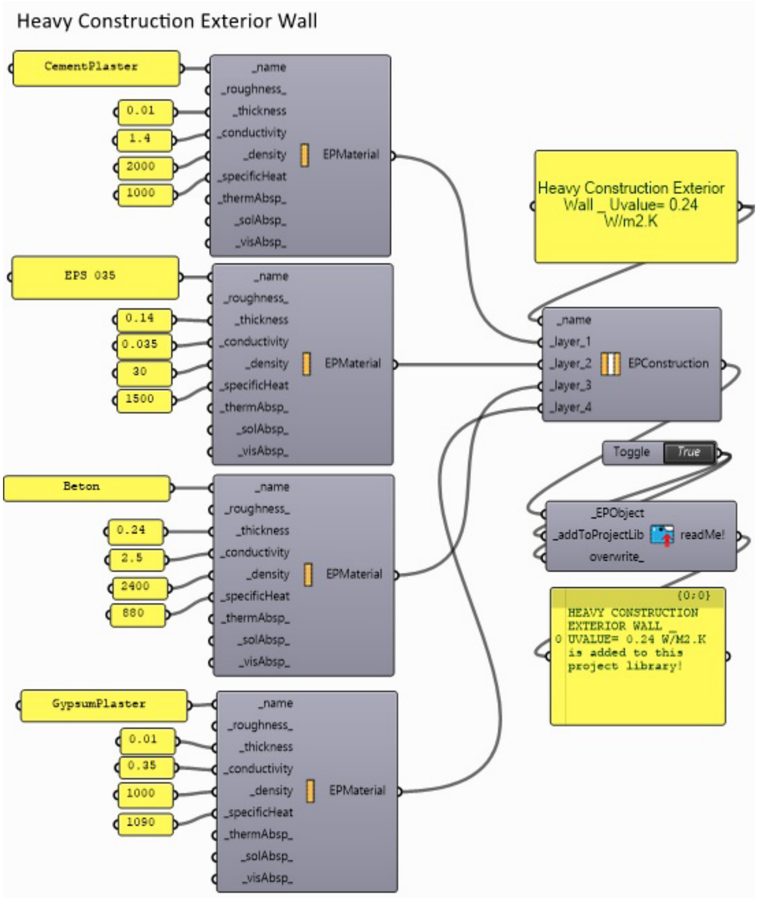
Q3: **Solution suggestions** to overcome the difficulties/drawbacks?

| |
|---|
| ... |

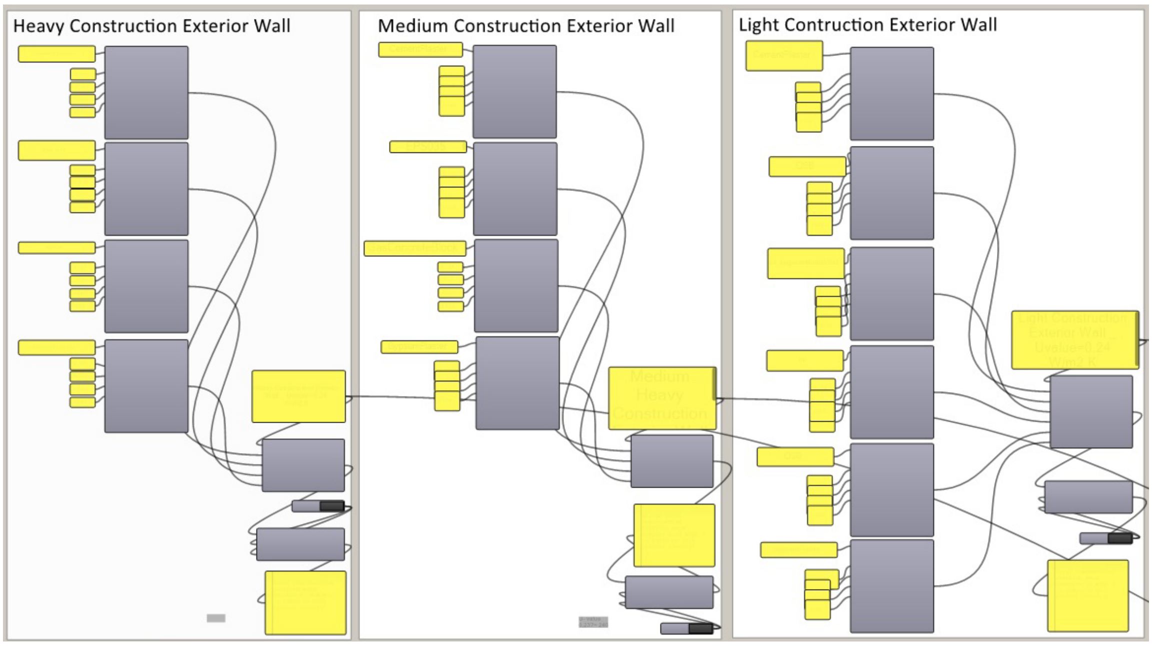
- End of questionnaire -

# Appendix B

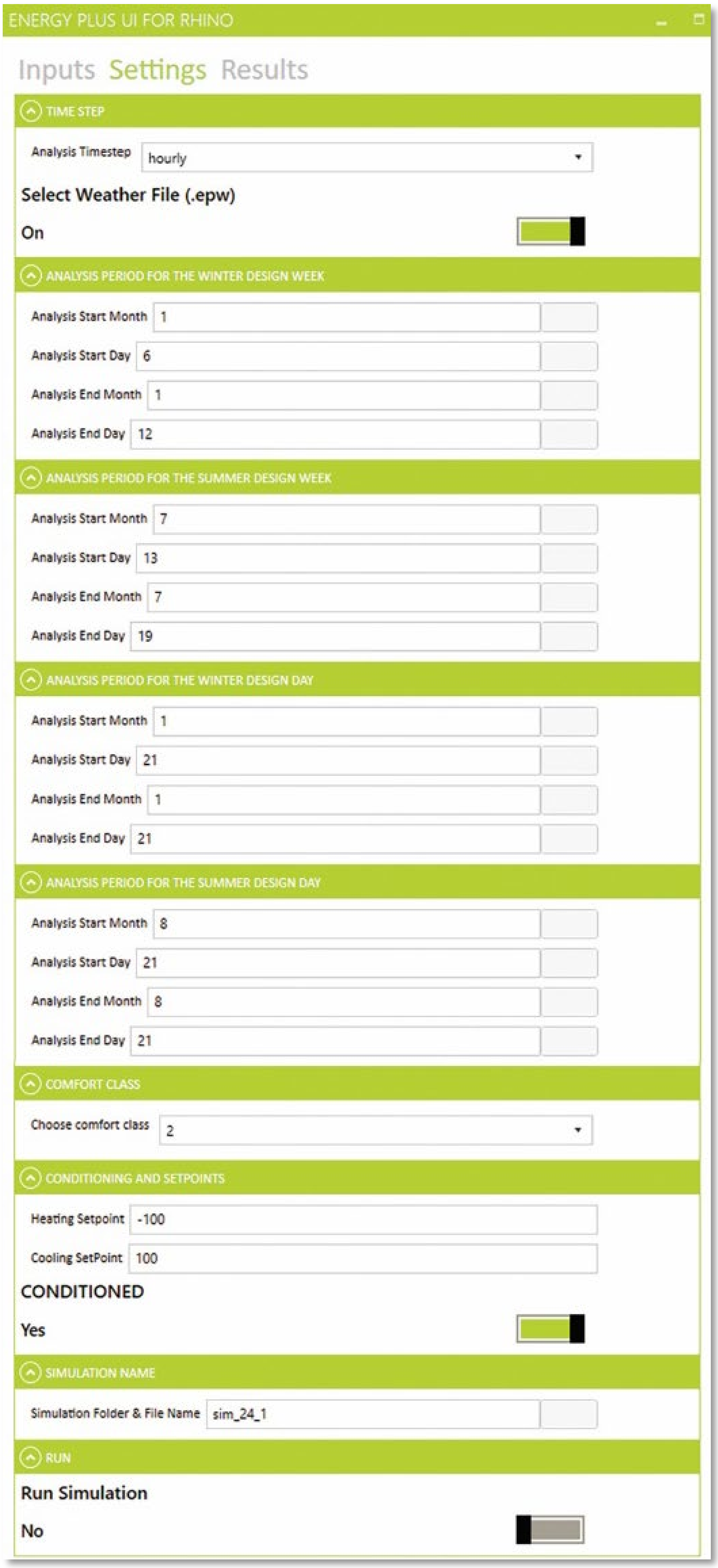
## BI: "EnergyPlus UI for Rhino" - Example scripting for building elements and materials: "Heavy Construction Wall"



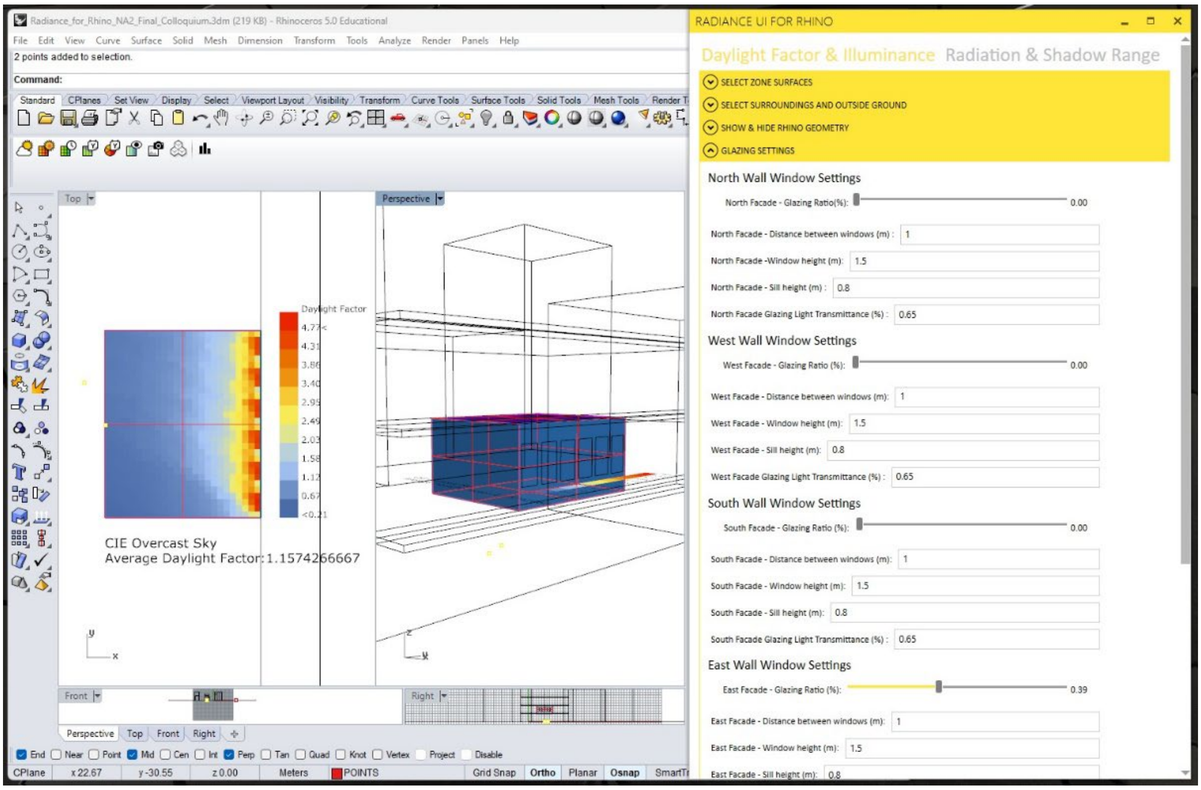

## BII: "EnergyPlus UI for Rhino" - Example scripting for building elements with different thermal mass properties



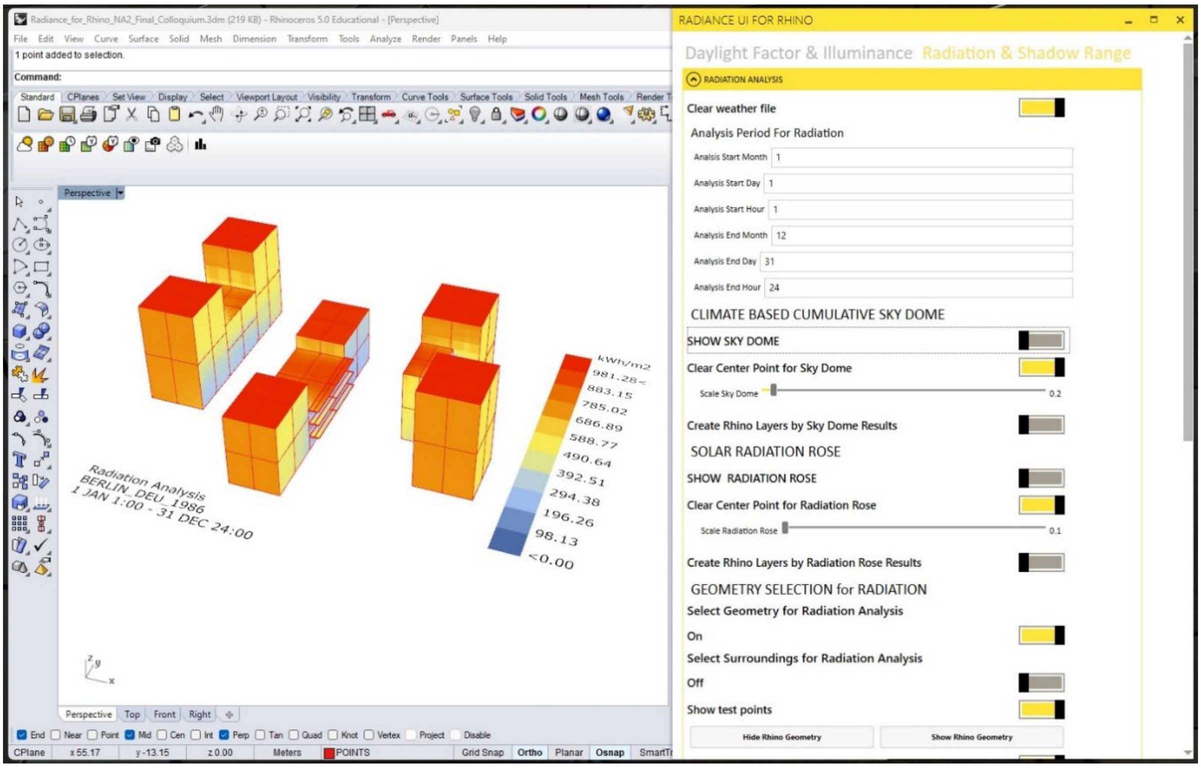
BIII: "EnergyPlus UI for Rhino" – Settings GUI



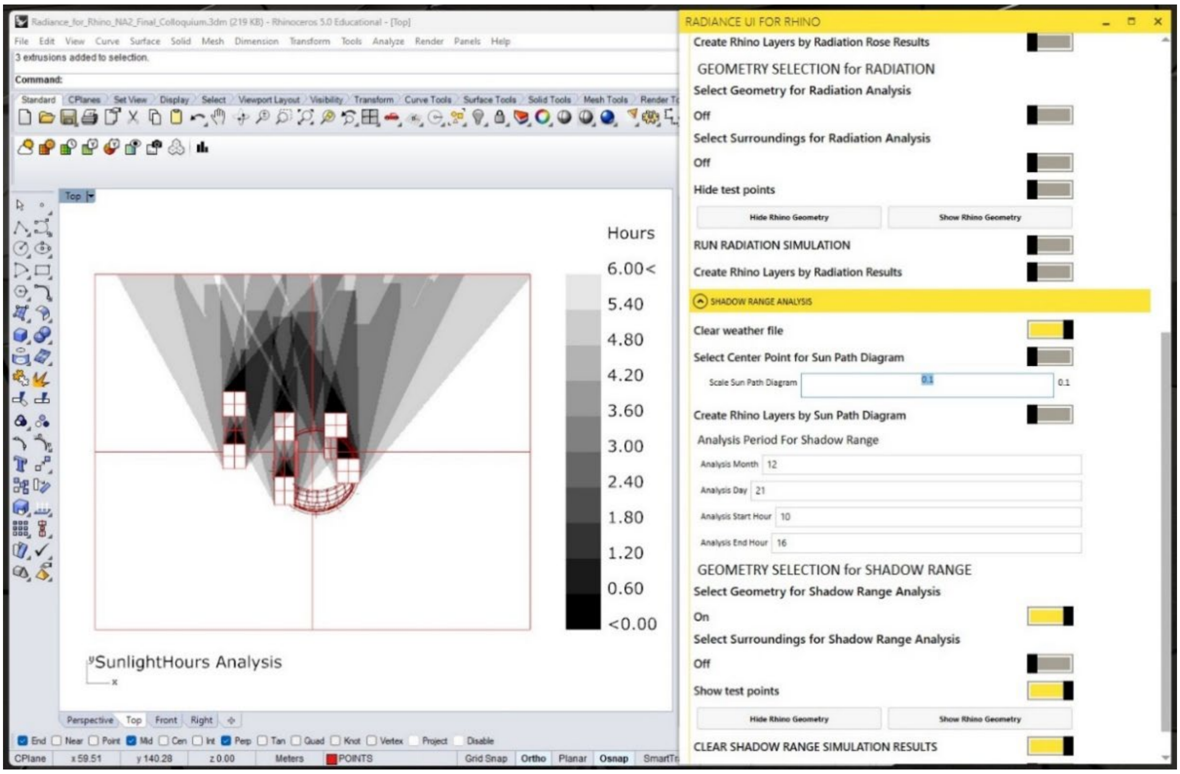
## BIV: "Radiance UI for Rhino" – Example daylight factor analysis




## BV: "Radiance UI for Rhino" – Example radiation analysis



BVI: "Radiance UI for Rhino" – Example shadow range analysis



# Appendix C

## CI: Semi-integrated Studio – Syllabus

Bergische Universität Wuppertal
Fakultät für Architektur und Bauingenieurwesen
b+tga - Bauphysik und Technische Gebäudeausrüstung
Prof. Dr.-Ing. Karsten Voss

**M.Sc.-Studio NB – NACHHALTIGES BAUEN - WS 2020.21**
**Start: 5.11.2020, Thursday at 10.00 am / via Zoom**

STUDIO SUSTAINABLE BUILDING AND BUILDING PERFORMANCE – MODULE 2 / STUDIO NACHHALTIGES BAUEN UND GEBÄUDEPERFORMANCE - MODULE 2

Prof. Dr.-Ing. Karsten Voss
M.Sc. Arch Isil Kalpkirmaz Rizaoglu





Studio Syllabus
(Updated Version: 10.11.2020)
CONTENT OF THE STUDIO

The contents of the 2-semester module are linked to the respective research work of the professorships involved and are developed specifically for each year.

The First Module of the NB Studio is headed by Prof. Hillebrandt's chair in summer semester 2020. In Winter Semester 2020-2021, the Second Module of the S-NB will be conducted by the team of Prof. Dr.-Ing. Karsten Voss, btg+a.

In continuation of the work from the previous semester, the primary focus of the Module 2 is the study of the luminous and thermal behavior of buildings. The studio aims to helps students examine sustainable design approaches by using computer-aided design (CAD) and Building Performance Simulation (BPS) tools in an integrated manner. Therefore, the goal is to advance the designs (existing designs from previous studio S-NB-1) in terms of visual and indoor thermal comfort, as well as the energy by using performance parameters. Also, evaluation of existing design in climate and site context is another significant part of that studio - to not fight against climate but integrate with the climate -. Integrated approach for the buildings, which means consideration of the already existing spaces and the additional design spaces, will be applied through the studio.

Language of the studio is English, but all presentation in the lectures will be supported also by German Language, and student presentations in German language are welcomed.

All studies of the students for colloquiums will be individual presentations including reports. Existing designs, which were carried out as group in Module 1, are required to be examined and re-evaluated individually based on each students' own basic design criteria. In the writing of the work results, the students are introduced to the level of a specialist publication. To do this, it is necessary to achieve a high degree of precision in language and graphic preparation.

The colloquiums are held in both semesters as joint events for both chairs.

**Prerequisite**: The first module of **S-NB** (S-NB - Moule 1: STUDIO NACHHALTIGES BAUEN UND GEBÄUDEPERFORMANCE - Module 1)

LEARNING GOALS

By the end of the studio, students will:

- conduct a series of design analysis workflows regarding climate, daylighting, thermal comfort, and building energy use.
- acquire the knowledge required to critically discuss/present the environmental concept of a building.
- gain integrated approach for sustainable building design.

STUDIO STRUCTURE

The studio is organized into 3 parts:

- **Part 1**: 5 Weeks: Climate and Energy Demand + First Colloquium
- **Part 2**: 5 Weeks: Daylighting Availability and Thermal Comfort + Second Colloquium
- **Part 3**: 4 Weeks: Sustainable Building Design + Final Colloquium

STUDIO ACTIVITIES

**Lectures:** Lectures will be held to remind the background information for the related topics and that will help students to complete weekly assignments. In total there will be 2 lectures at the beginning of part 1 and part 2. And each Lecture will be between 90 min and 120 min (**See Appendix 1** for the basic content of the lectures).

**Workshops**: At the first and the second part of the studio, there will be workshops, which are for application of the basic metrics about daylight, comfort and energy by adoption of the building performance simulation tools. Each workshop will cover how to use that tool in relation to mentioned topics / metrics. In total, there will be 4 workshops and they will be followed by hands on session to apply what students learn in workshops (**See Appendix 1** for the basic content of the workshops).

**Comprehension Questions (CQ):** Lectures and workshops will be accompanied by CQ that will underline the basics of the topic and will help you reinforce what you learn in that lecture. CQ will not be graded but, will be evaluated for participation.
**Weekly Assignments:** After each lecture and workshop week, students will be given an assignment about the topics of the week. These weekly assignments can be considered an application part of the lectures and workshops that requires students to implement solutions that they learn during the studio. Assignments are significant to advance their knowledge and to see if there is any gab between theory and application. All assignments will cover one of the basic tasks that





students are supposed to apply in their final submission, thereby each completed assignment by students will also assist them for their final project. In total, they will be given 6 assignments: 2 after weekly lectures and 4 after workshops. Assignments will include specific deadlines in their instructions. Assignments will not be graded but, will be evaluated for students' participation. Details for each assignment will be announced in Moodle under the title of "*M.Sc.-Studio NB -NACHHALTIGES BAUEN- WS 2020.21*" (https://moodle.uni-wuppertal.de/course/view.php?id=22302)

**Supervision:** These supervision sections will be held at the end of each part of the Studio, and also it will be main part of the third part of the Studio. Additional assistance for the final colloquium will be provided also by Prof. Hillebrandt's chair in Part 3. The aim of the consultancy is to support students while they are getting prepared for the colloquiums and for the final submission.

**Colloquiums**: At the end of each part, there will be colloquiums that requires students conduct, present and submit their original and independent work individually. First and Second Colloquiums will have their specific topics e.g.; climate and site analysis, daylight availability, visual comfort, energy use, thermal comfort, energy modeling and renewable energy use. Correspondingly the final colloquium should be approached in a comprehensive way. Student are expected to bring all solutions from first and second colloquiums together and reflect them into their designs. Re-evaluation of the existing designs from Module 1, based on each student's own sustainable design goals and creation of design alternatives, comparison of them and selection of the best alternatives are the main tasks for Final Colloquium. All studies for colloquiums will be presented individually by students including reports. Colloquium presentations and the related reports will include specific deadlines in their instructions and will be graded. Details for each colloquium will be announced in Moodle under the title of "*M.Sc.-Studio NB -NACHHALTIGES BAUEN- WS 2020.21*" (https://moodle.uni-wuppertal.de/course/view.php?id=22302)

**Research Forums**: There will be two research forums aiming to evaluate all master studios / seminars within the faculty through students' work and enhancing net-works. Students of this studio are also expected to present their studies up to that day. Students will be divided in two groups for the forums, and each will be responsible for only one forum (please see Appendix 2: Weekly schedules for the forum dates).

STUDIO CREDIT and GRADING
This is a 6-credit studio. Your final grade will be mainly based on presentations and reports which are asked for colloquiums. Additionally, your level of participation through the comprehension questions and weekly assignments will provide you extra points for the evaluations of your work.

STUDIO TIMELINE



Bergische Universität Wuppertal
Fakultät für Architektur und Bauingenieurwesen
**b+tga** - Bauphysik und Technische Gebäudeausrüstung
Prof. Dr.-Ing. Karsten Voss

Semester Time: 01.10.2020 - 31.03.2021

Studio Time: 05.11.2020 - 18.02.2021

Studio start: 5.11.2020, Thursday at 10.00 am / via Zoom

The Studio will be 2 hours (+ consultation meetings) in a week for 13 weeks, plus final colloquium, in total It is 14-week long studio. The official week time for the lectures and consulting is Thursday morning between 8.00 am and 1.00 pm. Any change regarding the day and the hours of the studio will be announced in Moodle under the title of "*M.Sc.-Studio NB -NACHHALTIGES BAUEN- WS 2020.21*" (https://moodle.uni-wuppertal.de/course/view.php?id=22302)

For the detailed schedule, please see **Appendix 2**: Weekly Schedule. Please note that day and the content of the lectures may be modified.

**STUDIO PLACE**

The Lecturing hours of the studio and the colloquiums will be conducted via video conferencing tool Zoom. Depending on the circumstances, the individual consultation and assistance appointments are planned to be held live / on-site.

**Hints for Students:**

Download and dial-in via the Wuppertal University portal: https://uni-wuppertal.zoom.us/

Please register with your first and last name (without abbreviations) and your university e-mail address so that we can assign you correctly in the meetings.

Tests the dial-up and functionality of microphones and cameras in advance.

**STUDIO TOOLS**

**3D Architectural Design CAD Tool: Rhinoceros3D** (Rhino) computer-aided design (CAD) modeler will be used as a base for building performance simulation (BPS), e.g. climate, daylighting and energy analysis, with ClimateStudio (CS), which is a plug in for Rhino. While Rhino is available for both Windows and Mac, the CS plug in only run under Windows. In order to use them, students will therefore need access to a newer Windows computer with Rhinoceros version 6 on it. A free 90-day trial version is available for students (https://www.rhino3d.com/download/rhino/6.0/evaluation).



**Important note**: Students, who do not have Rhinoceros3D 6 license, are recommended to consider the start date of the 90Day trial version of the Software in accordance with the lecture time. The first workshop that you will use Rhino 6 is at 19.11.2020 and the Final Colloquium is at 18.02.2021. This is an 89-day long interval. So, don not start your trial version earlier than 18.11.2020.

While this studio does not provide specific training for modeling in Rhino, lots
of free training material is available (https://www.rhino3d.com/training). Only a basic level Rhino knowledge is sufficient for the studio; e.g. creation of the simple geometry that representation your existing design. Also, you can import your 3D models, which are created in other 3D programs, into Rhino.

**BPS Tool 1: ClimateStudio** (CS) is Solemma 's new environmental modeling software (https://www.solemma.com/ClimateStudio.html). It is a plugin for Rhino under Windows. It is a tool for (day)lighting and thermal analysis. All students will be provided license key for the studio time. Student are not expected to know that BPS tool beforehand, studio will provide specific training for the necessary topic at basic level. Also, series of short video tutorials for ClimateStudio daylighting and thermal analysis are available (https://solemma.com/TrainingClimateStudio.html)

**BPS Tool 2: EnerCalc** is a tool, which deals with the energy balancing of buildings on a monthly basis as a multi-zone model. The software significantly simplifies the primary energy balancing of buildings and enables a rapid evaluation of building concepts with the aim of achieving net zero energy buildings. It is available by the developer free of charge for non-commercial use (https://projektinfos.energiewendebauen.de/en/project/enercalc-simplified-energy-balancing-to-din-v-18599/).

**STUDIO REFERENCE BOOKS**

Main reference books are available in Campus Haspel University Library as Reserve Collections (Semesterapparat). Also, work in progress to provide them all online as e-book. You can see reference books (by searching as "Semesterapparat Kalpkirmaz Rizaoglu"): https://moodle.uni-wuppertal.de/course/view.php?id=23581

**Syllabus - Appendix 1**: Content* of the Studio for M.Sc.-Studio NB – NACHHALTIGES BAUEN - WS 2020.21

| **Part 1:** Climate and Energy Demand | | **Part 2:** Daylighting Availability and Thermal Comfort | | **Part 3:** Sustainable Building Design | |
|---|---|---|---|---|---|
| Week 1 | **Lecture 1: Introduction**<br>- Introduction to Sustainable Building Design<br>- Site and Climate | Week 6 | **Lecture 2: Daylight availability and Thermal comfort**<br>- Daylight Availability and Visual Comfort<br>- Thermal Indoor Comfort<br>- Defining (Sustainable) Design Goals | Week 11 | **Supervision for the Final Colloquium: Climate and Energy Demand**<br>- Re-evaluation of climate-site and multi-zone energy models<br>- Creation of design alternatives by re-considering building envelope ((Re-massing) based on climate and energy demand<br>- Design upgrades for better energy harvesting |
| Week 2 | **Workshop 1: Multi-Zone Energy Modeling and PV system Design by EnerCalc**<br>- Multi-zone Energy Modeling<br>- PV System Calculations | Week 7 | **Workshop 3: Daylighting Simulation by ClimateStudio (CS)**<br>- Daylight Availability (Daylight Factor, Daylight Autonomy)<br>- Visual Comfort (Sunlight Exposure, Illuminance and Glare)<br>- Indoor Electric Lighting (Luminaire type, Lighting power density, Artificial Illuminance) | Week 12 | **Supervision for the Final Colloquium: Daylighting and Thermal Comfort**<br>- Re-evaluation of visual and thermal comfort models<br>- Creation of design alternatives by re-considering optical and thermo-physical properties of building elements<br>- Design upgrades for higher visual and summer thermal indoor comfort, as well as for lower energy use intensity by using different design measures, e.g. building envelope upgrades, PV installations etc. |
| Week 3 | **Workshop 2: Climate - Site Analysis and by ClimateStudio (CS)**<br>- Preparation of 3D model for climate and daylighting analysis in Rhino, defining the simulation model in CS.<br>- Sun Path Analysis<br>- Shadow analysis<br>- Radiation Analysis | Week 8 | **Workshop 4: Thermal Comfort Simulation by ClimateStudio (CS)**<br>- Preparation of 3D model for thermal comfort analysis in Rhino, and defining the simulation model in CS<br>- Building Scale and zone scale thermal comfort analysis<br>- Summer Indoor Thermal Comfort by free floating temperature (un-conditioned zone) | Week 13 | **Supervision for the Final Colloquium: Integration of Design Upgrades for the Final Design**<br>- Re-evaluation and revision of design based on all BPS analysis in an integrated manner<br>- Creation of final alternatives and selection one of them based on your sustainable design goals<br>- Case comparison: 'before (base-case)' and 'after (upgraded-case)' BPS |
| Week 4 | **Supervision for the First Colloquium:** Preparation of climate-site and multi-zone energy models. Envelope analysis considering the suitable parts of building envelope and site for energy harvesting according to base-case energy demand. | Week 9 | **Supervision for the Second Colloquium:** Preparation of visual and thermal comfort analysis for the second colloquium. Generation of design alternatives. Comparison of the base case and upgrades based on design goals. | Week 14 | **Final Colloquium** |
| Week 5 | **First Colloquium** | Week 10 | **Second Colloquium** | | |

***Note**: Please note that Content of the studio is subject to change. Please follow the announcements from Moodle under the title of "M.Sc.-Studio NB -NACHHALTIGES BAUEN- WS 2020.21" (https://moodle.uni-wuppertal.de/course/view.php?id=22302)



**Syllabus - Appendix 2**: Weekly Schedule* for NB Studio - Module 2: Studio Sustainable Building and Building Performance – Module 2

**Winter Semester 2020-2021** | **Studio NB Module 2** | **Prof. Dr.-Ing. Karsten Voss** | **Semester Time: 01.10.2020 - 31.03.2021** | **Seminar Time: 05.11.2020 - 18.02.2021**

| Part | Nr. | KW /Week | Tag/Day | Datum/Date | Studio Sustainable Building and Building Performance Module 2 | Dozent(in) / Lecturer | Bemerkungen / Notes |
|---|---|---|---|---|---|---|---|
| | | 44 | Tues | 27/10/2020 | **Master Study - Kick Off Event / Veranstaltung** | Voss,Kalpkirmaz Rizaoglu | |
| PART 1 | 1 | 45 | Thurs | 5/11/2020 | Introduction + **Lecture 1** + CQ 1 + WA1 | Voss,Kalpkirmaz Rizaoglu | WA: Weekly Assignment, CQ: Comprehension Questions |
| PART 1 | 2 | 46 | Thurs | 12/11/2020 | Feedback for WA1 + **WORKSHOP 1** + CQ 2 + WA2 | Voss, Kalpkirmaz Rizaoglu | Multi-Zone Energy Modeling and PV Design by EnerCalc |
| PART 1 | 3 | 47 | Thurs | 19/11/2020 | Feedback for WA2 + **WORKSHOP 2** + CQ 3 + WA3 | Kalpkirmaz Rizaoglu | Climate & Site Analysis by ClimateStudio BPS tool + Rhino3D CAD Modeling |
| PART 1 | - | 48 | Tues | 24/11/2020 | **Master Study - 1. Research Forum** | **Student Group 1** | **Student Presentations** |
| PART 1 | 4 | 48 | Thurs | 26/11/2020 | Feedback for WA3 + **Supervison** for the 1. Colloquium | Kalpkirmaz Rizaoglu | |
| PART 1 | 5 | 49 | **Thurs** | **3/12/2020** | **1. Colloquium / 1. Zwischenkolloquium** | **Voss, Hillebrandt, Kalpkirmaz Rizaoglu** | **Präsentation und Erläuterungsbericht / Presentation and Report** |
| PART 2 | 6 | 50 | Thurs | 10/12/2020 | Feedback for 1. Colloq. + **Lecture 2** + CQ 4 + WA4 | Kalpkirmaz Rizaoglu | |
| PART 2 | 7 | 51 | Thurs | 17/12/2020 | Feedback for WA4 + **WORKSHOP 3** + CQ 5 + WA5 | Kalpkirmaz Rizaoglu | Daylighting simulation by ClimateStudio BPS tool + Rhino 3D CAD Modeling |
| PART 2 | - | 52 | | 24/12/2020 | Weihnachten / Christmas | - | |
| PART 2 | - | 53 | | 31/12/2020 | Weihnachten / Christmas | - | |
| PART 2 | 8 | 1 | Thurs | 7/1/2021 | Feedback for WA5 + **WORKSHOP 4** + CQ 6 + WA6 | Kalpkirmaz Rizaoglu | Thermal Comfort Simulation by ClimateStudio BPS tool + Rhino 3D CAD Modeling |
| PART 2 | 9 | 2 | Thurs | 14/1/2021 | Feedback for WA6 + **Supervison** for the 2. Colloquium | Kalpkirmaz Rizaoglu | |
| PART 2 | 10 | 3 | **Thurs** | **21/1/2021** | **2. Colloquium / 2. Zwischenkolloquium** | **Voss, Hillebrandt, Kalpkirmaz Rizaoglu** | **Presentation and Report / Präsentation und Erläuterungsbericht** |
| PART 3 | - | 4 | Tues | 26/01/2021 | **Master Study - 2. Research Forum** | **Student Group 2** | **Student Presentations** |
| PART 3 | 11 | 4 | Thurs | 28/1/2021 | **Supervision*** for the Final Colloquium | Kalpkirmaz Rizaoglu | *Additional assistance for the final Colloquium will be provided by Prof. Hillebrandt's Chair. |
| PART 3 | 12 | 5 | Thurs | 4/2/2021 | **Supervision*** for the Final Colloquium | Kalpkirmaz Rizaoglu | |
| PART 3 | 13 | 6 | Thurs | 11/2/2021 | **Supervision*** for the Final Colloquium | Kalpkirmaz Rizaoglu | |
| PART 3 | 14 | 7 | **Thurs** | **18/2/2021** | **Final Colloquium, Exam / Schlußkolloquium,Prüfung** | **Voss, Hillebrandt, Kalpkirmaz Rizaoglu** | **Präsentation und Erläuterungsbericht / Presentation and Final Report** |

***Note**: Please note that date of the lecture is subject to change. Please follow the announcements from Moodle under the title of "M.Sc.-Studio NB -NACHHALTIGES BAUEN- WS 2020.21" (https://moodle.uni-wuppertal.de/course/view.php?id=22302)

## CII: Semi-integrated Studio – Entrance survey

# M.Sc.-Studio NB -NACHHALTIGES BAUEN- WS 2020.21

Home / My courses / M.Sc.-Studio NB -NACHHALTIGES BAUEN- WS 2020.21 / Week 1 / Studio NB Entrance Survey

## Studio NB 2 Entrance Survey

**Opened:** Thursday, 5 November 2020, 4:00 PM

Overview | Edit questions | Templates | Analysis | Show responses | Show non-respondents

Dear Studio NB Participants,

We are interested in learning more about studio participants' backgrounds, interests, and motivations, and encouraging engagement with the course, so we can do the best possible job designing, evaluating and refining this course.

The survey is available now, please join as soon as possible!

It will be closed on 10th of November at 11.59 pm.

Thanks in advance,

Prof. Dr.-Ing. Karsten Voss

M.Sc. Arch Isil Kalpkirmaz Rizaoglu

◄ Week 1 Content | Jump to... | Week 1 Lecture Presentations ►

Reset user tour on this page

M.Sc.-Studio NB -NACHHALTIGES BAUEN- WS 2020.21

Policies

Impressum

# M.Sc.-Studio NB -NACHHALTIGES BAUEN- WS 2020.21

Home / My courses / M.Sc.-Studio NB -NACHHALTIGES BAUEN- WS 2020.21 / Week 1 / Studio NB Entrance Survey / Questions / Edit questions

## Studio NB Entrance Survey

Overview | Edit questions | Templates | Analysis | Show responses | Show non-respondents

Add question Choose...

1. How familiar are you with the topics in this course?
Edit

- ○ Extremely familiar
- ○ Very familiar
- ○ Somewhat familiar
- ○ Slightly familiar
- ○ Not at all familiar

2. How important is the learning topics of this course to you?
Edit

- ○ (0)Not at all important
- ○ (1)A little important
- ○ (2)Moderately important
- ○ (3)Very Important
- ○ (4)Extremely important

3. Which activities of the course are more attractive for you? (Multiple selection is possible)
Edit

- ☐ Lectures
- ☐ Workshops
- ☐ Comprehension Questions
- ☐ Weekly assignments
- ☐ Supervision
- ☐ Colloquiums
- ☐ Research Forums

4. Which part of this course is more important to you?
Edit

- ○ Part 1: Climate and Daylighting
- ○ Part 2: Energy Use and Thermal Comfort
- ○ Part 3: Sustainable Building Design

5. What is your goal in taking this course? What do you expect by the end of the course, which knowledge and skills? Please explain by your own words.
Edit

6. How do you rate your general knowledge and skills in terms of Building Performance Simulation Tools (BPSTs)?

Edit

◯ (1)Low
◯ (2)Little
◯ (3)Good
◯ (4)Very Good
◯ (5)Excellent

7. Which BPS tools did you use before? Please write name(s) of the tool(s). Edit

8. Which of these tools – that you mentioned in previous question – are you most comfortable with? Edit

9. Mostly in which design stage you use BPSTs? (Multiple choice is possible)

Edit

☐ Pre-design stage
☐ Conceptual design stage
☐ Early/ Initial Design Stage
☐ Detailed design stage
☐ Construction drawing stage
☐ Construction Stage

10. What are the main purposes to use BPSTs for you? (Multiple choice is possible)

Edit

☐ Energy and Indoor
☐ (Day)lighting
☐ Hygrothermal
☐ Urban Micro Climate
☐ Life Cycle analysis
☐ Acoustics
☐ Renewable Energy Technologies

11. What are the main reasons and drivers for you for the selection of BPSTs? Main reasons for your preference.(Multiple choice is possible)

Edit

☐ Easy to learn/get in
☐ Ease of use

☐ All in one (all basic BPS features included in one tool)
☐ Design stage options (both suitable for early and advanced design)
☐ Short simulation time
☐ User Friendly Graphical User Interface (GUI)
☐ Easy training and learning resources
☐ Easy to reach developer or user forums in case of problem
☐ Reliable and reasonable outputs
☐ Suitable for both research and teaching
☐ Transparent process
☐ Validated
☐ Code compliance (e.g. DIN V18599)
☐ Generates design alternatives
☐ Compare design alternatives
☐ Support for new building technologies (e.g. renewable energy systems)
☐ Tool is integrated in CAD tools
☐ Commercially accepted
☐ In-house development (e.g. developed by your institute)
☐ Available free Educational version
☐ Price & quality balance
☐ Instant & real-time simulation preview
☐ 3D Design modelling option
☐ Visual representation of the results
☐ Compatibility and interoperability (e.g. easy file exchange with tools)

12. Which simulation environment most you prefer?
Edit

○ Building Information Modeling (BIM)- based (e.g. Revit )
○ Computer Aided Design (CAD)-based (e.g. Rhinoceros. Sketchup)

13. Please select one of the options about your first impression about the course after first lecture.
Edit

○ I felt exited, and looking forward for the next classes.
○ I was surprised with the content of the course, which is not what I expected.
○ I felt satisfied with the content of the course, which was what I expected.
○ I felt overwhelmed because of intensive and heavy content of the course.
○ I felt neutral after first lecture, I will consider in coming lectures.

14. If possible, please share your comments on the course structure, course content, course materials etc. Your comments are really appreciated and will be considered for the next steps of the course to make it more enjoyable and productive for you. Edit

◄ Week 1 Content

Jump to...

Week 1 Lecture Presentations ►

# CIII: Semi-integrated Studio – Example "Assignment" document

btg+a

Prof. Dr.-Ing. Karsten Voss

University of Wuppertal

Faculty of Architecture and Civil Engineering

Chair of Building Physics and Technical Building Equipment

M.Sc.-Studio NB 2 -NACHHALTIGES BAUEN- WS 2020-2022

Prof. Dr.-Ing. Karsten Voss and

M.Sc. Arch Isil Kalpkirmaz Rizaoglu,

**Assignment 5.2**

**A design upgrade for daylighting, and evaluation of that upgrade in terms of thermal comfort**

Please prepare a report about a design upgrade for daylighting, and evaluation of that upgrade in terms of thermal comfort for the space that you chose in Assignment 5.1.

Please follow the steps below in your report

**Step 1: Base Case - Daylighting**

Summarize the existing situation for the space that you investigated in terms of daylight availability and visual comfort in Assignment 5.1. as below:

- Explain if your space meets the needs of space use / program regarding daylight availability and visual comfort.
- Specify the main problems by mentioning the metrics and the values (Low daylight availability, high obstruction angle, exceeding sun light exposure, disturbing glare, etc.).

**Step 2: Design Upgrade - Daylighting**

- Select one of the main problems
- Try to predict main parameters that cause the problem (orientation and / or position of windows and / or space, low / high WWR, ratio between WHH and space depth, poor structural shading design etc)
- Select of the parameters and apply it in your design.
- Run daylighting simulation for upgraded 3D model. (In addition to simulation studies, you can investigate the upgraded model by using rules of thumb.)
- Compare *the base-case* and *the upgrade* in terms of daylight availability and visual comfort.

Note: In that step, the upgrade should be a design modification, which is directly related to your 3D design model. Optical and Thermo-physical parameters related to daylighting (such as Tvis and Rvis ) for Building Envelope Elements should be remained same for that assignment. Also, please do not apply any dynamic shading system in daylighting simulations.

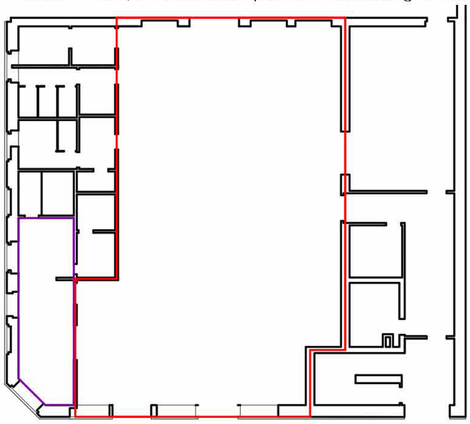
**Step 3: Investigate the Base-Case in terms of Thermal Comfort**

At that step you are asked to run single-zone thermal analysis for your base-case.

Example **"Single-Zone Thermal Modeling" file can be found in Moodle under week 8 (File name: CafeAda_BaseCaseModel_DT).**

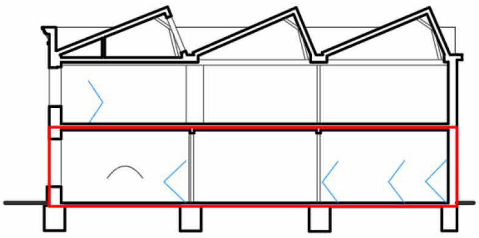
1

- Model the zone, windows, boundary condition and structural shading surfaces in Rhino:
  - A zone must be closed 3D shape with planner surfaces without thickness.
  - For the 3D closed Brep, use outside dimensions of the space for exterior surfaces and centreline dimensions for interior surfaces, see the Café Ada ground floor plan below, red color represents the border of zone, and the black represent the real design borders.



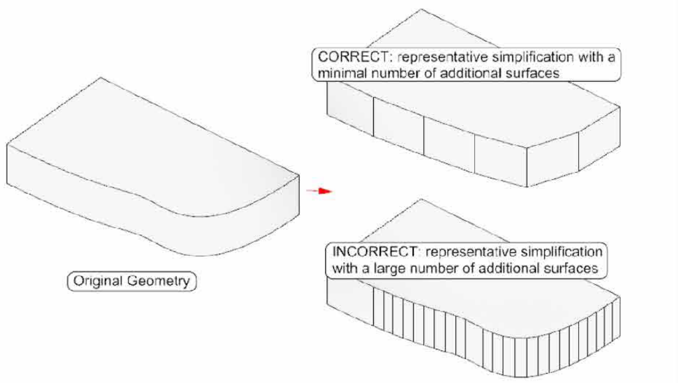
Plan

  - Also, sections can be considered in same way, se the image below.



Section

  - Windows (and any other transparent surfaces) should be drawn as co-planner surfaces, without thickness and coincident with the associated surface. Window frames are included in the calculation of the window dimensions by CS; therefore, a window surface that you model in rhino for your thermal model should include the window frame. You can think of the dimension of the windows surface as a gap, which is left on the wall after pulling of the window assembly.
  - Simplify the design geometries when you are creating a thermal zone: see the image below.

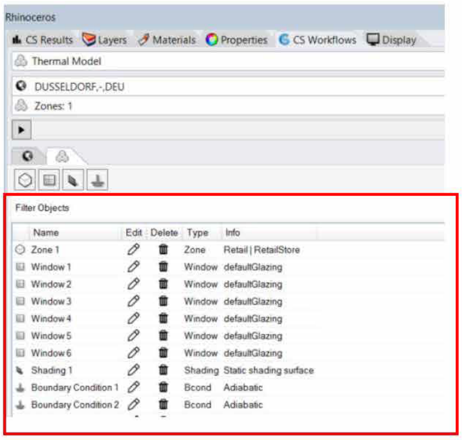



(Image source: https://honeybee.readthedocs.io/en/latest/single_zone_model/modelling_zone_geometry.html)

- Boundary conditions: CS considers all surfaces as exterior surface interacting with outside air if you do not define it in any other way. First create plain surfaces without thickness and coincident with the surface that you want to define boundary condition.

- As a final step in thermal zone modelling in Rhino, draw your structural shading as simplified as possible.

▪ Define your simplified rhino model as a Thermal model in CS under Thermal model.




Note: For the all non-exterior surfaces, you should define boundary condition; for example, for interior surfaces choose “Adiabatic”, for ground floor choose “Ground” option.

Note: To check if your rhino layers (elements) are defined as thermal model elements, view your model in “Wireframe” mode in rhino. For different elements colors are such as - 3D Zone: White, Windows: blues, adiabatic surfaces: red and shading: grey, and ground boundary surface is green.

▪ Zone settings: Summarize your zone settings about “Loads”, “Ventilation” and “Materials” as a table. And show schedules that you use for occupancy, equipment, lighting and ventilation.

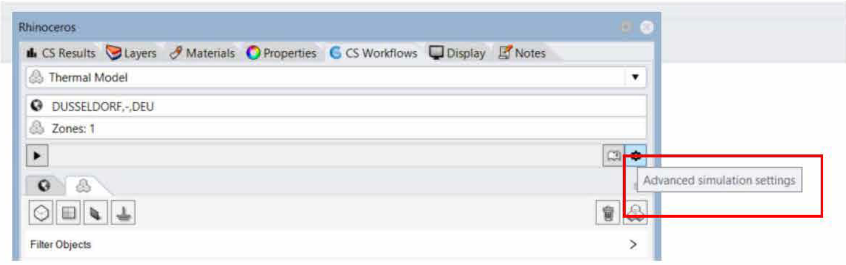
▪

Note: All active systems must be turned off during your evaluations. You are expected to evaluate the free-floating temperature situation, which means no mechanical conditioning is available in zone. Please be sure heating, cooling and mechanical ventilation are un-clicked (turned-off) before you ran the simulation.

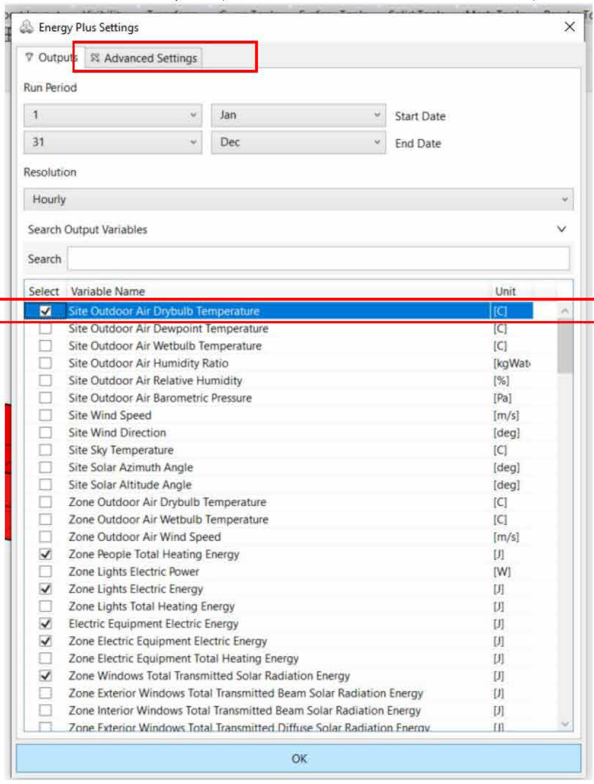
- Window Settings: Summarize your window settings as a table or image. Point out layers, U value, Tvis, SHGC values.
- 

Note: Do not use "shading system" under window settings.
Note: Do not select "internal" window. This option can be used for multi-zone modelling.

- Before running the thermal simulation, go to CS – thermal Model, and click to advanced settings, see the image below.




Select "*Site Outdoor Air Drybulb Temperature*" and click "OK". This is important to do before running simulation. Otherwise the file that you export from CS won't include outside air temp data in CSV output.



- Run thermal model simulation and present the results/ visuals about only **temperature and energy flows**, which is provided in CS result tab.

- Additionally, you are asked to extract the "outside dry bulb temperature" and "zone operative temperature" data from CS and use it in the excel file named "ATM_190604 kw". This is a excel file that you will automatically have the chart after filling the related cells in "simulation input" sheet, you can see the results in "simulation evaluation" sheet. You should include the annual and typical summer design week (which is a typical week of the hottest season in a typical meteorological year) charts showing operative temperature in relation with outside temperature.

  - **Find the excel file named as "ATM_190604 kw" in Moodle under section Week 8.**
  - **Find the explanation documentation about "Data Export from CS - Energy Plus"in Moodle:** How to Export Report; and how to Split Comma Separated Values (CSV) Into columns in excel and change the decimal separation; How to enter data in excel File "ATM_190604 kw"

**Step 4: Investigate the Daylighting Upgrade in terms of Thermal Comfort**

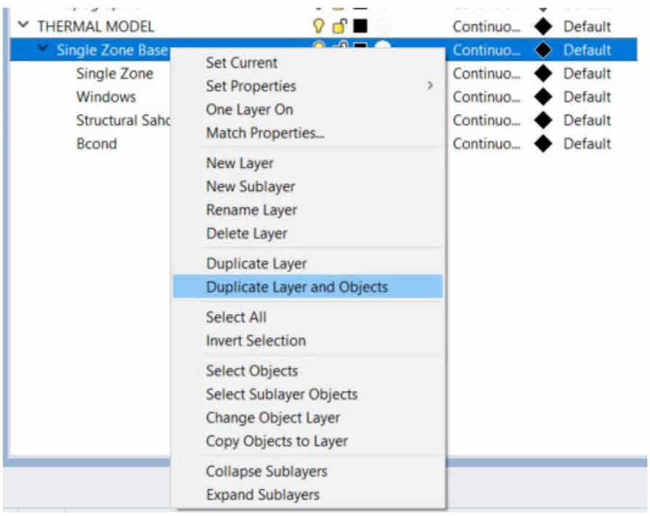
- Model the zone, windows, boundary condition and structural shading surfaces in Rhino based on your daylighting upgrade model.

  Note: You can duplicate layers and objects of your already existing 'base thermal model'. And only adjust / modify the elements that you changed in daylighting model. See the image below how to duplicate Rhino Layer.
  if you use that duplication method, do not forget to turn off the Rhino layers of your "base single zone thermal model", when you are running thermal simulation for upgraded model.

- All setting for zone, windows, and boundary conditions must be kept same as base model.

- Run thermal model simulation and present the results/ visuals about zone temperature and energy flows, which is provided in CS result tab.

- Same as step 3, you should include, in your report, the annual and typical summer design week charts showing operative temperature in relation with outside temperature by exporting simulation data and using the excel file named "ATM_190604 kw". Keep the base case data, and add upgrade data, therefore result can be seen in comparison for base case and upgrade.



**Format and Deadline**

- Please try to summarize your findings in a table format and write a conclusion evaluating all steps together.
- Max 10 page (A4) including all figures, tables and explanation.
- **Submit your assignment until 12.01.2021, Tuesday evening 23.59**
- Upload your Report file (.pdf) and other work files [digital modelling and simulation files: EnerCalC (.txt), ClimateStudio (.csr) and Rhino models (.3dm)., Excel (.xlsx)]

in Moodle, under section Week 8 - Assignment 5.2

**Sources:** You have the list of reference books and other sources in the course syllabus. Also, you can check the sources below.

- For ClimateStudio Documentation you can visit: https://solemma.com/Docs/ClimateStudio/
- For Climate Studio Video Tutorials, you can visit: https://www.solemma.com/TrainingClimateStudio.html
- You are recommended to check Standard: EN 15521

Prepared by Isil Kalpkirmaz Rizaoglu,

If you have questions, please contact

kalpkirmazrizao@uni-wuppertal.de

**- End of the Document -**

## CIV: Semi-integrated Studio – Example “Expectations for Colloquium” document

**btg+a**

**B**auphysik und **T**echnische **G**ebäude**a**usrüstung

Prof. Dr.-Ing. Karsten Voss

Bergische Universität Wuppertal

Fakultät für Architektur und Bauingenieurwesen -

Bauphysik und Technische Gebäudeausrüstung

Pauluskirchstraße 7

42285 Wuppertal

**M.Sc.-Studio NB -NACHHALTIGES BAUEN- WS 2020.2**

By Prof. Dr.-Ing. Karsten Voss and

M.Sc. Arch Isil Kalpkirmaz Rizaoglu

**SECOND COLLOQUIUM EXPECTATIONS DOCUMENT**

**Week 10 – Studio NB Module 2 – SECOND COLLOQUIUM**

**Investigation of a Space for Visual and Thermal Comfort**

**LOCATION AND TIME**

**21.01.2021, 8:30 am. – 12:00 pm, via Zoom**

**Link for the Zoom meeting** (same zoom link for weekly meetings):

https://uni-wuppertal.zoom.us/s/95643571405?pwd=R0tFMk1XNkFQU1d2ajNzY1FwNWNPQT09#success

This link is also available in Moodle, under title “M.Sc.-Studio NB -NACHHALTIGES BAUEN-WS 2020.21”, in general announcements section. To see the Moodle page of the Studio please visit: https://moodle.uni-wuppertal.de/course/view.php?id=22302

**PRESENTATIONS**

- 13 individual presentations by students
- Max 10 min for each presentation + 5 min. for Q&A
- Max 15 slides for each presentation
- Students are required to present and submit their original and independent works individually.

1

**CONTENT - Tasks to be presented**

**Task 1: Defining Daylighting Design Goals** (Ref. Assignments 4 and 5.1)

- Introduce your design (section, plans, perspectives etc.) by summarizing your design approach and expectations for whole building in terms of daylighting.
- Select one of the main uses from your extension part and define your expectation and daylighting design goals in more detail for that space (requirements, metrics, limit values, investigation surface etc)
- Give reference for requirements and metrics: Standards, certification systems, manuals, design guidelines, rules of thumb, books, lectures etc…
- Additionally, try to define your thermal comfort goals / expectations, especially for summer thermal comfort; what do you want to avoid or provide for the user in summer time?

**Task 2: Description of Base-Case for Daylighting Simulation** (Ref. Assignment 5.1)

- Prepare and present daylight model for the base case
- Describe main elements of the thermal model and the properties of them

**Task 3: Description of Base-Case for Thermal Simulation** (Ref. Assignment 5.2)

- Prepare and present the thermal model for the base-case (single zone model)
- Describe main elements of the thermal model and the properties of them

<u>*Basic settings for Single Zone Thermal Model for Summer Thermal Comfort evaluation</u>

<u>Zone settings:</u>
<u>Loads:</u>
- All loads are on (click)

<u>HVAC:</u>
- Heating is on. Set point is 20 degrees Celsius, Availability schedule is “AllOn”.
- Cooling is off.
- Humidity Control is off.
- Mechanical Ventilation is on, Heat recovery (choose “none”) and economizer (choose “NoEconomizer”) are always off.
- Fan Energy using EMS is off.

**Note:** Sometimes building program and the conditioning setting may conflict. If your simulation fails when you turned off one of the system, you can in-active the system by using availability schedule of it. It is the same thing to tun off system or select the “AllOff” option as a schedule.
<u>Ventilation:</u>
- Nothing is active in that section. (Both Scheduled and Natural ventilations are off.
- Infiltration is off.)

<u>Water:</u>
- Hot water (DHW) is off.

<u>Window Settings</u>
- Do not use “Internal Glazing” option
- Do not change anything under “Ventilation Settings” and “Zone Mixing” in window settings section.

*Please note that these basic settings will remain same for any investigation, in other words; these settings will be same for your “base-case” thermal model, for your “test-case” thermal models, and for your “upgrade-case”.

**Task 4: Investigation of Base-Case for Daylight Availability and Comfort, and Thermal Comfort** (Ref. Assignment 5.2)

- Investigate the "base-case" for both daylighting and thermal comfort.
- Explain if your space meets the needs of space use / program regarding daylight availability, visual comfort and thermal comfort.
- Specify the main problems by mentioning the metrics and the values (Low daylight availability, high obstruction angle, exceeding sun light exposure, disturbing glare, exceeding solar gains, exceeding hours of thermal discomfort, etc).

**Task 4: Investigation of "Test-Cases": Testing Parameters for Daylight Availability and Comfort, and Visual Comfort**

Main parameters to test are:

- Para. 1: Window Wall Ratio (WWR)
- Para. 2: Window (Glazing) Material properties (Tvis, SHGC and U value)
- Para. 3: Structural Shading
- Para. 4: Dynamic Shading (Operable Blinds)
-

To solve the problems that you detected in previous steps and/or improve the quality of the design in terms of daylighting and thermal comfort, you are asked to test these parameters.

- Select and apply only one parameter for each investigation.

For example, let's think that the WWR ratio of base case is 30%, you already run daylighting and thermal comfort simulation with 30%. Change the WWR (the way you change this value depends on your design problem; you may decrease or increase the ratio), and apply that change both to your daylighting and thermal model, and see the changing results. Repeat that for each parameter. You can use 1 parameter more than once, for example, you can try two different WWR variations or 3 different structural shading variations. Anyway, you are asked to test each parameter by using at least one variable, so you will have at least four "Test- Cases" for each model (daylight and thermal models).

**Note:** There are high number of other parameters that effect visual and thermal comfort design, but, in this study, due to the didactic reasons we ask you to use / explore these parameters during investigations.

**Task 5: Re-evaluation of "Test-Cases" and "Upgrade"** – Searching optimum solution both for daylighting and thermal comfort

You are asked for one final design "upgrade" both for daylighting availability and thermal comfort.

- Evaluate the test-cases to see how each parametric variation effected results.
- Detect the variations that improved your design for daylighting and/or thermal comfort.
- Apply the variations that significantly improved your design all together to the base-case for your final design "upgrade"

**Task 6: Summary**

- Summarize your findings in a table format (it is good for comparison of the results)

  Please see an example table format, which explains also how to use Parameters and variables through your investigation, below. Here in that table, metrics and variations are just examples; you can decide which metric to use and you can decide how many variations to test for one parameter.

| | | BASE-CASE | TEST-CASE 1 | TEST-CASE 2 | TEST-CASE 3 | TEST-CASE 4 | TEST-CASE 5 | TEST-CASE 6 | UPGRADE |
|---|---|---|---|---|---|---|---|---|---|
| | **Parameter** | | Para.1 WWR | Para.1 WWR | Para.2 Glazing_SHGC | Para.2 Glazing_SHGC | Para. 3: Structural Shading - Overhang Depth (m) | Para. 4: Dynamic Shading (ON/OFF) | Para.1 WWR<br>Para. 2 Glazing-SHGC |
| | **Variable** | | Para.1- Var.1 | Para.1- Var.2 | Para.2- Var.1 | Para.2- Var.2 | Para.3- Var.1 | Para. 4- Var.1 | Para.1- Var.2<br>Para.2- Var.2 |
| | **Parameter Value** | | 20% | 60% | 0,35 | 0,21 | 1 | ON | 60%<br>0,21 |
| **Daylight availabilty and Visual Comfort** | **avrDF** | | | | | | | | |
| | **sDA** | | | | | | | | |
| | **ASE** | | | | | | | | |
| | **avgUDIa** | | | | | | | | |
| | **sDG** | | | | | | | | |
| | **Blinds Open** | | | | | | | | |
| | . | | | | | | | | |
| **Summer Thermal Comfort** | **Hours outside the comfort (> 25 C)** | | | | | | | | |
| | . | | | | | | | | |
| | . | | | | | | | | |

- Mention about the key findings and evaluate all work.

**PRESENTATION STRUCTURE AND DESIGN**

Please consider the notes below when you are preparing your presentations.

- **Font style**: Arial
- **Font Size**: not smaller than 14 pt.
- **Color Range and Graphical Language**: Use the same color range (green tones) for your graphics and iconic images.

**Note:** Same design structure must be maintained in report with only one difference, which is font size. Font size for the report is 11 pt. The page size should be A4 and the report should be max. 15 pages, all images and figures included.

**FINAL SUBMISSION**

The first colloquium submission includes two main documents*:

1. Colloquium presentation
2. Report

Your reports should include all the content of your presentations with more comprehensive explanations.
You can submit your folders into Moodle, under section Week 10-Seconf Colloquium-Assignments.

* Please also submit your other digital modelling and simulation files: Excel (.xlsx), ClimateStudio (.csr) and Rhino models (.3dm).

## Deadline for the Second Colloquium Submission: 21.01.2021, 23:59 pm.

**Language:** The final output - publication of Second Module - is planned to be in German Language. Thereby, your main work (Colloquium Report) is better to be in German.

On the other hand, it would be great that either your verbal or visual presentation is in English during colloquium.

**If you have any questions, please contact:**

Isil Kalpkirmaz Rizaoglu

e-mail: kalpkirmazrizao@uni-wuppertal.de or kalp@uni-wuppertal.de

# CV: Semi-integrated Studio – Evaluation Survey

## M.Sc.-Studio NB -NACHHALTIGES BAUEN- WS 2020.21

Startseite / Meine Kurse / M.Sc.-Studio NB -NACHHALTIGES BAUEN- WS 2020.21 / Allgemeines / Studio NB Modul 2 WS 2020-2021 Evaluation Survey

### Studio NB Modul 2 WS 2020-2021 Evaluation Survey

**Geöffnet:** Mittwoch, 24. Februar 2021, 18:40

Überblick | Elemente bearbeiten | Vorlagen | Auswertung | Einträge anzeigen

Dear participants,

By the end of Studio NB Modul 2, we would like to ask you several questions to understand how effective our course was and also to receive your comments to be able to improve and upgrade it.

Survey is set in an anonymous way, so your identities won't be visible to us, as well as to the other participants. Please feel comfortable and free when you are answering the questions

It is a short survey with 10 questions, and average duration is between 10 -15 minutes.

Please participate the survey as soon as possible, and participations before the 1st of March is really appreciated.

If you have any questions or further feedbacks, please don't hesitate to contact me.

Isil Kalpkirmaz Rizaoglu

e-mail: kalp@uni-wuppertal.de

◄ Second Research Forum Group and Content | Direkt zu: | Updated Studio Syllabus (10.11.2020) ►

Tour erneut starten

M.Sc.-Studio NB -NACHHALTIGES BAUEN- WS 2020.21

Datenschutzinfos

Impressum

# M.Sc.-Studio NB -NACHHALTIGES BAUEN- WS 2020.21

Home / My courses / M.Sc.-Studio NB -NACHHALTIGES BAUEN- WS 2020.21 / General / Studio NB Modul 2 WS 2020-2021 Evaluation Survey / Questions / Edit questions

## Studio NB Modul 2 WS 2020-2021 Evaluation Survey

Overview | Edit questions | Templates | Analysis | Show responses

Add question: Choose...

Edit

**Question 1**: Through the Studio you had a number of different activities, please Indicate how useful you found each of them.

Please select a number between1 and 5 for each activity.

**1** means **"not useful"** and **5** means **"very useful"**.

LECTURES

Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

WORKSHOPS

Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

COMPREHENSION QUESTIONS

Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

WEEKLY ASSIGNMENTS

Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

SUPERVISION

Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

COLLOQUIUMS

Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

Edit

**Question 2:** Which topic of the Studio was the **most attractive** one for you?

most attractive topic

Edit

○ (0)Climate and Site
○ (0)Energy Demand and Solar Energy
○ (0)Daylighting and Visual Comfort

○ (0)Thermal Comfort
○ (0)Integrated approach for Sustainable Building Design

Edit

**Question 3**: Which topic of the Studio was the **most difficult** one for you?

most difficult topic

Edit

○ (0)Climate and Site
○ (0)Energy Demand and Solar Energy
○ (0)Daylighting and Visual comfort
○ (0)Thermal Comfort
○ (0)Integrated Approach for Sustainable Building Design

Edit

**Question 4**: At the very first steps of the Studio, before you start building performance related investigations, you are asked to mention about your expectation and presumption for your design in terms of energy, daylighting and thermal comfort.

At the end of the Studio, after detailed investigations, when you compare your expectations with the simulation results, are they inline or did simulation results show you a completely new picture, which is fay away from your expectations and presumptions.

Expectations & Simulation Results

Edit

○ (0)The whole investigation did not show me anything new about the performance of my design, the simulation results were exactly same with my presumptions.
○ (0)The whole investigation showed me something new, I got some results different than my presumptions, but not much different than my expectations.
○ (0)The whole investigation showed me completely different picture than I expected. I got simulation results far from my presumption.

If you want to add other comments on Question 4, please use the text box. Edit

Edit

**Question 5**: Some descriptions about Climate Studio (CS) are given below.

Please select a number between 1 and 5 for each description.

**1** means **"disagree"** and **5** means **"fully agree"**

CS is easy to learn

Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

CS is easy to use

Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

CS is suitable for both early and advanced design stages

Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

CS has a short simulation time

Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

CS has rich learning resources, i.e. documentations and video tutorials
Edit

○ {0}1 ○ {0}2 ○ {0}3 ○ {0}4 ○ {0}5

CS has a user friendly Graphical User Interface (GUI)
Edit

○ {0}1 ○ {0}2 ○ {0}3 ○ {0}4 ○ {0}5

CS has a good export features, i.e. ready-to-go reports, simulation data as csv file etc.
Edit

○ {0}1 ○ {0}2 ○ {0}3 ○ {0}4 ○ {0}5

CS is good integrated with Rhino
Edit

○ {0}1 ○ {0}2 ○ {0}3 ○ {0}4 ○ {0}5

CS enables user create custom zone templates
Edit

○ {0}1 ○ {0}2 ○ {0}3 ○ {0}4 ○ {0}5

CS has a rich material library
Edit

○ {0}1 ○ {0}2 ○ {0}3 ○ {0}4 ○ {0}5

CS default zone settings (thermal model) are very helpful
Edit

○ {0}1 ○ {0}2 ○ {0}3 ○ {0}4 ○ {0}5

CS enables user to customize the simulation
Edit

○ {0}1 ○ {0}2 ○ {0}3 ○ {0}4 ○ {0}5

Edit

**Question 6**: What was the most difficult thing that you experienced while using CS?

Please use the text box. For example: creating a 3D model in Rhino or/and assigning daylighting materials or/and assigning & defining thermal zone elements or/and setting weather data or/and adjusting thermal zone settings etc.
Edit

Edit

**Question 7**: Do you think that BPS tools raise confidence for taking architectonic decisions?

For instance; do you say that I can decide more confidently if I can support my design decision with the performance simulation results?

**1** means **"disagree"** and **5** means **"fully agree"**.

BPS raises confidence
Edit

◯ {0}1 ◯ {0}2 ◯ {0}3 ◯ {0}4 ◯ {0}5

Edit

**Question 8**: What do you think, if the building performance simulation that you conducted through the Studio supported or limited your design creativity?

**1** means "**BPS limited my creativity**" and **5** means "**BPS supported my creativity**"

BPS supports creativity
Edit

◯ {0}1 ◯ {0}2 ◯ {0}3 ◯ {0}4 ◯ {0}5

Edit

**Question 9**: After completing the Studio, how do you see the level of improvement of your skills and self-confidence for using Building Performance Simulation Tools (BPSTs).

**1** means "**very little**" and **5** means "**noticeably high**".

improvement of BPSTs use skills
Edit

◯ {0}1 ◯ {0}2 ◯ {0}3 ◯ {0}4 ◯ {0}5

Edit

**Question 10**: Do you plan to use Building Performance simulation Tools (BPSTs) in your future studies, i.e. for your Master Thesis?

BPSTs use in future studies
Edit

◯ {0}YES ◯ {0}NO

If your answer is "NO" for the question 10, please indicate the reason very briefly. Please use the text box. Edit

Edit

**Comments**

If possible, please share your comments on the course regarding structure, content, materials, activities.

Your comments are really appreciated and will be considered for the next steps.

Please use the text box for your comments. Edit

# CVI: Integrated Studio – Syllabus

Bergische Universität Wuppertal
Fakultät für Architektur und Bauingenieurwesen
**b+tga** - Bauphysik und Technische Gebäudeausrüstung
Prof. Dr.-Ing. Karsten Voss

**M.Sc.-Studio NB Part 2 – WS 21-22**
STUDIO SUSTAINABLE BUILDING AND BUILDING PERFORMANCE – Part 2

## Performance-based Early Design Investigations
## A SPACE BETWEEN

**Start:** 14.10.2021, Thursday, HB.03.03 at 10:00 am

Prof. Dr.-Ing. Karsten Voss
M.Sc. Arch Isil Kalpkirmaz Rizaoglu

## Studio Syllabus

1

**CONTENT**

The contents of the 2-semester module are linked to the respective research work of the professorships involved and are developed specifically for each year in the scope of sustainable buildings and building performance. In summer semester 2021, the first part of the Studio NB is headed by Prof. Hillebrandt's chair. In Winter Semester 2020-2021, the second part of the Studio NB will be conducted by the team of Prof. Dr.-Ing. Karsten Voss, btg+a. Both chairs are involved in consultation, discussion and colloquiums during these two semesters to keep the interaction and coo-operation between two parts.

At the first part of Studio NB, students made intensive research about the massive and half-timber structures of - *Gründerzeit* - Wuppertal, as well as the investigations regarding embodied energy, life cycle assessment and summer thermal performance of these specific buildings. In continuation of the work, part 2 brings a new design challenge in urban context in the age of climate change: a space between *Gründerzeit* houses. In this content "performance-based early design" investigation creates the main theme of the Studio.

The studio aims to support students to examine sustainable design approaches by using computer-aided design (CAD) and building performance simulation (BPS) tools. Therefore, the second part aims to reinforce students' skills of operating BPS and design tools in tandem for sustainable building design. At the Winter Semester 2021-2022, studio will focus on utilization of BPS in the early design phase to stimulate and inspire design investigation by using performance indicators. As well as, the climate change scenarios will be included in performance evaluations to see how present designs are resilient to the climate change and how do they cope with that predicted future scenarios.

**STRUCTURE**

**PHASE 1: Understanding Performance on the Edge of Climate Change – *A Case Study: Building 2226***

The part 1 starts with an investigation of Building 2226, which is one of the most well-known recent architectural works with its low-tech passive house approach. This phase aims to understand the impact of the climate change on design and performance, in the meantime to refresh the basic knowledge regarding selected main performance tasks, which are solar energy utilization, daylight availability and summer thermal comfort. Five-week long Part 1 includes 2 workshops as an introduction for the use of tools and for the main performance tasks of the Studio, a supervision week follows the second workshop, then this phase ends with the *First Colloquium*. Student will conduct their works to answer the questions of *"How does Building 2226 perform in different climates?"* and *"How can you adapt it to a new climate?"*. Different location with different climate patterns will be selected, and research & simulations will be conducted as a group studies for each location. The expected final output of this phase are proposals from each group to increase the performance of the Building 2226 for investigated climate considering present and future climate scenarios.

2

**PHASE 2: Investigating Design and Performance Interaction – *A Space Between***
Second phase of the studio comes with a new design challenge on a space located between two *Gründerzeit* buildings. The aim of this phase is the investigation of the solution space at the intersection of design and performance. The use of space will be flexible under the main content of residential use. Seven-week long phase 2 includes 3 workshops, which will provide further details about the use of tools and furthermore, introduce parametric design and simulation methods for each performance task. Each workshop will be followed by a supervision week including hands-on sessions, discussions and consultations. *The Second Colloquium* will be the conclusion for this phase. Students will conduct their works to answer the question of *"How much does FORM matter for Performance?".* Massing and form finding studies will be done by using specific performance indicators – such as; energy self-sufficiency as an indicator for solar energy utilization, daylight autonomy for daylight availability and neutral hours for Summer thermal comfort - in order to reach the solution space for aimed performance task. Rule-based – parametric – design and simulation workflows will be implemented. For the investigation of possible solutions, space related parameters such as compactness, height, depth, as well as envelope related thermo-physical and optical properties will be included in the form finding process. Climate groups will be formed based on the climates discussed at the first phase. Each student will work individually to develop their own designs, also it is optional to work in pairs for this phase of the Studio. Design investigations will be driven separately for each performance task including future climate scenarios. By the end of second phase, each student (or each pair) is asked to come with at least one *pre-design* for each main performance task. Specifically, for there are three main performance tasks, expressly at least three *pre-design solutions* – each of them considering present and future climate scenarios – are expected.

**Phase 3: Design for Performance - *A Space Between***
The third phase is about learning how to recognize key parameters and how to manage contradicting performance goals for a final design. Three-week long phase 3 includes 1 workshop by which students will be guided about how to conduct iterative design and simulation workflows. Further investigation through the parameters will be done to see changing performance rates of different tasks depending on changing variables of these parameters. Then, two supervision weeks will follow for further discussions and consultation. Students will conduct their works to answer the question of *"How to find a design solution that meets different performance goals".* Main task is integration of the performance-specific *pre-designs* from previous phase into a design - alternatives - with overall performance. Each student will work individually to develop their own design alternatives based on their own design and performance criteria.

**STUDIO ACTIVITIES**

**Lectures:** Lectures will be held to refresh the theoretical basic knowledge regarding the main performance tasks. In total there will be only one main lecture at the beginning of phase 1, if needed short lectures will be held during workshop weeks.

**Workshops**: The main activity of the Studio is workshop. In total, there will be 6 workshops and they will be followed by hands-on session through supervision weeks.



**Comprehension Questions (CQ):** Lectures and workshops will be accompanied by CQ that will underline the basics of the topic and will help students reinforce what they learn. CQ will not be graded but, will be evaluated for participation.

**Weekly Assignments**: Each workshop will be followed by an assignment. All assignments will cover one of the basic tasks that students are expected to apply in their final submission, thereby each completed assignment can be considered as one step taken for their final project. In total, students will be given 6 assignments and they will include specific deadlines in their instructions. Assignments will not be graded but, will be evaluated for students' participation. Details for each assignment will be announced in Moodle under the title of "*M.Sc. Studio Nachhaltiges Bauen und Gebäudeperformance Teil 2 - WS 2021/2022*" (https://moodle.uni-wuppertal.de/course/view.php?id=27606)

**Supervision:** In total, there are already planned 6 supervision weeks. If needed, extra consultation and discussion can be provided with a request in beforehand. Additional assistance for the colloquium will be provided also by Prof. Hillebrandt's chair.

**Colloquiums**: At the end of each phase, there will be colloquiums that requires students conduct, present and submit their original and independent work. All studies are responsible for the preparation and the presentation of their works at the day of colloquium. Colloquium presentations and the related reports will include specific deadlines in their instructions and will be graded. Details for each colloquium will be announced in Moodle under the title of "*M.Sc. Studio Nachhaltiges Bauen und Gebäudeperformance Teil 2 - WS 2021/2022*" (https://moodle.uni-wuppertal.de/course/view.php?id=27606)

**Research Forums**: There will be two research forums aiming to evaluate all master studios and seminars within the faculty through students' work and enhancing net-works. Students of this studio are also expected to present their studies up to the day of the forum. Students will be divided in two groups for the forums, and each group will be responsible for only one forum presentation.

Also, see **Appendix 1**: ***M.Sc.-Studio NB Part 2 – WS 21-22 CONTENT*** for the further information about the content of the main activities.

**STUDIO CREDIT and GRADING**
This is a 6-credit studio. Students' final grade will be mainly based on presentations and reports. Additionally, level of participation through the comprehension questions, weekly assignments, and most importantly performance for the final studio booklet as a summary of whole semester work will provide extra points for the final grade.

**STUDIO TIME and PLACE**
The Studio will be 2 hours (+ consultation meetings) in a week for 13 weeks. Adding colloquium weeks, in total It is 16-week-long. The planned day of the week is Thursday, and the time is between 8.00 am and 12.00 pm. The lectures, workshops and supervision will take place in Room 3 on the 3rd floor of Building HB (HB.03.03).

Colloquium places and any change regarding the time and place will be announced in Moodle under the title of "M.Sc. Studio Nachhaltiges Bauen und Gebäudeperformance Teil 2 - WS 2021/2022" (https://moodle.uni-wuppertal.de/course/view.php?id=27606). For the detailed schedule, please see **Appendix 2: M.Sc.-Studio NB Part 2 – WS 21-22 TIMETABLE**. Please note that day and the content of the lectures may be modified.

**STUDIO TOOLS**

**Design Tool: Rhinoceros3D** (Rhino) computer-aided design (CAD) tool will be used as a base for design and building performance simulation (BPS). Trial version is available for students (https://www.rhino3d.com/download/). While this studio does not provide specific training for modeling in Rhino, free training materials are available (https://www.rhino3d.com/training). Only a basic level Rhino knowledge is sufficient for the studio; Also, 3D models created in other 3D programs can be imported into Rhino.

**BPS Tool 1: ClimateStudio** (CS) is Solemma 's environmental modeling software (https://www.solemma.com/climatestudio). All students will be provided license key for the studio time. Student are not expected to know that this tool beforehand, for the Studio will provide specific training for the necessary tasks. Also, series of short video tutorials for ClimateStudio daylighting and thermal analysis (https://www.solemma.com/climatestudio-tutorial-videos) and documentation (https://climatestudiodocs.com/) are available. Basic hardware requirement is a computer running a windows operating system. ClimateStudio does not currently run on the Mac operating system. Mac users can still use ClimateStudio by running Windows through a multi-boot utility such as boot camp. Basic software requirements is Rhinocerose3D (6 or 7).

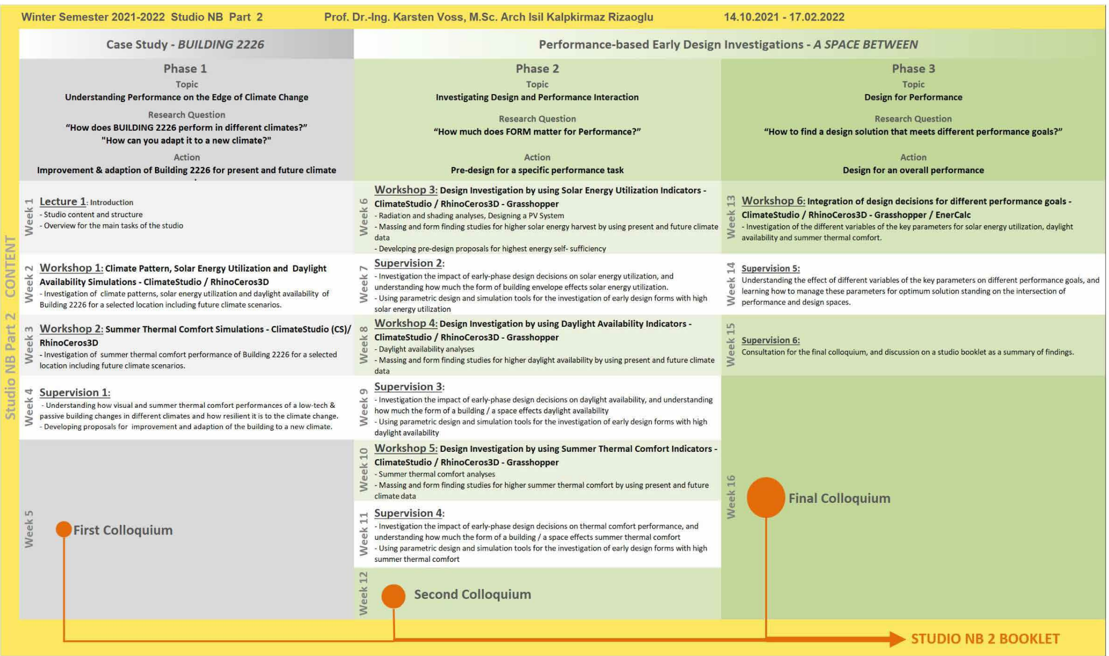
**BPS Tool 2: EnerCalc** is a tool, which deals with the energy balancing of buildings on a monthly basis as a multi-zone model. The software significantly simplifies the primary energy balancing of buildings and enables a rapid evaluation of building concepts with the aim of achieving net zero energy buildings. It is available by the developer free of charge for non-commercial use (https://projektinfos.energiewendebauen.de/en/project/enercalc-simplified-energy-balancing-to-din-v-18599/).

**STUDIO REFERENCE BOOKS**

Main reference books are available in Campus Haspel University Library as Reserve Collections (Semesterapparat). Reference books can be seen (by searching as "Semesterapparat Kalpkirmaz Rizaoglu"): https://moodle.uni-wuppertal.de/course/view.php?id=23581 (Also see **Appendix 3**).



**Syllabus - Appendix 1: M.Sc.-Studio NB Part 2 – WS 21-22 CONTENT**



**Syllabus -Appendix 2**: M.Sc.-Studio NB Part 2 – WS 21-22 TIMELINE

Studio NB Part 2 TIMETABLE

Winter Semester 2021-2022 Studio NB Part 2 — Prof. Dr.-Ing. Karsten Voss, M.Sc. Arch Isil Kalpkirmaz Rizaoglu — 14.10.2021 - 17.02.2022

| Part | Nr. | Week | Day | Date | Room & Time | Activities | Lecturer | Notes |
|---|---|---|---|---|---|---|---|---|
| Phase 1 | - | 41 | Tuesday | 11-Oct-2021 | - & 11:00 am | MSc Kick Off Event | Voss, Kalpkirmaz Rizaoglu | Lecturer Presentations |
| Phase 1 | 1 | 41 | Thursday | 14-Oct-2021 | HB.03.03, 10:00 am | INTRODUCTION | Voss, Kalpkirmaz Rizaoglu | Structure, Content and Main Tasks |
| Phase 1 | 2 | 42 | Thursday | 21-Oct-2021 | HB.03.03, 10:00 am | WORKSHOP 1 + Assignment 1 | Kalpkirmaz Rizaoglu | Climate, Solar Energy Utilization and Daylight Availability - CS / RhinoCeros3D |
| Phase 1 | 3 | 43 | Thursday | 28-Oct-2021 | HB.03.03, 10:00 am | WORKSHOP 2 + Assignment 2 | Kalpkirmaz Rizaoglu | Summer Thermal Comfort - CS / RhinoCeros3D |
| Phase 1 | 4 | 44 | Thursday | 4-Nov-2021 | HB.03.03, 10:00 am | SUPERVISION 1 | Kalpkirmaz Rizaoglu | See the content table |
| Phase 1 | 5 | 45 | Thursday | 11-Nov-2021 | to be announced & 09:00 am | FIRST COLLOQUIUM | Voss, Hillebrandt, Hans Kalpkirmaz Rizaoglu | Presentation and Report |
| Phase 2 | - | 46 | Tuesday | 16-Nov-2021 | - & 11:00 am | MSc First Research Forum | Student Group 1 | Student Presentations |
| Phase 2 | 6 | 46 | Thursday | 18-Nov-2021 | HB.03.03, 10:00 am | WORKSHOP 3 + Assignment 3 | Kalpkirmaz Rizaoglu | Design Investigation by using Solar Energy Utilization Indicators - CS / RhinoCeros3D - GH |
| Phase 2 | 7 | 47 | Thursday | 25-Nov-2021 | HB.03.03, 10:00 am | SUPERVISION 2 | Kalpkirmaz Rizaoglu | See the content table |
| Phase 2 | 8 | 48 | Thursday | 2-Dec-2021 | HB.03.03, 10:00 am | WORKSHOP 4 + Assignment 4 | Kalpkirmaz Rizaoglu | Design Investigation by using Daylight availability Indicators - CS / RhinoCeros3D - GH |
| Phase 2 | 9 | 49 | Thursday | 9-Dec-2021 | HB.03.03, 10:00 am | SUPERVISION 3 | Kalpkirmaz Rizaoglu | See the content table |
| Phase 2 | 10 | 50 | Thursday | 16-Dec-2021 | HB.03.03, 10:00 am | WORKSHOP 5 + Assignment 5 | Kalpkirmaz Rizaoglu | Design Investigation by using Summer Thermal Comfort Indicators - CS / RhinoCeros3D - GH |
| Phase 2 | - | 51 | Thursday | 23-Dec-2021 | - | Christmas | - | - |
| Phase 2 | - | 52 | Thursday | 30-Dec-2021 | - | Christmas | - | - |
| Phase 2 | 11 | 1 | Thursday | 6-Jan-2022 | HB.03.03, 10:00 am | SUPERVISION 4 | Kalpkirmaz Rizaoglu | See the content table |
| Phase 2 | 12 | 2 | Thursday | 13-Jan-2022 | to be announced & 09:00 am | SECOND COLLOQUIUM | Voss, Hillebrandt, Hans Kalpkirmaz Rizaoglu | Presentation and Report |
| Phase 3 | - | 3 | Tuesday | 18-Jan-2022 | - & 11:00 am | MSc Second Research Forum | Student Group 2 | Student Presentations |
| Phase 3 | 13 | 3 | Thursday | 20-Jan-2022 | HB.03.03, 10:00 am | WORKSHOP 6 + Assignment 6 | Kalpkirmaz Rizaoglu | Integration of design decisions for different performance goals - CS / RhinoCeros3D - GH / EnerClac |
| Phase 3 | 14 | 4 | Thursday | 27-Jan-2022 | HB.03.03, 10:00 am | SUPERVISION 5 | Kalpkirmaz Rizaoglu | See the content table |
| Phase 3 | 15 | 5 | Thursday | 3-Feb-2022 | HB.03.03, 10:00 am | SUPERVISION 6 | Kalpkirmaz Rizaoglu | See the content table |
| Phase 3 | 16 | 7 | Thursday | 17-Feb-2022 | to be announced & 09:00 am | FINAL COLLOQUIUM | Voss, Hillebrandt, Hans Kalpkirmaz Rizaoglu | Presentation and Final Report |
| | - | 11 | Thursday | 17-Mar-2022 | | STUDIO BOOKLET | Students | Digital version of the publication for proof reading |

7

# CVII: Integrated Studio – Entrance Survey

M.Sc. Studio Nachhaltiges Bauen und Gebäudeperformance Teil 2 - WS 2021/2022

Startseite / Meine Kurse / Studio NB Part 2 - WS21-22 / Allgemeines / Studio Kick-off Survey

## Studio Kick-off Survey

**Geöffnet:** Samstag, 16. Oktober 2021, 00:00

Überblick | Elemente bearbeiten | Vorlagen | Auswertung | Einträge anzeigen

Dear Students

Before we start Studio Part 2, we are interested in learning more about studio participants' backgrounds, interests, and motivations, so we can do the best possible job for the design of this course.

The Survey is set in an anonymous way, so your identities won't be visible to us, as well as to the other participants. Please feel comfortable and free when you are answering the questions

It is available now, please join as soon as possible!

Thanks in advance,

Prof. Dr.-Ing. Karsten Voss

M.Sc. Arch Isil Kalpkirmaz Rizaoglu

## Überblick

**Ausgefüllte Feedbacks:** 7
**Fragen:** 15

## Abschlussmitteilung

Thank you for your participation!

◄ Syllabus | Direkt zu: | Studio NB2 WS21/22 Color Palette ►

Tour erneut starten

Studio NB Part 2 - WS21-22

Datenschutzinfos

Impressum

# M.Sc. Studio Nachhaltiges Bauen und Gebäudeperformance Teil 2 - WS 2021/2022

Home / My courses / Studio NB Part 2 - WS21-22 / General / Studio Kick-off Survey / Questions / Edit questions

## Studio Kick-off Survey

Overview | Edit questions | Templates | Analysis | Show responses

Add question Choose...

How familiar are you with the topics in this course?
Edit

- ◯ (0)Extremely familiar
- ◯ (1)Very familiar
- ◯ (2)Somewhat familiar
- ◯ (3)Slightly familiar
- ◯ (4)Not at all familiar

How important is the learning topics of this course to you?
Edit

- ◯ (0)Not at all important
- ◯ (1)A little important
- ◯ (2)Moderately important
- ◯ (3)Very Important
- ◯ (4)Extremely important

Which activities of the course are more attractive for you? (Multiple selection is possible)
Edit

- ☐ Lectures
- ☐ Workshops
- ☐ Comprehension Questions
- ☐ Weekly assignments
- ☐ Supervision
- ☐ Colloquiums

Which phase of this course is more attractive and/or important to you?
Edit

- ◯ Phase 1: Case Study - BUILDING 2226
- ◯ Phase 2: Investigation of Design and Performance Interaction - Pre-designs for each performance task
- ◯ Phase 3: Final Design for an overall performance

Which performance tasks of this course is more important to you? Please select max. two tasks.
Edit

- ☐ Understanding Climate Pattern and effect of Climate Change
- ☐ Solar Energy Utilization by PV
- ☐ Daylighting Availability
- ☐ Summer Thermal Comfort

What is your goal in taking this course? What do you expect by the end of the course, which knowledge and skills? Please shortly explain by your own words. Edit

How do you rate your general knowledge and skills in term of Building Performance Simulation Tools (BPSTs)?
Edit

- (0)Low
- (1)Little
- (2)Good
- (3)Very Good
- (4)Excellent

Which BPSTs did you use before? Please write name(s) of the tool(s) (e.g. SimRoom, EnerCalc, ClimateStudio, DesignBuilder, IDAICE etc.) and your level (e.g. low, dedium, high, advanced).) Edit

Mostly in which design stage you use BPSTs? (Multiple choice is possible)
Edit

- ☐ Pre-design stage
- ☐ Early/ Initial Design Stage
- ☐ Detailed/Advanced Design Stage
- ☐ Construction Drawing Stage
- ☐ Construction Stage

What are the main purposes to use BPSTs for you? (Multiple choice is possible)
Edit

- Site and Climate
- Energy and Indoor Comfort
- (Day)lighting
- Hygrothermal
- Urban Micro Climate
- Life Cycle analysis
- Acoustics
- Renewable Energy Technologies

What are the main reasons and /or drivers for you for the selection of BPSTs? Main reasons for your preference.(Multiple choice is possible)
Edit

- ☐ Easy to learn/get in
- ☐ Ease of use
- ☐ All in one (all basic BPS features included in one tool)
- ☐ Design stage options (both suitable for early and advanced design)
- ☐ Short simulation time
- ☐ User Friendly Graphical User Interface (GUI)
- ☐ Easy training and learning resources
- ☐ Easy to reach developer or user forums in case of problem
- ☐ Reliable and reasonable outputs

☐ Suitable for both research and teaching
☐ Transparent process
☐ Validated
☐ Code compliance (e.g. DIN V18599)
☐ Generates design alternatives
☐ Compare design alternatives
☐ Support for new building technologies (e.g. renewable energy systems)
☐ BPS Tools integrated in Design Tools (e.g. Rhnino, Revit, ArchiCAD)
☐ Commercially accepted
☐ In-house development (e.g. developed by your institute)
☐ Available free Educational version
☐ Price & quality balance
☐ Instant & real-time simulation preview
☐ 3D Design modelling option
☐ Visual representation of the results
☐ Compatibility and interoperability (e.g. easy file exchange with tools)

Which simulation environment most you prefer?
Edit

○ Building Information Modeling (BIM)- based (e.g. Revit )
○ Computer Aided Design (CAD)-based (e.g. Rhinoceros. Sketchup)

Please select one of the options regarding your first impression about the course after first lecture.
Edit

○ I felt exited, and looking forward for the next classes.
○ I was surprised with the content of the course, which is not what I expected.
○ I felt satisfied with the content of the course, which was what I expected.
○ I felt overwhelmed because of intensive and heavy content of the course.
○ I felt neutral after first lecture, I will consider in coming lectures.

If possible, please share your comments on the course structure, course content, course materials etc. Your comments are really appreciated and will be considered for the next steps of the course to make it more enjoyable and productive for you.
Edit

If possible, please share your comments and/or suggestions regarding the planned Studio Booklet. Also please tell if you are interested or not, and explain your reason. Your comments are really appreciated and will be considered for the next steps
Edit

◄ Syllabus
Jump to...
Studio NB2 WS21/22 Color Palette ►

Studio NB Part 2 - WS21-22

Policies

# CVIII: Integrated Studio – Example “Assignment” document

BERGISCHE
UNIVERSITÄT
WUPPERTAL

btg+a

Bauphysik und Technische Gebäudeausrüstung

Prof. Dr.-Ing. Karsten Voss

Bergische Universität Wuppertal

Fakultät für Architektur und Bauingenieurwesen -

Bauphysik und Technische Gebäudeausrüstung

M.Sc.Studio NB Part 2 - WS 2021 / 2022

By Prof. Dr.-Ing. Karsten Voss and

M.Sc. Arch Isil Kalpkirmaz Rizaoglu

## Assignment 1

### Investigation of climate patterns, solar energy potential and daylight availability of Building 2226 for a selected location including future climate scenarios

- Due to 26.10.2021, 23.59
- Upload your file in Moodle, under section Week 2 - Assignment 1
- Max 4 page (A4) including all figures, tables and explanation
- You will find the required materials for this assignment in Moodle, under section Week 2 (Climate data, Building 2226 3D model, CS Workshop Model as an example)

Research Questions: *“How does Building 2226 (by Baumschlager Eberle Architekten) perform in different climates in terms of solar energy potential and daylight availability?”* and *"How can you adapt it to a new climate for better solar energy potential and higher daylight availability?"*.

Research & simulations will be conducted as a group studies for each location.

- Group 1: Climate 1 – Wuppertal, Germany - 51.283Latitude [°N] & 7.767 Longitude [°E]
- Group 2: Climate 2 – Istanbul, Turkey - 40.967 Latitude [°N] & 29.083 Longitude [°E]
- Group 3: Climate 3 – Amman, Jordan - 31.983Latitude [°N] & 35.983Longitude [°E]

The expected final output of this assignment are proposals from each group to increase the solar energy potential and the daylight performance of the Building 2226 for investigated climate considering present and future climate scenarios.

Steps:

1. **Briefly introduce your present climate by examining it through CS.**
   - Location on world map with Latitude and Longitude
   - Weather data (EPW - Temperature period: 2000–2009 and Radiation period:1991–2010)
   - Koppen Climate Zone
   - Annual total (horizontal) solar radiation (kWh/m2)
   - Heating or cooling dominated (if HDD > CDD, then it is heating dominated)

1

- Design temperatures
- Shadow analyses for winter and summer solstices
- Sun chart*

*Orthographic Sun Charts by ClimaPlus is preferred for that step. To use ClimaPlus online tool, please go to http://climaplusbeta.com/ , just drag and drag EPW and choose "OUTDOOR". If the EPW file provided by me does not work, go to https://energyplus.net/weather and download EPW file for your location and try with it.

2. **Run Radiation Analysis by CS for present climate**
   - Show total (direct + diffuse) solar exposure monthly graphic.
   - Average Total (direct + diffuse) solar exposure (irradiation) for whole envelope (kWh/m2-yr)
   - Average total (direct + diffuse) solar exposure (irradiation) for each investigated surface

3. **Run Daylight Availability Analysis (sub-section: Custom) by CS for present climate**
   - Spatial Daylight Autonomy ($sDA_{500,50\%}$)
   - Useful Daylight Illuminance (avgUDIa)

4. **Repeat all the investigation (steps 1,2,3) for future climate (IPCC Scenario A2 and projection year is 2100) and compare them**

5. **Shortly explain main differences between present and future climate**

6. **Make your proposals for adapting this building to the future climate to increase the solar energy potential and daylight availability.**

*If you have any question please feel free to contact me*

*M.Sc. Arch. Isil Kalpkirmaz Rizaoglu*

*E-mail kalpkirmazrizao@uni-wuppertal.de / kalp@uni-wuppertal.de*

## CIX: Integrated Studio – Example "Expectations for Colloquium" document


BERGISCHE UNIVERSITÄT WUPPERTAL

btg+a

Bauphysik und Technische Gebäudeausrüstung

Prof. Dr.-Ing. Karsten Voss

Bergische Universität Wuppertal

Fakultät für Architektur und Bauingenieurwesen -

Bauphysik und Technische Gebäudeausrüstung


**M.Sc.Studio NB Part 2 - WS 2021 / 2022**


By Prof. Dr.-Ing. Karsten Voss and

M.Sc. Arch Isil Kalpkirmaz Rizaoglu


# FINAL COLLOQUIUM EXPECTATIONS DOCUMENT

## Performance-based Early Design
## Investigations for Energy, Daylight and Thermal Comfort

### "A SPACE BETWEEN"

*Dear participants, the main tasks of the final colloquium have already been announced and explained in our meetings. This document is an additional document to underline the main task by providing you a check-list. Only new thing is that you will find some recommendation for your final reports in terms of design structure.*

**Date & Place:** 17.02.2022, 09:00 am -12:00 pm & **HB.03.03**, Campus Haspel

For the students, who are not able to join the colloquium in person, here is a zoom link, but please come to the class if you do not have any compelling reasons!

Join Zoom Meeting

Time: Feb 17, 2022 09:00 AM Amsterdam, Berlin, Rome, Stockholm, Vienna

Join Zoom Meeting

https://uni-wuppertal.zoom.us/j/94852552290?pwd=UzQ2dXl4a2tEVk1UQnVuZWtrcWo1dz09

Meeting ID: 948 5255 2290

Passcode: zK5mUQjm

One tap mobile

+496950502596,,94852552290#,,,,*27314433# Germany

+496971049922,,94852552290#,,,,*27314433# Germany

Dial by your location

+49 695 050 2596 Germany

+49 69 7104 9922 Germany

Meeting ID: 948 5255 2290

Passcode: 27314433

Find your local number: https://uni-wuppertal.zoom.us/u/ackW8svPU

**Colloquium Time Schedule**

## 09:00 am - Introduction

**09:05 am** – Group 1: Wuppertal
25 min presentations + 10 min Q&A

**9:40 am** - Group 2.1: Istanbul
25 min presentations + 10 min Q&A

## 10:15 am – 15 min Coffee Break

**10:30 am** - Group 2.2: Istanbul
25 min presentations + 10 min Q&A

**11:05 am** - Group 3: Amman
25 min presentations + 10 min Q&A

## 11:40 am – 12:00 pm - Discussions

**SUBMISSION**

**Colloquium presentations**: Presentation are limited to **max 20 pages (A4 Landscape) and 25 min** presentation time for each group, and plus 10 min Q&A session after each presentation, Please, bring your presentation with USB stick (or another external hard disc) and be ready at the room latest at 8.45am to upload your presentations to the laptop.

**Reports:** Each group should submit their own reports. Your reports should include all the content of your presentations with more comprehensive explanations. There is no page limitation for the reports.

Deadline for submissions is 17.02.2022, 23:59 pm. You can submit your presentations and reports in Moodle, under section Week 17 – Final Colloquium Submission. Please also submit your other digital modelling, simulation and work files: Rhino Ceros (.3dm), ClimateStudio (.csr.) and Excel (.xlsx). etc.

**Language:** Final outcome of Studio NB Modul 2 (i.e. exhibitions) is planned to be in English. Thereby, you are recommended to prepare your presentation and report in English. If you are not comfortable with English during your presentations, you can present your works in German.

**Final Colloquium Content**

**Topic:**
Performance-based Early Design - A SPACE BETWEEN

- Investigating Design and Performance Interaction in the Early Design Phase

**Performance tasks:**

- Solar energy utilization,
- Daylight availability
- Thermal comfort, and
- Energy use
- Energy generation by PV systems.

**Research Questions:**

- How early design decisions effect the performance tasks
- How much does FORM matter for PERFORMANCE?
- Can performance evaluation be a STIMULATOR for early design?
- What are the key parameters related to building form and envelope in term of selected performance tasks during changing climate conditions in the scope of your works?
- Optimization: How to find a design solution that meets overall performance goals?

1. **Design Concept, Climate, Location and Site -** (max 2 slides): Please briefly explain

    - Building **use** and target **user** profile
    - Main functions/**design program**
    - **Location and site** (mention latitude & longitude on a world map, also you can show one perspective image from existing site model)
    - **Climate pattern** (Climate zone, heating or cooling dominated, comparison of present and expected future climate 2100 in terms of total annual solar radiation and outdoor temperature over the course of a year)
    - **Strengths, treads and potentials of that climate** in terms of sustainable design and energy efficiency considering present and future climates scenarios?
    - **Expected main challenges** in terms of daylight & thermal comfort, and energy efficiency for the aimed design program considering the present and future climate.
    - **Metrics / terms / limit values** that you use as an indicator for your performance investigation (Describe sDA, UDIa, neutral hours and other terms that you use for the performance investigation.)

2. **Local Architecture Literature Research -** (max 1 slides): Briefly explain / point out the **links between building form & elements and climate** through the examples

3. **Building Integrated Photovoltaic (BIPV) Literature Research -** (max 1 slides): Briefly explain / point out **why and how** are these examples **applicable** considering your climate and your design

4. **Massing Studies for Higher Solar Energy Harvest by Using Solar Exposure Analysis -** (max 2 slides): Aim of this task is to detect the **parts of building envelope with highest solar energy potential** and adjusting the cubature accordingly for possible PV installation in the next steps of the study.

- Please, briefly present **your whole investigation with one comparison graphic** and support the graphic by visuals for each mass.

5. **Massing Studies for Higher Daylight Availability by using sDA and UDI metrics -** (max. 3 slides)

- Briefly explain **basic simulation settings** (Weather Data: x- future, Sky Model: Perez all-weather).
- Mention the **metrics and their target values** that you try to fulfil or limit values that you try to avoid. Key metrics for the representation of results are UDI and SDA (additionally you can consider ASE).
- Please show **base-case values of the key parameters** (wwr, glazing type, Tvis, shading type and dimensions etc).
- For each variation please point out **only the changing values of the parameters**.
- Please, briefly present your **whole investigation with one comparison graphic** and support the graphic by visuals.
- Select the best /optimum alternative(s) in terms of daylight availability and solar energy utilization to test the thermal comfort performance of them.
- **Please, briefly present your whole investigation with one comparison graphic and support the graphic by visuals for each test-case.**

6. **Investigation of Design Alternatives for Higher Thermal Comfort by Using Neutral Hours Approach, and Integrating PV systems to Pre-designs to See the Energy Use & Generation Balance -** (max. 4 slides).

- Please also mention **basic simulation settings** of thermal model and add visual of thermal model. (Thermal model type, which floor is used as a representation of whole building, what is the pattern of occupancy and other loads, how are the conditioning and ventilation scenarios, what are the important building envelope elements for this simulation study and what are the basic features of these elements i.e. U values, SHGC, Construction type - Heat Capacity etc.).

- Key indicators for thermal comfort are "***energy flows***" and "***thermal comfort hours***" over the course of the year. Your primary aim is to extend the neutral hours band (comfort range) by narrowing down first *cooling hours band*, and second *heating hours band.* **Briefly present your whole investigation with one comparison graphic**

- Key indicator for energy efficiency is the ***"Annual Solar to Load Ratio"***. Please show monthly ***"energy generation and use"*** (kWh/$m^2$,yr) graphic over the course of the year for your selected final pre-design alternatives. **Please briefly present your whole investigation with one comparison graphic.**

**Until sub-task 7, all subtasks were already evaluated in Second Colloquium, so please consider feedbacks from Second Colloquium when you are improving and summarizing your works for these subtasks.**

7. **Objective-oriented Investigation of the Key Parameters for Solar Energy Utilization, Daylight Availability and Summer Thermal Comfort by Using Multi Objective Optimization (MOO) Method.** (max. 4 slides) (Reference work for this sub-task is Assignment 6)

- You are expected to propose your final design (design alternatives) for overall performance by using optimization method.

- At each optimization session, please select and explain which performance goals (objectives) and parameters (variables) you will explore and why?

- You are recommended to start with one parameter and one objective. For example, if you want to discover which parameter is the key parameter among the number of other parameters for the selected performance goal (objective), keep your objective and change only parameter for each run. After discovering the most effective (key) parameter for the selected objective. Start with a new objective, again each time using one parameter. By the final end it will be clear for you, which of the parameters are key parameters for your selected goals, so you can run multi-objective optimization by selected parameters.

- When you are defining a – design - problem (what for you are running this optimization), be specific and try to find a problem, which is unique to your design case and your location (climate). Try extreme forms and values!

- About optimization setting and results, please mention:
  - parameters (variable)
  - objectives (performance goals)
  - number of iterations
  - minimum, maximum and optimum values of parameters and performance results in regard.
  - Show visualization of the selected iteration (s)

8. **Conclusion** - **Summary and Key Findings –** (<u>max. 3 slides</u>)

Please briefly summarize your work in terms of daylight availability, summer thermal comfort and solar energy performance. Explain the links between these main tasks from your point of view. Please visually present the **base-case model** and your ***final upgraded model in comparison.***

Please see the questions below to structure the conclusion part:

- Please introduce your final pre-design, and explain the key parameters that you applied to that final model: For example, about the selected final WWR ratio, you can say "This WWR is selected, because values higher than this value cause extreme summer thermal comfort problems".

- Did you achieve all of your general and task specific goals? Is there any goal left behind?

- Which of the main tasks was the most difficult to achieve? Try to explain why.

- What was the most difficult parameters to manage?

- What are the key parameters for your design and location?

- What are your key findings?

- What might be the next steps of this work?

- What is your general impression about Studio NB2 WS 2021-2022? (Optional to answer)

General Notes

- **Weather data:** You are asked to make the investigations (variable studies regarding the solar energy utilization, daylight and thermal comfort performance) for the future climate. But, you are strongly recommended to test the base case (for solar / for daylight / for thermal) both for present and future climates before starting your variation studies. So, this will provide you an insight about the expected future challenges in your locations.

- **Most updated work file for optimization can be found under Week 14 in Moodle**: Optimization GH File

  Also, if you are interested, please see optimization example for parametric PV surface under Week 15 in Moodle: Optimization example for Parametric PV surface

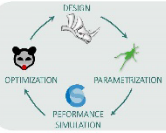
- **Animation**: You are expected to create animation for the geometries that you investigated. Please see the instruction document how to create animation (gif. image) under Week 15 in Moodle: Animating Grasshopper Geometry

- **Structure of your presentations:** Please try to make your presentation compact and visually rich. Try to avoid text size smaller than 18pt. You can use "Studio Color palette" for your all graphic representations, or you can decide on a new color palette.

*If you have any question please feel free to contact me*
*M.Sc. Arch. Isil Kalpkirmaz Rizaoglu, 03.02.2022, Wuppertal*
*E-mail kalpkirmazrizao@uni-wuppertal.de / kalp@uni-wuppertal.de*

- End of the document -

# CX: Integrated Studio – Students' Posters




Performance-based Early Design

A SPACE BETWEEN

Design and Performance Intersection

at the Edge of Climate Change

# WUPPERTAL

GROUP 1

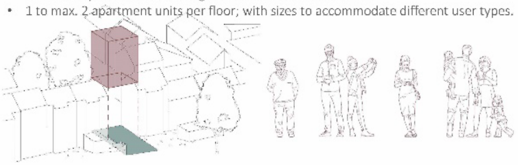
## Design Concept and Goals

**Goals**

- to maintain the indoor operative temperature between 20°C and 26°C and sufficient amounts of usable interior daylight.
- to minimize the use of active heating and cooling systems as far as possible- **neutral hours-approach**

**Building Use / Target User Profile**

- multi-storey residential building with total floor area of 600m²
- 1 to max. 2 apartment units per floor; with sizes to accommodate different user types.



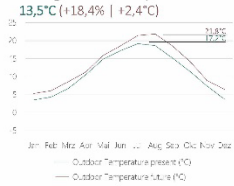
## Wuppertal Climate

The local climate of Wuppertal is distinctly different from the Istanbul and Amman location, with the lowest outdoor temperature and its heating dominated pattern.

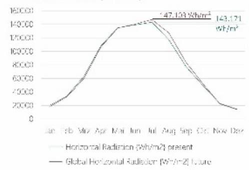
**The greatest challenges are:**

- High heating hours and heat losses
- Seasonal mismatch of energy generation and consumption

- Average Outdoor Temperature
  13,5°C (+18,4% | +2,4°C)

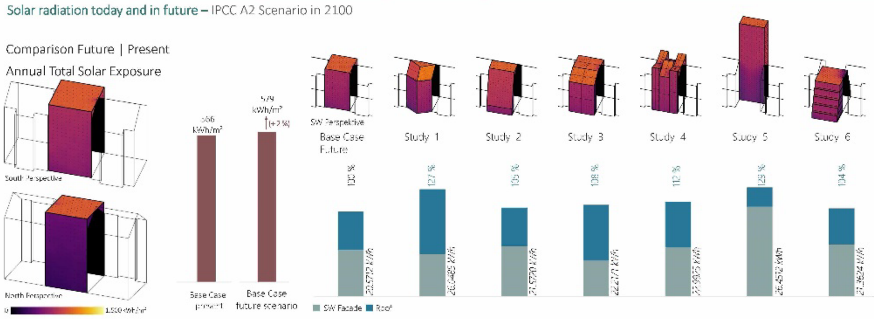



- Annual Total (Horizontal)Solar Radiation
  939 kWh/m² (+1,7%)




## FOCUS - Massing Studies for Higher Solar Energy Harvesting

Solar radiation today and in future – IPCC A2 Scenario in 2100




Solar radiation analyses are integrated to massing studies in order to detect the most promising forms / surfaces for active solar energy utilization

After investigating the performance for the whole envelope as well as only the exposed surfaces in comparison to the volume, Studies 1, 3 and 4 are selected for further investigation.

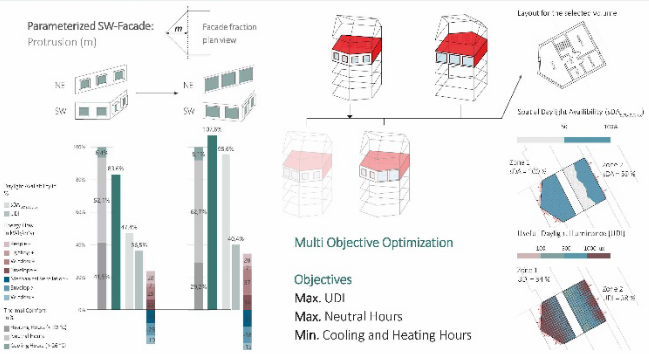
Although Version 5, it has a very high solar yield, was not in question for further analysis due to its high surface-to-volume ratio.

## Optimization for Overall Performance and Key Findings

**From Beginning to Final**

Objective-oriented Investigation of the key parameters for solar energy utilization, daylight availability and summer thermal comfort

| Parameters | Beginning | Final |
|---|---|---|
| **Window Geometry:** | | |
| WWR NE: | 30 % | 50 % |
| WWR S: | 50 % | 46 % |
| WWR W: | 30 % | 46 % |
| Window reveal: | 0,5 m | 0,1 m (SW) 0,2 m (NE) |
| **Glazing:** | Type 1 | Type 4 |
| Tvis: | 77,4 % | 71,5 % |
| SHGC: | 0,7 | 0,6 |
| U-Value: | 2,45 W/(m²K) | 1,05 W/(m²K) |
| **Envelope:** | | |
| Wall Thermal Mass: | light | heavy |
| **Volume:** | | |
| Protrusion SW facade: | 3 m | 4,4 m |
| Number of floors: | 5 | 5 |
| Square meters / floor: | 120 m² | 127 m² |
| Total Floor area: | 600 m² | 635 m² |




**Objectives**

**Max.** UDI

**Max.** Neutral Hours

**Min.** Cooling and Heating Hours

**Key Findings | Performance**

- Protrusion depth has little to low effect on thermal, but significant impact on daylight Performance.
- Deep recessions are therefore not favorable for the location considering daylight
- Different wall constructions (mass) don't have strong impact on building's performance
- Glazing properties are highly significant for overall performance

## Building Integrated Photovoltaic Systems

**Roof**

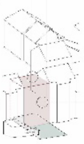
**PV Roof-Tiles**

Site context favors sloped roof geometry

- near seamless roof surface is possible

Redundancy of construction

- replacing individual tiles



**Facade**

**Fused Glass Composite PV Panels**

Large vertical surface

- adaption to low declination angle in winter

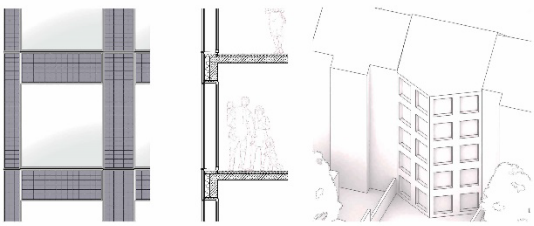
Homogenous glass surface

- integration of different window formats

**Opaque PV Facade Panels**

Additional depth layer for shading

- dynamic shading elements
in homogenous facade possible



**Proposal | Facade**

Visualization of final version with 46% Window-Wall-Ratio on the backwards façade.
Large Windows enable more internal heat annual solar gains
The rest of the entire envelope is reserved for PV-modules.

Ronja Lehmann
Lukas Salomon
Julius Weritz

WS 2021/2022 Architecture Master Study
Studio Sustainable Building and Building Performance Part 2
(S-NB 2)

Prof. Dr.-Ing. Karsten Voss
M.Sc. Arch Isil Kalpkirmaz Rizaoglu
BERGISCHE UNIVERSITÄT WUPPERTAL


# Performance-based Early Design
# A SPACE BETWEEN
## Design and Performance Intersection at the Edge of Climate Change

# ISTANBUL
GROUP 2.1

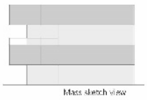
## Design Concept and Goals

A space in Bandstraße 31 , Wuppertal with surrounding buildings, trees


### Challenges and Goals

The summer thermal comfort is the biggest challenge regarding the climate.

- Providing a comfortable indoor temperature in summer without active cooling systems
- Finding an optimum glazing ratio for daylight without causing overheating in summer




### Residential Building | Multifamily house

- Larger Flats – Extra Space, shared Garden
- Smaller Flats – Extra Outdoor Space, shared Garden

## Istanbul Climate

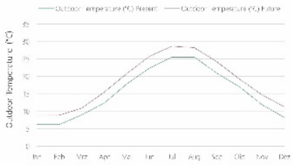



Figure compares the present and future temperatures

### Istanbul climate in the future based on IPCC Scenario A2 for 2100

- Warmer winter, and hot summers - cooling dominated- are expected
- Average annual temperature is likely to increase +2,8°C in the future

### Potentials of the Climate

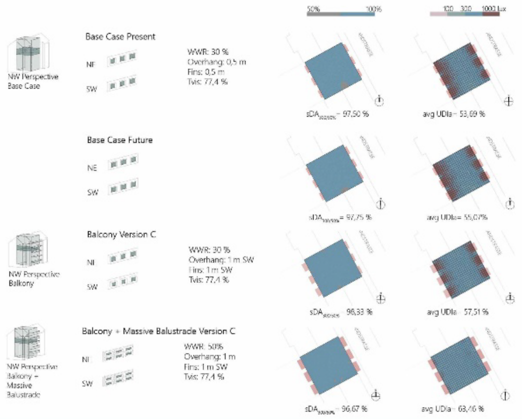
- The high solar radiation brings a high potential for a PV-System.
- In general, not the winter thermal comfort, but the summer seems to be challenging when the temperature patterns are considered

## FOCUS - Massing Studies for Higher Useful Daylight Availability

During conceptual design, the massing studies are coupled by daylight availability analyses to investigate relation between the building form and the daylight performance.. It is seen that building form has an high impact on the overall daylight availability of a space, as well as high level of daylight does not necessarily leads to high level of visual comfort.

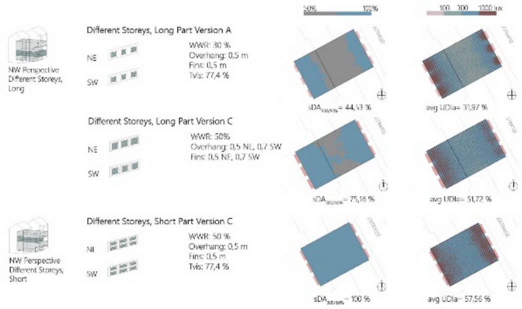
Metric of spatial daylight autonomy (sDA) used for daylight analysis. sDA refers the percentage of space that reaches a specific amount of lux at least 50% of the time. In addition, UDIa , which refers to a space with illuminance in specified range, is used to detect the useful part of available daylight.

To see how the daylight changes due to the increased solar radiation, first the present and future daylight performances of the base-case were simulated and compared. There was not a significant difference due to low changes in solar radiation in future.

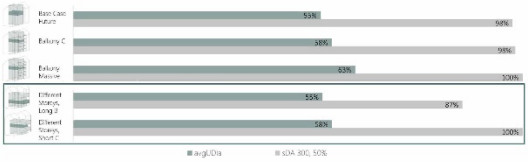



Further variants for daylight availability are investigated only for future climate scenarios through the parameters, i.e. space dimension – space width & height – different arrangements of windows on a façade – vertical and horizontal division, window wall ratio (%) and glazing properties – light transmittance (Tvis), and shading - overhangs and fins.

The results shown below are already optimized versions.




Daylight Availability in the Future based on IPCC Scenario A2 for 2100



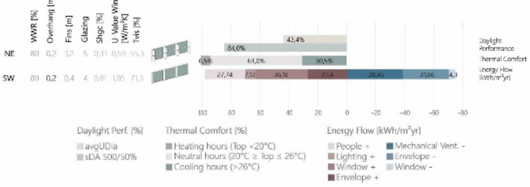

Due to the similar values of the best optimizations, it was further worked with the version "*Different Storeys*". It offers the highest potential for the PV system and has a prominent form, which refers to the vernacular architecture of investigated location, Istanbul.

## Optimization for Overall Performance and Key Findings

### Daylight and Summer Thermal Comfort

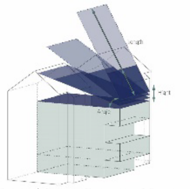
The selected floor space is optimized for a high daylight performance and a high summer thermal comfort.

These performance goals work against each other > Achieving required amount of the useful daylight, while keeping the indoor temperature below 26 °C for summer thermal comfort




### Building integrated PV

The PV system designed as a roof terrace, so the residents have an additional shaded outdoor space in summer. The Roof PV was parametrized regarding the length, height and angle to find the optimum values for a high PV yield, as well as efficiency.



Objective: High Energy Generation Intensity
Variables for Height 0,2 m -2,5 m
for Angle 15°- 45°

### Roof PV - Terrace

- Meeting point for residents
- Ventilated and shaded in summer
- Additional „Summer Room"
- Generates energy for the building

### Parameters with significant impact on the performance

- The Window-Wall-Ratio between 70-80% had the best results regarding daylight and thermal comfort.
- The Glazing properties heat transmission coefficient, light transmittance and Solar Heat Gain Coefficient made a big difference.
- Different glazing types were chosen for each orientation.

Jelka Seidel
Sophie Weuste

WS 2021/2022 Architecture Master Study
Studio Sustainable Building and Building Performance Part 2
(S-NB 2)

Prof. Dr.-Ing. Karsten Voss
M.Sc. Arch Isil Kalpkirmaz Rizaoglu
BERGISCHE UNIVERSITÄT WUPPERTAL


Performance-based Early Design

A SPACE BETWEEN

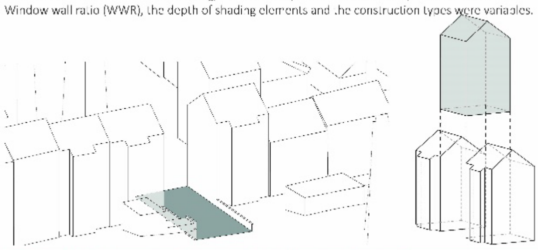
Design and Performance Intersection at the Edge of Climate Change

# ISTANBUL

GROUP 2.2

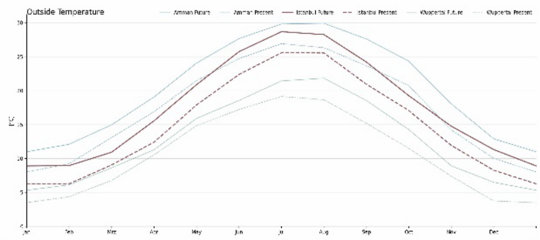
## Design Concept and Goals

The site context is used as a guide. Both the height and the roof shape were taken from the adjacent buildings. The total area, which is divided into 6 floors, is 600 m². The first floor is used as a restaurant, the floors above are used for residential purposes. During the optimizations, the the reference form and the orientation of the building, whic was adopted from site context, was remained same Window wall ratio (WWR), the depth of shading elements and the construction types were variables.



## Site and Climate

The climate change brings new challenges for an architect. In the future, the issue of how buildings can be constructed to minimize overheating in urban environments in summer will become increasingly relevant. The weather data is creatd based on the IPCC scenario A2 for the year 2100. It can be clearly seen how temperatures will rise in the future.

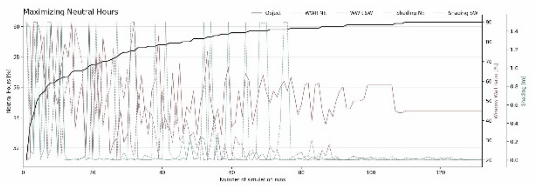



## FOCUS - Massing Studies for Higher Solar Energy Harvesting

**Optimization 1** By parameterizing the facade, many different variants were tested in an automated way to maximize *Neutral Hours* within an indoor temperature between 20°C and 26°C without heating and cooling.

Variables: - Window Wall Ratio NE (20% - 90%)
- Window Wall Ratio SW (20% - 90%)
- Shading Depth NE (0,0m - 1,5m)
- Shading Depth SW (0,0m - 1,5m)

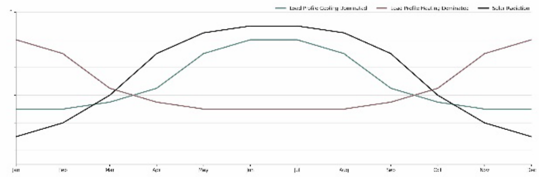
Target: - Maximizing Neutral Hours




| 8,3% | 60,3% | 31,4% |
|---|---|---|

■ Heating Hours, T<20°C ■ Neutral Hours, 20°C≤T≤26°C ■ Cooling Hours, T>26°C

**Optimization 2** The next goal was minimizing the heating hours. By maximizing the Neutral Hours, the total energy demand can be minimized. Subsequently, the building was optimized so that the energy demand, which is unavoidable, occurs when sufficient energy is available through generated electricity via photovoltaics in the summer. For this optimization, the type of glazing was adapted and materials with a high thermal mass were chosen.



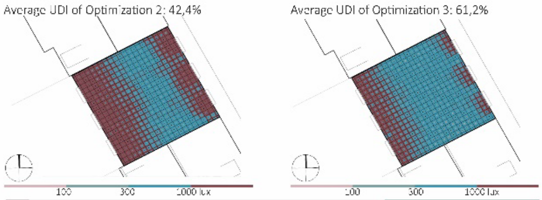
| 0% | 68,4% | 31,6% |
|---|---|---|

■ Heating Hours, T<20°C ■ Neutral Hours, 20°C≤T≤26°C ■ Cooling Hours, T>26°C

**Optimization 3** It should be noted that when a variable is changed, it affects many other parameters of the performance. The building had relatively large windows to maximize solar gain in winter, but it resulted in excessive daylight. In this optimization, two objectives were chosen. The useful daylight (between 300lux and 1000lux) and the *neutral hours* were considered and those of the parameterized optimization were improved. *Heating Hours* have increased, but useful daylighting has been significantly improved.

Average UDI of Optimization 2: 42,4%

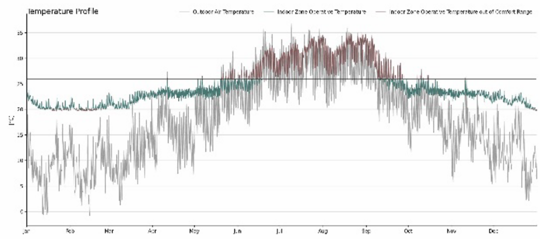
Average UDI of Optimization 3: 61,2%




| 4,4% | 66,6% | 29,0% |
|---|---|---|

■ Heating Hours, T<20°C ■ Neutral Hours, 20°C≤T≤26°C ■ Cooling Hours, T>26°C

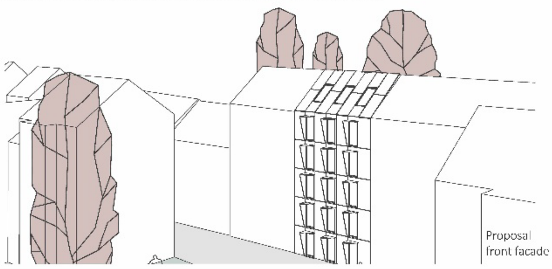
**Evaluation** The evaluation of the interior temperature clearly shows that a heating system can be dispensed within this scenario by the optimizations. By the help of high thermal mass, fluctuations can be compensated well. The building can be sufficiently heated solely by the presence of people in the building and the electricity consumption of the household appliances. The energy needed for cooling in summer can be generated by photovoltaics.



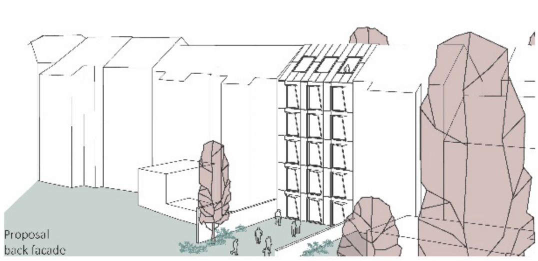

## Optimization for Overall Performance and Key Findings

It should be noted that the user has a high influence on thermal comfort, and it is difficult to predict and exactly simulate the user behaviour. However, the simulations helpful to gain an insight throughout the test of scenarios.Morover, non-user-related paremeters can be evaluated to see the impact of each parameters on a performance, s well as the combination of parameters .

The simulations show that there are many parameters that affect performance, even if the building form remains untouched in this urban environment. In addition, it is found that the earlier the performance evaluation started, the higher the control of the performance parameters was.



Proposal front facade

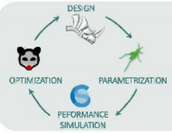


Proposal back facade

B.Sc. Marvin Kaliga
B.Sc. Mila Kretschmann

WS 2021/2022 Architecture Master Study
Studio Sustainable Building and Building Performance Part 2 (SNB 2)

Prof. Dr.-Ing. Karsten Voss
M.Sc. Arch Isil Kalpkirmaz Rizaoglu
BERGISCHE UNIVERSITÄT WUPPERTAL




Performance-based Early Design

**A SPACE BETWEEN**

Design and Performance Intersection

at the Edge of Climate Change

# AMMAN

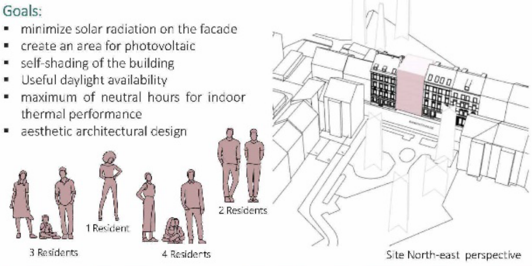
GROUP 3

## Design Concept and Goals

The design concept contains around 600 m² of residential space, with target user profile: single person to family, within the urban conte›

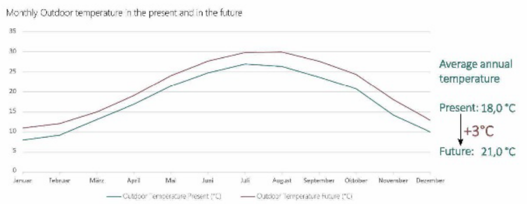
Goals:

- minimize solar radiation on the facade
- create an area for photovoltaic
- self-shading of the building
- Useful daylight availability
- maximum of neutral hours for indoor thermal performance
- aesthetic architectural design

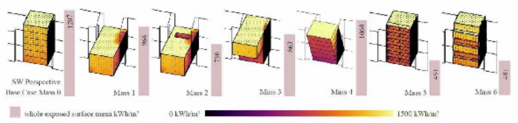


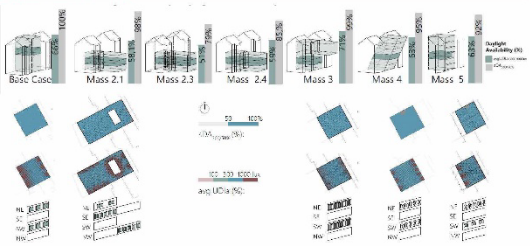

## Amman Climate

The climate challenges in Amman are high temperature and high solar radiation, which are likely to cause overheating in summer. The goal is to minimize solar radiation on facade and still provide an area where a photovoltaic system can be installed. A roof area is useful for this purpose, but the solar radiation on other parts of the envelope should be kept low. In addition, good lighting and pleasant thermal comfort of the inner space should be ensured.




## Massing Studies for Solar Energy Harvesting and Useful Daylight Availability

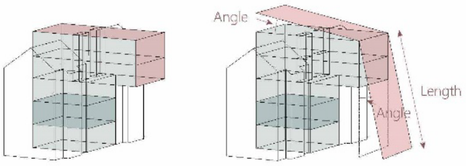




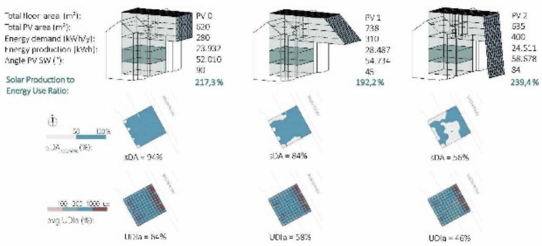

Different building forms are tested by coupling solar radiation analysis to find out how the building can shade itself in south orientation or additional shaded facade areas can be created.

Massing studies are conducted for higher useful daylight availability by using spatial daylight autonomy (sDA) and useful daylight illuminance (UDI)m metrics.

## FOCUS - Building Integrated Photovoltaic Systems

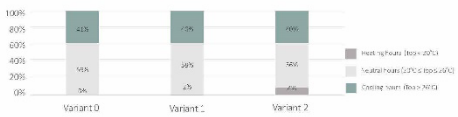



Annual Solar Production to Energy Use Ratio: ——→ ?

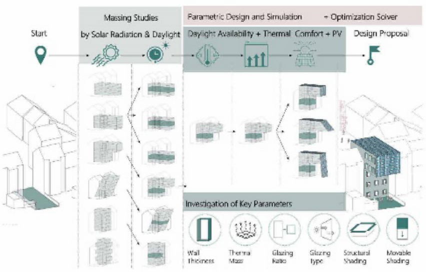



After investigation of the building forms, accompanying the radiation analyses, in order to maximize suitable surfaces for active solar energy utilization, detected most efficient surfaces are tested for building integrated PV systems.

Optimization technique is used to find the optimum dimensions and the position of the possible PV systems. The objective of the optimization was the maximizing a *solar production to energy load* by using an energy use intensity of previously investigated forms. This task aimed to gain an insight about the potential of renewables by simply comparing potential of energy generation and use. Variation are re-evaluated for their daylight and thermal performances by considering the shading effect of the PV systems.




## Optimization for Overall Performance and Key Findings




climate challenge: hot-arid climate with high temperatures and high solar radiation

| solution proposal: | Variant 0 | Variant 9 | Opt. 3.1 |
|---|---|---|---|
| Floor Height (m): | 3 | 3 | 4 |
| WWR NE/SW (%): | 50 | 40 | 34 / 19 |
| Overhang NE/SW (m): | 0,7 | 0,5 | 0,1 / 0,5 |
| Fins NE/SW (m): | 0,7 | 0,5 | 1,5 / 0,6 |
| Vertical Division: | 1 | 3 | 3 |
| $U\text{-Value}_{window}$ (W/m²K): | 2,48 | 1,26 | 1,26 |
| SCGH (%): | 0,71 | 0,54 | 0,54 |
| Thermal Mass: | medium | heavy | heavy |
| $U\text{-Value}_{wall}$ (W/m²K): | 0,25 | 0,25 | 0,25 |
| **goals:** | | | |
| - minimize solar gains on the facade | ✓ | ✓ | ✓ |
| - create an area for photovoltaic | ✓ | ✓ | ✓ |
| - maximize useful daylight | ✓ | ✓ | ✓ |
| - maximize neutral hours for thermal performance | ○ | ✓ | ✓ |
| - increase aesthetic quality | ✓ | ✓ | ○ |

challenging parameters:
- minimizing cooling hours without increasing heating hours, therefore it was difficult to maximize neutral hours
- minimize annual sunlight exposure (ASE), while keeping the daylight autonomy high.

### Gains at the end of the Studio

- Using various design and building simulation tools in tandem
- Better estimation of daylight and thermal comfort also in other climates
- Relevance of form and performance
- Influence of wall thickness, window size etc. on performance
- Understanding the links between design and climate
- Ways of PV integration integrated
- Decisions in early design have an significant impact on performance.


Farah Alnihawi
Sarah Coppens
Julia Wiechert

WS 2021/2022 Architecture Master Study
Studio Sustainable Building and Building Performance Part 2
(S-NB 2)

Prof. Dr.-Ing. Karsten Voss
M.Sc. Arch Isil Kalpkirmaz Rizaoglu
BERGISCHE UNIVERSITÄT WUPPERTAL

# CXI: Integrated Studio – Evaluation Survey

M.Sc. Studio Nachhaltiges Bauen und Gebäudeperformance Teil 2 - WS 2021/2022

Home / My courses / Studio NB Part 2 - WS21-22 / General / Studio NB 2 WS 2021-2022 Evaluation Survey / Questions / Edit questions

Studio NB 2 WS 2021-2022 Evaluation Survey

Overview | Edit questions | Templates | Analysis | Show responses

Add question Choose...

Edit

**Question 1**: Throughout the studio you had a number of different activities, please indicate how useful you found each of them.

Please select a number between1 and 5 for each activity.

**1** means **"not useful"** and **5** means **"very useful"**.

LECTURES - theoretical explanations
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

WORKSHOPS - hands-on session
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

COMPREHENSION QUESTIONS
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

WEEKLY ASSIGNMENTS
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

SUPERVISION - Discussions & Feedbacks
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

COLLOQUIUMS
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

Edit

**Question 2**: Which phase of the studio was the **most attractive** to you?

Most attractive phase
Edit

○ (0)Phase 1: Building 2226 Case-study
○ (0)Phase 2: Manual investigations of design and performance Interaction
○ (0)Phase 3: Automated investigation of design and performance interaction via optimization

Edit

**Question 3**: Please indicate how attractive were the studio topics to you?

Please select a number between1 and 5 for each topic.

**1** means **"not attractive"** and **5** means **"very attractive"**.

Present and future patterns of different climates
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

Solar potential of the building envelope - Solar exposure analysis
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

Daylight availability
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

Thermal comfort
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

Energy and PV system
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

Edit

**Question 4**: Which topic of the Studio was the **most difficult** one?

Most difficult topic
Edit

○ 0/Climate
○ 0/Solar Exposure
○ 0/Daylight Availability
○ 0/Thermal Comfort
○ 0/Energy and PV Systems

Edit

**Question 5**: Regarding the performance of a design, if you compare the performance that you expected before you run the simulation to the simulation results, what would you say? For example, were the expected result and the simulation result inline or did simulation results show you a completely new picture, which was far away from your expectations and presumptions?

Please select one of the answers below.

Expectations & Simulation Results
Edit

○ 0/Building performance simulation did not show me anything new about the performance of my design, the simulation results were exactly same with what I expected.
○ 0/Building performance simulation showed me something new, I got some results different than my expectation, but not much different.
○ 0/Building performance simulation showed me completely different picture than I expected.

If you want to add other comments on Question 5, please use the text box. Edit

Edit

**Question 6**: How do you rate your progress for the aspects mentioned below?

**1** means **"not improved"** and **5** means **"much improved"**.

General knowledge about building physics & performance
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

Skills for running building performance simulation
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

Edit

**Question 7**: How attractive were the methods and techniques to you?

**1** means **"not attractive"** and **5** means **"very attractive"**.

Computer Aided Modelling (CAD,) (i.e. Modeling in Rhino)
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

Performance simulations with a certain interface (i.e. Climate Studio for Rhino)
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

Customized Parametric Simulation (i.e. Climate Studio for GH)
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

Parametric design (i.e. creating parametric design models in GH
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

Automated Optimization (i.e. Opossum)
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

Edit

**Question 8**: Some descriptions about Climate Studio (CS) are given below.

Please select a number between 1 and 5 for each description.

**1** means **"disagree"** and **5** means **"fully agree"**.

CS is easy to learn
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

CS is easy to use
Edit

○ {0}1 ○ {0}2 ○ {0}3 ○ {0}4 ○ {0}5

CS is suitable for both early and advanced design stages
Edit

○ {0}1 ○ {0}2 ○ {0}3 ○ {0}4 ○ {0}5

CS has a short simulation time
Edit

○ {0}1 ○ {0}2 ○ {0}3 ○ {0}4 ○ {0}5

CS has rich learning resources, i.e. documentations and video tutorials
Edit

○ {0}1 ○ {0}2 ○ {0}3 ○ {0}4 ○ {0}5

CS has a user friendly Graphical User Interface (GUI).
Edit

○ {0}1 ○ {0}2 ○ {0}3 ○ {0}4 ○ {0}5

CS has a good export features, i.e. ready-to-go reports, simulation data as csv file etc.
Edit

○ {0}1 ○ {0}2 ○ {0}3 ○ {0}4 ○ {0}5

Using CS in Rhino is very attractive , because you can design and make performance investigation in the design environment
Edit

○ {0}1 ○ {0}2 ○ {0}3 ○ {0}4 ○ {0}5

CS has a rich construction material library
Edit

○ {0}1 ○ {0}2 ○ {0}3 ○ {0}4 ○ {0}5

Creating thermal zone templates in CS is very helpful
Edit

○ {0}1 ○ {0}2 ○ {0}3 ○ {0}4 ○ {0}5

Edit

**Question 9** : What was the most difficult thing that you experienced while using CS?

Please use the text box. For example: creating a 3D model in Rhino or/and assigning daylighting materials or/and assigning & defining thermal zone elements or/and setting weather data or/and adjusting thermal zone settings a/o using CS for Grasshopper... Edit

Edit

**Question 10**: Do you think that building performance simulation raised your confidence in making design related decisions?

**1** means **"disagree"** and **5** means **"fully agree"**.

For instance; do you say that I can decide more confidently if I can support my design decision with the performance simulation results?
Edit

○ {0}1 ○ {0}2 ○ {0}3 ○ {0}4 ○ {0}5

Edit

**Question 11**: If you think of the studio experience, did building performance simulation support or limit your design creativity?

**1** means **"BPS limited my creativity"** and **5** means **"BPS supported my creativity"**.

BPS supports creativity
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

Edit

**Question 12**: Do you plan to use building performance simulation tools (BPSTs) in your future studies, i.e. for your master thesis?

BPS use in future studies
Edit

○ (0)YES ○ (0)NO

If your answer is "NO" for the question 12, please indicate the reason very briefly. Please use the text box. Edit

Edit

**Question 13**: How satisfied are you with the course in general?

**1** means **"not satisfied"** and **5** means **"very satisfied"**.

Studio general satisfaction
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

Edit

**Question 14**: How likely are you to recommend this studio to others?

**1** means **"no at all"** and **5** means **"I would definitely recommend"**.

Recommendation of the studio
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

Edit

**Question 15**: What would you improve about the studio if you could?

If you have a suggestion, please use the text box below. Edit

Edit

**Question16**: How would you rate the performance of the lecturer(s) for the aspects below?

**1** means **"very low"** and **5** means **"very high"**

Explaining a topic
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

Explaining expectations for an assignment
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

Consultation & supervision
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

Being open to discussion & criticism
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

Being accessible
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

Edit

**Question 17**: Do you think that having this course in English was beneficial for you?

**1** means "**not beneficial**" and **5** means "**very beneficial**".

How beneficial
Edit

○ (0)1 ○ (0)2 ○ (0)3 ○ (0)4 ○ (0)5

Edit

**Question 18**: Do you have any additional comments or feedback, if yes please enter below?

Your comments will be really appreciated and taken into consideration for the future courses.

Please use the text box for your comments. Edit

◄ VOTE! Studio NB2 Meeting on Thursday: Online or in Person?

Jump to...

Studio NB2 WEEK 1 Introduction Presentation ►

Studio NB Part 2 - WS21-22

Policies

Impressum

CXII: Studio Interview – Presentation

# Performance Based Design Studio

Isil Kalpkirmaz Rizaoglu

Chair of Building Physics and Technical Services, Prof. Dr.-Ing. Karsten Voss
Faculty of Architecture and Civil Engineering, University Wuppertal, Germany

BERGISCHE
UNIVERSITÄT
WUPPERTAL

## About - *Isil Kalpkirmaz Rizaoglu*

**Since 2019: Research Assistant /** research & teaching **/ b+tga , University of Wuppertal**

**2017 - 2019: Site Manager /** planning and execution**/ TAN Construction**

**2014 – 2017: Design and Construction Manager /** planning and execution **/ DK Architecture**

**2013 – 2014: Design and Site architect /** interior design **/ Detay Akustik**

**2018 - M. Sci. Arch**
Istanbul Technical University**,** Graduate School of Science Engineering and Technology
Division of Architecture
Environmental Control and Construction Technologies Graduate Program

**2013 - B. Arch**
İstanbul Technical University, Faculty of Architecture
Department of Architecture
(Double Major Undergraduate Program)

**2010 - B. Plan.**
İstanbul Technical University, Faculty of Architecture
Department of Urban and Regional Planning
(Double Major Undergraduate Program)

11 July 2023 PERFORMANCE BASED DESIGN STUDIO
Isil Kalpkirmaz Rizaoglu
BERGISCHE UNIVERSITÄT WUPPERTAL

## Survey - *BPS in Teaching 2020*

- To find out **how Building Performance Simulation (BPS) is taught** especially in the architecture education in Germany, ***BPS in Teaching* on-line survey** was conducted between November 2019 and March 2020.

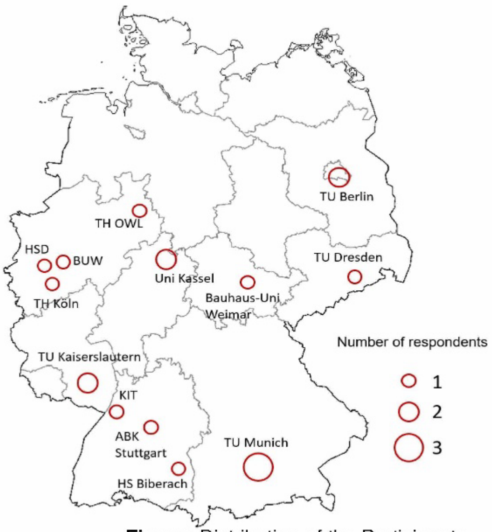
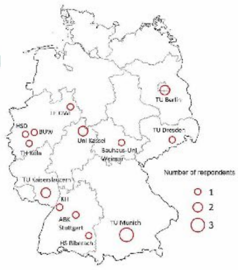



**Figure:** Distribution of the Participants

Kalpkirmaz Rizaoglu, I., Voss, K. (2020) Internal report for the Results of the "Building Performance Simulation in Teaching" Survey for the participants in the scope of the Conference of Professors for Building Physics and Technical Building Equipment. University of Wuppertal, Germany.

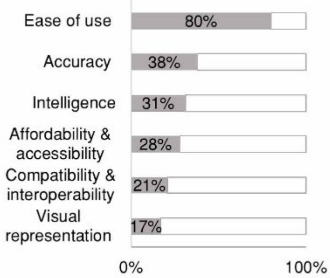


## Key Results of the Survey - *BPS in Teaching 2020*



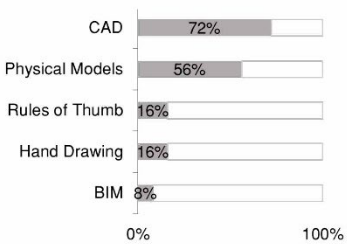
### Reason for choosing a specific BPS tool for teaching

(Respondents in %)



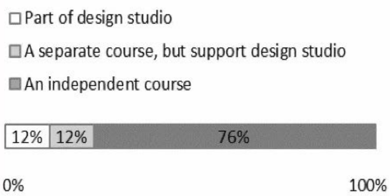

### Most used Design & Documentation Tools during BPS

(Courses in %)




### Integration of Design Studio & BPS Teaching

(Courses in %)




(*Kalpkirmaz-Rizaoglu, Voss., 2020)

## User Interface for BPS in Architects' Design Ecosystems

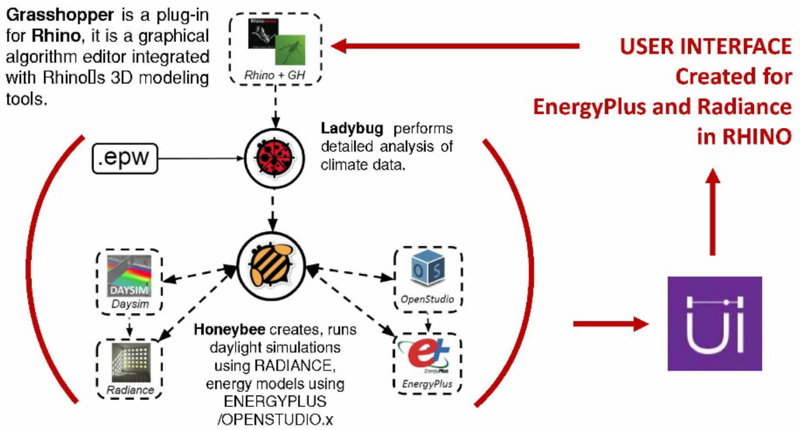



**Figure:** Employed Tools And Visual Scripting To Create Simulation Workflows And Graphical User Interface

**This image is a revised version of an image to represent the created GUIS – Original Image source:** https://docs.ladybug.tools/honeybee-wiki/



## Graphical User Interface for BPS in Architects' Design Ecosystems

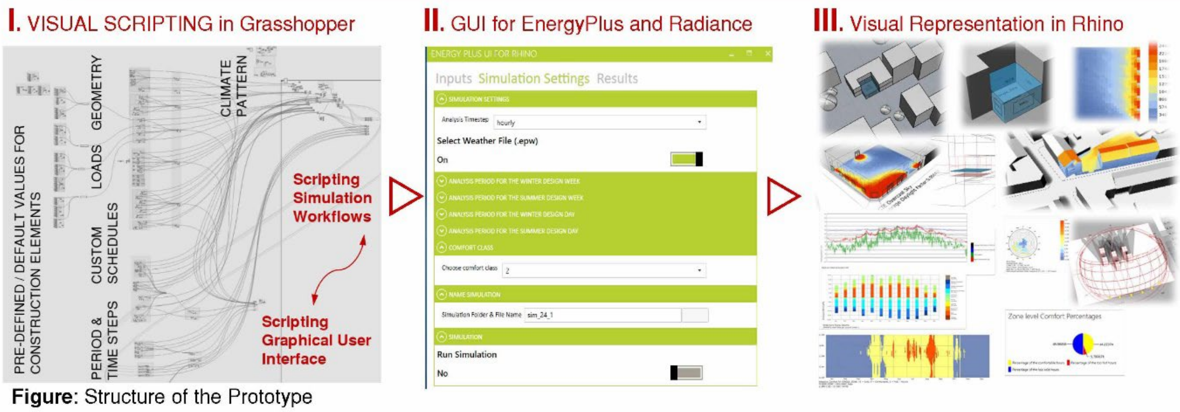



**Figure**: Structure of the Prototype

**The prototype is used in an architecture master'** Seminar in Summer Semester 2020.
**+** Positive: **pre-defined workflows**, **guidance of user interface** and **availability in 3D design environment.**
**-** Negative**: run time was unfavorable** due to the employment of high number of tools in tandem.

11 July 2023
PERFORMANCE BASED DESIGN STUDIO
Isil Kalpkirmaz Rizaoglu
BERGISCHE UNIVERSITÄT WUPPERTAL

## Performance Based Design Studio as a Framework

Research Question

**Is design studio a useful method**
**for integration of BPS into design process**
**in architectural education?**

11 July 2023
PERFORMANCE BASED DESIGN STUDIO
Isil Kalpkirmaz Rizaoglu
BERGISCHE UNIVERSITÄT WUPPERTAL

## Introduction to Courses

Studio - **Sustainable Building and Building Performance (S.NB)**

- two-semester-long
- master level
- elective design course
- as **part 1** and **part 2**
- with a total of 12 credits.

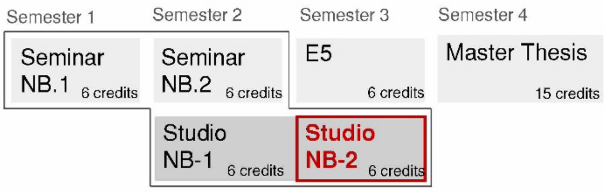



**Figure**: The courses in master program that BPS is addressed


11 July 2023
PERFORMANCE BASED DESIGN STUDIO
Isil Kalpkirmaz Rizaoglu
BERGISCHE UNIVERSITÄT WUPPERTAL

## Design Studio **CONTENT**

| Semester 1 | Semester 2 | Semester 3 | Semester 4 |
|---|---|---|---|
| Seminar NB.1 6 credits | Seminar NB.2 6 credits | E5 6 credits | Master Thesis 15 credits |
| | Studio NB-1 6 credits | Studio NB-2 6 credits | |

**Studio NB-2 in winter semester 2020/2021 = STUDIO A**

**Studio NB-2 in winter semester 2021/2022 = STUDIO B**

**CONTENT**
**Residential use in a urban context**

**STUDIO A**
Students investigated performance of their designs, which they created in the first part of the Studio

**STUDIO B**
Students started from scratch for a new design.

**A design upgrade for an overall performance**

**Main performance tasks**
climate and site integration, solar energy utilization, daylight availability and achieving indoor thermal comfort while minimizing active heating and cooling.

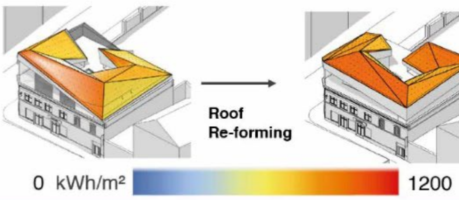
**Only design proposals**



## Design Studio **ADOPTION of BUILDING PERFOMANCE ASESSMENT**

**STUDIO A**
- **Upgrade of an Existing roof...**

**SEMI-ADDITIVE**




**STUDIO B**
- **Massing studies from Studio B...**

**INTEGRATED**

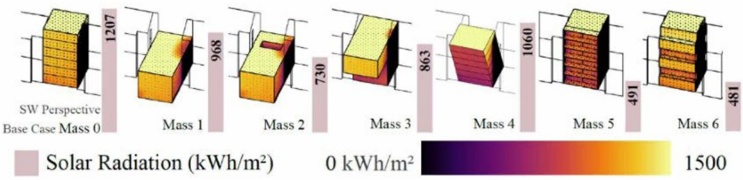


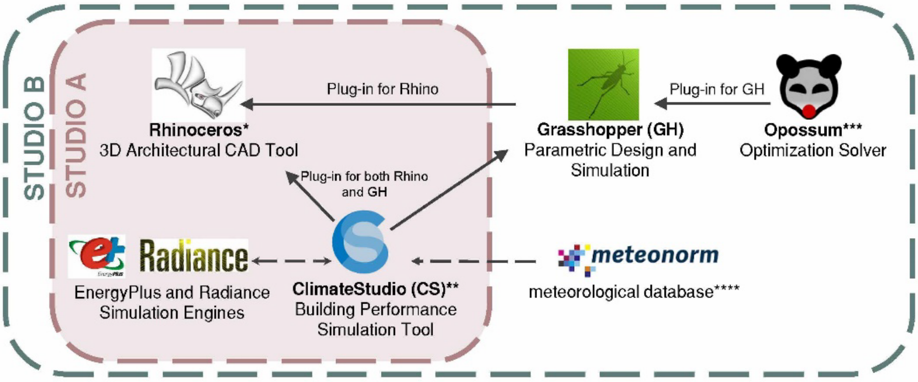

**Figure**: Examples od use of solar radiation analyses for design decisions in Studio A and Studio B
Existing roof design upgrade from Studio A (upper image) and massing studies from Studio B (lower image).

## Design Studio Schedule

| Semester Weeks | | Schedule of Studio A based on BPS Topics | Schedule of Studio B based on BPS Methods |
|---|---|---|---|
| W1<br>W2<br>W3<br>W4 | PHASE 1 | Climate Pattern<br>Site Context<br>Solar Energy Utilization | **Case Studies** for performance |
| W5 | | 2nd Colloquium | |
| W6<br>W7<br>W8<br>W9 | PHASE 2 | Daylight Availability<br>Thermal Comfort | Design investigation through **parametric modeling and simulations** |
| W10 | | 3rd Colloquium | |
| W11<br>W12<br>W13 | PHASE 3 | Re-evaluation of overall performance | Re-evaluation of parameters and goals by **Optimization** |
| W14 | | Final Colloquium | |



## Design Studio TOOLS



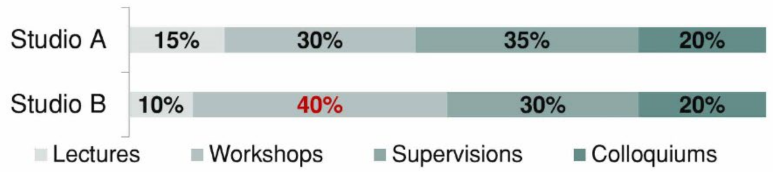

* McNeel R., et al., (2010). Rhino3D Version 6.0. Seattle : Robert McNeel & amp Associates, WA.

** Solemma, (2019). ClimateStudio. [https://www.solemma.com/climatestudio]

*** Wortmann, T., (2017). Opossum: Introducing and evaluating a model-based optimization tool for Grasshopper.

**** Meteotest (2015). Meteonorm Version 7. [https://meteonorm.com/en/]

## Design Studio **ACTIVITIES**




**More *hands-on* sessions by workshops**

11 July 2023

PERFORMANCE BASED DESIGN STUDIO
Isil Kalpkirmaz Rizaoglu

BERGISCHE UNIVERSITÄT WUPPERTAL

## Design Studio **METHODS**

- **workshops & supervision provided** both lecturers' and students' **active participation**
- **Comprehension questions and assignments** were useful for **tracking students learning curve**
- **Colloquiums, booklets and exhibitions posters** were useful for Highlighting **key learning topics**
- **Case studies** were useful for **refreshing theoretical knowledge and introduce tools**
- **Step-by-step approach** was useful for **better comprehension of the BPS**

11 July 2023

PERFORMANCE BASED DESIGN STUDIO
Isil Kalpkirmaz Rizaoglu

BERGISCHE UNIVERSITÄT WUPPERTAL

## Design Studio **METHODS**

| Studio A | Studio B |
|---|---|
| **All BPS inputs at once**<br>➢ **difficult to comprehend** | Starting **only geometry related BPS input**<br>+ custom templates for non-geometric inputs<br>➢ **easy to comprehend and more attractive** |
| **Evaluations of Existing advanced designs**<br>➢ **reluctant / less willing to change design** | **Investigation of early design alternatives**<br>➢ **More willing to form investigations**<br>➢ **extreme variations** |
| **BPS in 3D modeling environment**<br>➢ **Manual investigation of design revisions** | **BPS in 3D modeling** and **parametric design and optimization environment**<br>➢ **fast and flexible generation of design alternatives** |

11 July 2023 PERFORMANCE BASED DESIGN STUDIO
Isil Kalpkirmaz Rizaoglu
BERGISCHE UNIVERSITÄT WUPPERTAL

## Design Studio **METHODS - Simplifications**

***Early design seeks detection and quick evaluation of possible design alternatives** in relatively **short time** and with **relatively less input.**

**SIMPLIFICATIONS**

**TECHNICAL**

- **Tailored custom templates**
  - Occupancy
  - Lighting + equipment
  - Ventilation
  - Conditioning scenarios
- **Example workflows for a start**
  - modeling, simulation, parametrization, optimization

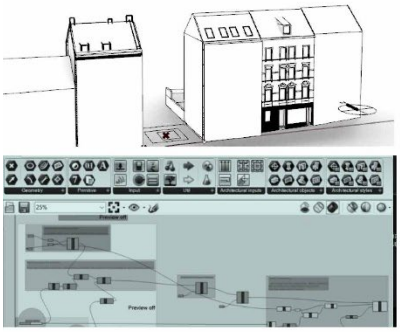
**THEORETICAL**

- **Active solar energy utilization**
- **Daylight availability**
- **Thermal Comfort**

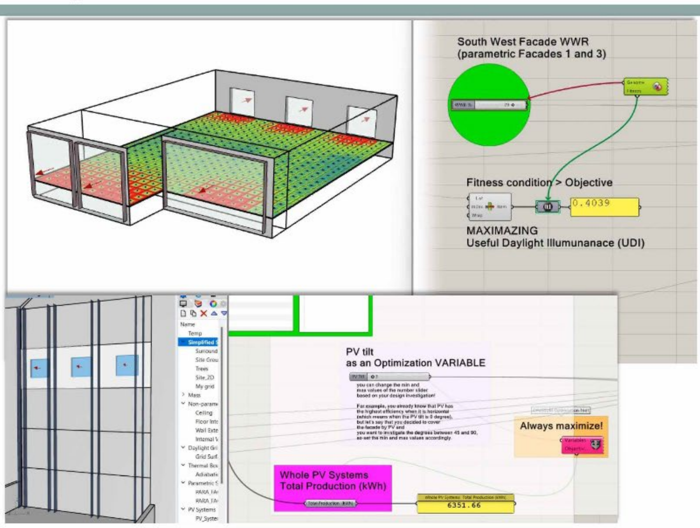
*Kalpirmaz Rizaoglu, K.Voss. (2020) Building Performance Simulation to stimulate Architectural Early Design, Proc. Of PLEA Conf., (Spain,2020) pp. 1525.
https://doi.org/10.17979/spudc.9788497497947

11 July 2023 PERFORMANCE BASED DESIGN STUDIO
Isil Kalpkirmaz Rizaoglu
BERGISCHE UNIVERSITÄT WUPPERTAL

## Design Studio **METHODS - Simplifications TECHNICAL**



**Parametric design example workflows**




**Example optimization workflows**



## Design Studio **METHODS - Simplifications THEORETICAL**

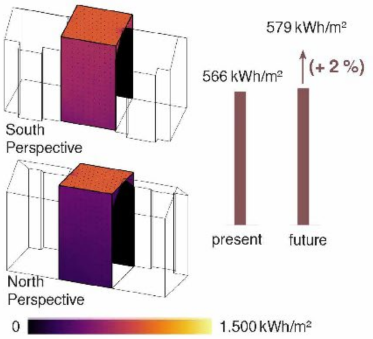
### **Solar Radiation** & Massing Studies

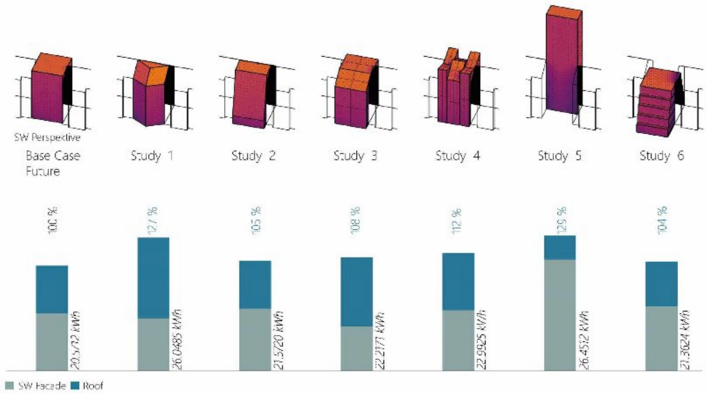
**Solar radiation today and in future**

IPCC A2 Scenario in 2100

**Comparison Future | Present**

Annual Total Solar Exposure



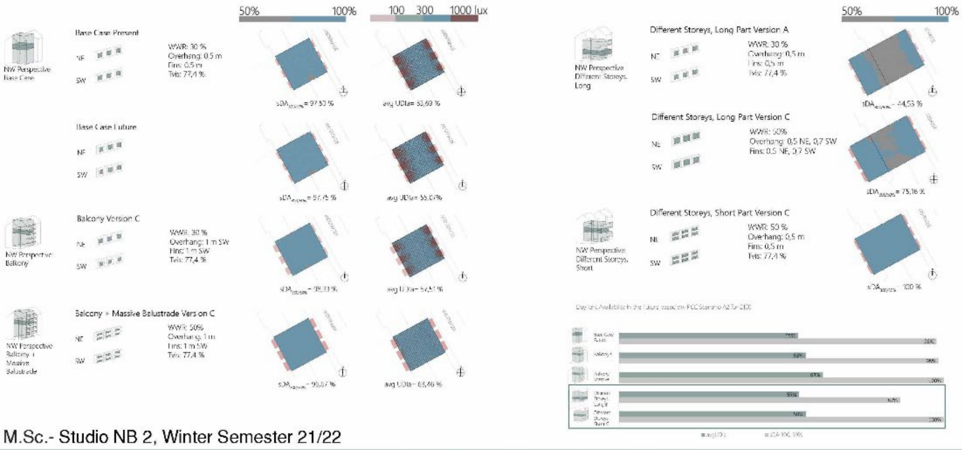




M.Sc.- Studio NB 2, Winter Semester 21/22

11 July 2023
PERFORMANCE BASED DESIGN STUDIO
Isil Kalpkirmaz Rizaoglu
BERGISCHE UNIVERSITÄT WUPPERTAL

## Design Studio **METHODS - Simplifications THEORETICAL**

### **Daylight availability** & Building Form and Space Dimensions




M.Sc.- Studio NB 2, Winter Semester 21/22

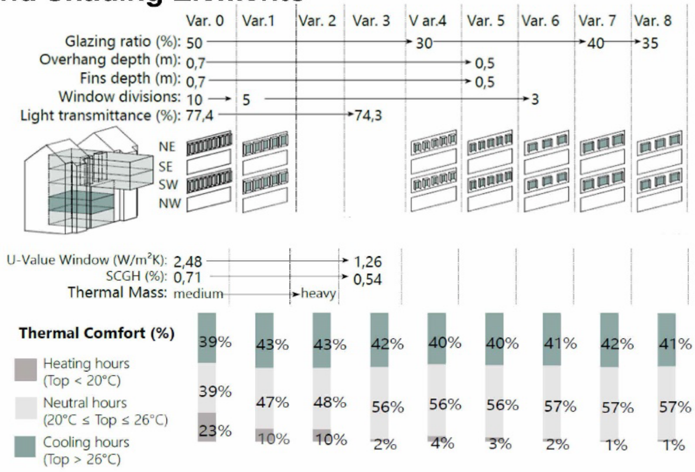


## Design Studio **METHODS - Simplifications THEORETICAL**

### Thermal Comfort & Glazing and Shading Elements

* **Neutral hours**

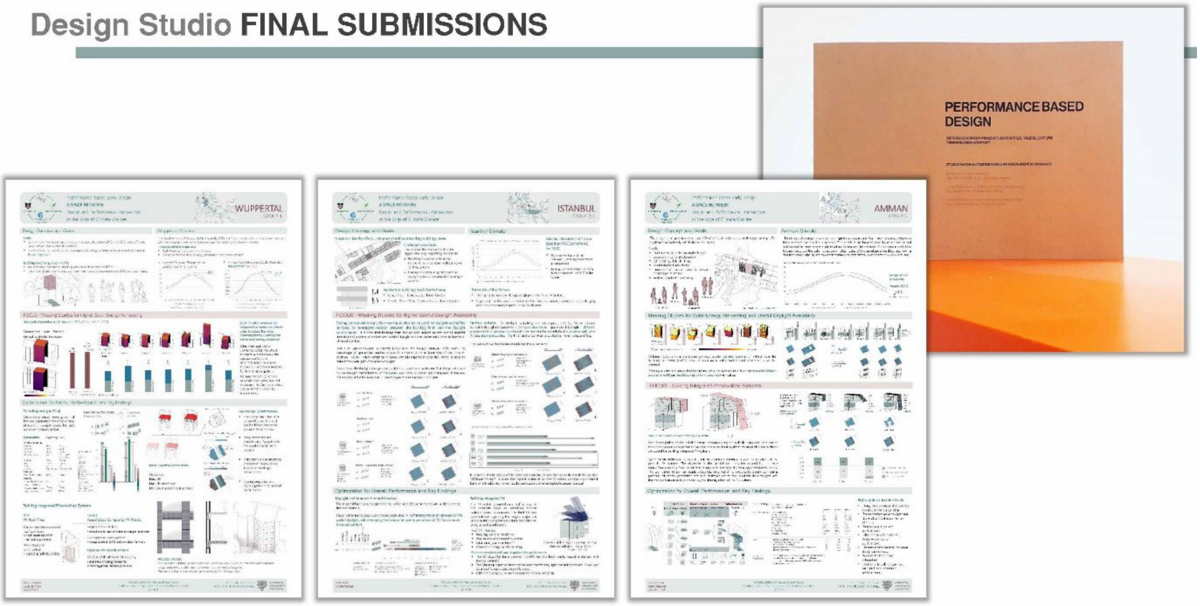
- Refers to the capacity of a building to run without active heating and cooling.
- A simplified approach to give students an insight about thermal comfort rather than a definitive method of a building's cooling and heating demand.




* Kalpkirmaz- Rizaoglu, I., Voss, K. (2022). Summer Thermal Comfort in Architectural Early Design Workflows. CESBP 2022 Bratislava, Slovakia,5th Central European Symposium on Building Physics.

M.Sc.- Studio NB 2, Winter Semester 21/22

## Design Studio **FINAL SUBMISSIONS**






## Design Studio **STUDENTS' FEEDBACK**

**Anonymous studio evaluation surveys** were conducted to capture the students' views about the studio experiences by the end of each course. Each survey had 8 respondents.

[A rating range is given between 0 (low) and 4 (high) points, and the results are presented as weighted arithmetic means. ]

- **Most difficult topic:** thermal comfort

- **When the expectations are compared to the simulation results...**

*"The whole investigation showed them something new, but not much different than their expectations"*

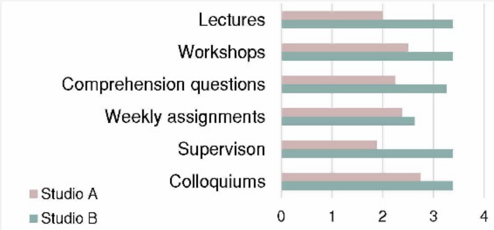
- **What is the level of improvement regarding their skills and self-confidence for using a BPS Tool by the completion of the studio** (1:min - 4:max)?

  - Studio A: between medium and high (2,5),
  - Studio B: very high (3,88).

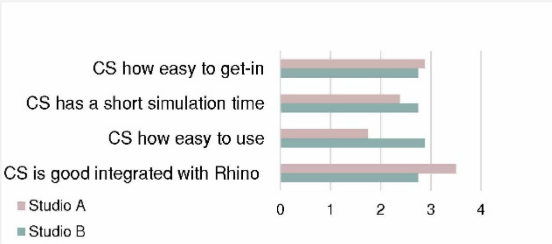
11 July 2023
PERFORMANCE BASED DESIGN STUDIO
Isil Kalpkirmaz Rizaoglu
BERGISCHE UNIVERSITÄT WUPPERTAL

## Design Studio **STUDENTS' FEEDBACK**

- **How useful the studio activities**
(0= not useful – 4 = very useful)




- **Experiences with BPS Tool (Climate Studio)**
(0= fully disagreed – fully agreed 4)




11 July 2023

PERFORMANCE BASED DESIGN STUDIO
Isil Kalpkirmaz Rizaoglu

BERGISCHE UNIVERSITÄT WUPPERTAL

## Design Studio **STUDENTS' FEEDBACK**

- **Do you plan to use Building Performance simulation Tools (BPSTs) in your future studies, i.e. for your Master Thesis?**

Studio A students: **50% (4 students) YES** and 50% NO
Reasons not to plan

*"**BPST limits** me mentally when designing and makes me feel very insecure and overwhelmed."*

*"Since **I don't use Rhino**, the effort to create my own 3d model for the simulation would be too great."*

*"Simulations in detail take to much **time**!"*

*"**I don't know yet**, what i want to focus on with my master thesis, On the other hand, usually there is very few time for the submissions and handling new software always is quite time-consuming, brief evaluations may cause very wrong conclusions"*

Studio B students: **87% (7 Students) YES** and 12,5% (1 student) NO
Reasons not to plan

*"There are other things I want to focus on"*

11 July 2023

PERFORMANCE BASED DESIGN STUDIO
Isil Kalpkirmaz Rizaoglu

BERGISCHE UNIVERSITÄT WUPPERTAL

## Design Studio **CONCLUSION**

- Requested only revision by students were "**decreasing the work load of studio**"

➢ **New course structure is planned as two-semester-long.**

- One **limitation** of applying BPS in **early design** was the **uncertainties**

➢ Custom templates and pre-defined workflows were helpful as plausible solutions

- Besides recognizing the **benefit of simplification**.

➢ It was important to remind students that they must be accompanied always by **critical thinking**

- **Parametrization and optimization** techniques were the unique catalyzers for speeding-up and supporting the decision making.

➢ But these techniques require a certain level of knowledge, which means **intensive supervision** for beginners.



## Thank you!

Please go back to the questionnaire!

11 July 2023
PERFORMANCE BASED DESIGN STUDIO
Isil Kalpkirmaz Rizaoglu
BERGISCHE UNIVERSITÄT WUPPERTAL